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Residential Proximity to Major Roadways and Prevalence of Hypertension in the Atlanta, GA Metropolitan Area

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An abstract of
A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
in partial fulfillment of the requirements for the degree of
Master of Public Health
in Environmental Health
2018

Abstract

Residential Proximity to Major Roadways and Prevalence of Hypertension in the Atlanta, GA Metropolitan Area

By Alexander Chang

Background: Hypertension contributed to the death of 1,100 Americans per day in 2014. Air and noise pollution, particularly from traffic sources, can affect cardiovascular health. Increasing urbanization in the United States is resulting in more people living closer to high traffic roadways; the implications of this trend for cardiovascular health are unclear. The purpose of this study was to estimate associations of residential proximity to major roadways and hypertension and blood pressure outcomes in a metropolitan Atlanta area cohort.

Methods: Residential proximity to major roadways was assessed for a cohort of Emory University employees (n=635) recruited during 2008-2010. Baseline hypertension status (>130/80 mmHg) and blood pressure readings were acquired for each participant. Associations of residential roadway proximity (as a categorical or continuous metric) with hypertension status and systolic and diastolic blood pressure were estimated using logistic and linear regression respectively, controlling for potential confounders. Estimated primary traffic-related fine particle ($PM_{2.5}$), nitrogen oxides (NOx), and carbon monoxide (CO) concentrations at participant residences and participant anxiety and perceived stress levels from survey data were tested as potential mediators of the association between roadway proximity and the outcomes.

Results: Adjusting for covariates, participants living within 100 m of a major roadway had 2.32 (95% CI: 0.98, 5.50) the odds of having hypertension, and participants living 100 to 500 m from a major roadway had 1.41 (95% CI: 0.85, 2.33) the odds of having hypertension, compared to those living greater than 500 m from a major roadway. Within the 100 m zone, those living 50 m to 100 m of a major roadway were most at risk, with an odds ratio of 6.14 (95% CI: 1.37, 6.89) compared to the reference level of >500 m. The patterns of association across roadway proximity categories were similar for blood pressure. Traffic-related air pollution was found to mediate only some of the observed effects of residential roadway proximity. Roadway proximity as a continuous linear predictor was not significantly associated with the outcomes.

Conclusions: Results suggest that living within 100 m of a major roadway within the Atlanta area may increase the odds of having hypertension.

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I. **Introduction**

Hypertension in the United States is a condition that affects 1 in 3 adults, and has been described by the American Heart Association as a "Silent Killer" contributing to the death of 1,100 Americans every day in 2014 (Merai et al., 2016). Hypertension is defined as an abnormally high blood pressure where the force of blood pumping out of the heart (systolic) exceeds 130 manometric units of pressure (mmHg), and the force within arterial walls when the heart rests between beats (diastolic) exceeds 80 mmHg – according to the 2017 Hypertension Clinical Practice Guidelines (Whelton et al., 2017). Hypertension exists as a systemic condition of the body in which the elevated blood pressure causes damage to the cardiovascular system which can, in turn, lead to prognosis such as stroke, heart failure, and heart attacks (AHA 2018).

Major identified factors that increase the risk for hypertension center on lifestyle and behaviors including consumption of fat-rich diets, low levels of physical activity, high sodium intake, and smoking (Eckel et al., 2014). In addition to the importance of lifestyle and behavioral factors comes an emerging recognition of environmental risk factors. Clinical studies have suggested that factors such as exposure to air pollution, noise, temperature, chemicals, and altitude can all increase the possibility of the onset of hypertension (Brook 2011, Jarup et al. 2008, Tellez-Plaza 2008). With an increasing proportion of the US population choosing to live in urban environments (US Census 2012), one of the more recently-identified environmental factors of concern for hypertension is pollution from traffic. Motor vehicles are one of the largest sources of air and noise pollution in the US, both of which are risk factors for hypertension (Goines 2007, Dockery 1993). A plausible mechanistic pathway for the potential effect of air pollution is the degradation of the endothelium lining within blood vessels as a result of the micro-abrasion caused by the presence of air pollution particulates (Brook et al., 2009). This could lead to downstream effects like oxidative stress and inflammation which induces an increase in the resting blood pressure of a person (Brook 2005).

However, the evidence for the impacts of traffic pollution on hypertension is still limited, particularly in the American metropolitan setting (Sorensen et al, 2012). Selected panel studies, in which participants are followed over time and serve as their own control, have considered short-term associations of traffic-related air pollution (TRAP) exposures, inflammation, and blood pressure (Andersen et al., 2011, Steerenberg et a., 2000, Alexeeff et al., 2011). This literature has shown some mixed results, with a recent study on 23 non- smoking adults finding no association between systemic inflammation markers following an acute exposure to TRAP when testing for an association for blood pressure and heart rate (Mirowsky et al., 2015). Cross-sectional studies of TRAP and hypertension have demonstrated a dose-response relationship between fine particulate matter ($PM_{2.5}$) concentration and the mean blood pressure in healthy cohorts based in Los Angeles and western Germany (Fuks et al 2011, Delfino et al 2010, Sorensen et al 2012). Some observational studies suggest there may be interactions between body mass index (BMI) and air pollution contributing to hypertension, with stronger associations among individuals with higher BMI (Dong et al., 2015, Zhang et al., 2016).

Moreover, it is important to consider that air pollution is just one facet of exposure related to traffic, with other stressors being noise pollution, light pollution, and socially perceived traffic stress (Gee and Payne-Sturges 2004, Davies et al., 2009, Lyytimaki et al., 2012), each of which may influence blood pressure-related outcomes independently or jointly with air pollution. Limited epidemiological work conducted in Europe appears to confirm the effect of traffic-related noise exposures at a population level. For example, cross-sectional studies have consistently found elevated odds of hypertension for individuals living close to roads characterized as having high traffic-related noise levels compared to those that live near roads with average traffic-related noise levels (Bluhm et al., 2007, de Kluizenaar 2007, van Kempen 2012).

The association between traffic exposures and health become increasingly important given the existence of structural inequalities in urban environments. Low-income and minority residents in southern California, for example, disproportionately reside in high traffic areas and are disproportionately exposed to air and noise pollution as a direct result (Houston 2004). Across America, 84% of counties with residents living near major roadways experience income disparity (Harvard University 2018). Air pollution concentrations are generally observed to be elevated at roadways and have been observed to decay to background levels by 115-570 m away from the roadway (Karner 2010, Jerrett et al., 2005).

Only few studies that have investigated residential proximity to major roadways as an exposure have specifically considered hypertension or blood pressure as outcomes. American children have been the population of interest of well-funded studies assessing the impacts of residential proximity to major roadways and lung growth and function (McConnell et al., 2010, Urman et al., 2013, Perez et al., 2012). In the Jackson Heart Study, residential proximity to major roadways was studied in relation to cardiac structure and function, but not hypertension (Weaver et al., 2017). In a Spanish cohort, there was no association between residential proximity to roads with high traffic and hypertension (Foraster et al., 2014). However, in a San Diego cohort of post-menopausal women, the odds of having hypertension was higher for those living within 1000 meters of a major roadway versus those living greater than 1000 m from a major roadway (Kirwa et al., 2014). While limited in geographic scope, these results are of concern given that 19% of Americans in the 2010 census lived near (<1000 m) high volume roads, with this number expected to rise as urbanization continues (Rowangould 2013).

The current project was motivated by the need for additional assessments of the impacts of the near-roadway environment on hypertension and blood pressure, particularly in the general adult working population in American urban settings with heavily-used roadway networks. To do so, we leveraged a rich set of baseline visit data from the Center for Health Discovery and Well-Being (CHDWB) Cohort, a cohort of approximately 700 Emory University employees recruited between 2008 and 2012 (Tabassum et al., 2014). Participants' residential locations were linked with major roadway proximity measures as well as estimates of traffic-related $PM_{2.5}$, carbon monoxide (CO), and nitrogen oxides (NO_x) estimated using the Research LINE-source (R-LINE) dispersion model (Zhai et al., 2016). This work was done in the context of a larger endeavor, the TRAPHIC (Traffic-Related Air Pollution and Health in the CHDWB Cohort) study, a pilot project under Emory HERCULES Research Center.

II. Methodology

Data Acquisition and Management

Data from four sources were used to investigate the association between residential proximity to major roadways and hypertension and blood pressure outcomes in Atlanta: CHDWB cohort data, heart medication data, roadway data, and air quality data.

CHDWB Cohort Data

Data from the Center for Health Discovery and Well-Being Cohort were used for this analysis. The participants were predominantly healthy Emory University employees recruited between 2008 and 2012. Information gathered at baseline, 6-month, and annual follow-up visits over the course of five years were obtained from questionnaires, clinical assessments, and laboratory tests conducted at the Emory University Midtown Hospital (Atlanta, GA, USA). Data from each visit included information on family health history, occupational history and exposures, tobacco and alcohol use, traditional medical and complementary medication use, detailed food intake, measures of stress, anxiety, depression, spirituality, validated metrics of physical functioning, social support, sleepiness and sleep quality. Participants also underwent traditional medical testing including blood pressure, treadmill testing, body composition and bone density testing, measures of cardiovascular function and risk, and laboratory resting such as blood chemistry and hormone profiles.

For the current analysis, we focused on baseline visit blood pressure, BMI, and questionnaire data, collected during 2008 to 2012. During the clinical assessment, sitting blood pressure was measured and medical drug usage history was assessed by interview. Body metrics such as BMI were collected by a trained nurse using the Tanita® Body Composition Analyzer (Omron, Kyoto, Japan). Participants were instructed to rest for 10 minutes in a supine position in a quiet, temperature-controlled room. Afterwards, blood pressure was measured 3 times in 5-minute intervals using the Omron HBP-1300 Blood Pressure Monitor from the participants' dominant arm and the blood pressure was documented as the mean value of the final two measurements (Al Mheid et al., 2011). Hypertensive status was defined as having a blood pressure of 130 systolic and 80 diastolic as per the definition adopted by the American Heart Association (AHA 2018). Participants that satisfied this condition had a hypertension status coded as 1, whereas those that did not were coded as 0. It is important to note that this updated definition of hypertension was not used at the time of the original cohort (Tabassum et al., 2014).

Participants were also given surveys that quantify their stress and anxiety levels. Two of metrics that were included for this analysis were the Perceived Stress Scale (PSS) and the Generalized Anxiety Disorder 7-item scale (GAD-7). The PSS is a classic stress instrument developed in 1983 that remains popular for helping researchers understand how different situations affect feelings and perceived stress. It asks the frequency of stress-related events to a survey taker and asks them to respond on a Likert scale beginning at 0 for 'never' and 4 for 'very often' (Levenstein et al., 1993). The GAD-7 is a more recent tool that poses 7 questions to a survey taker asking if he or she has trouble relaxing or feels nervousness, with the response being a 4-strata Likert scale of certainty with 0 being 'uncertain' and 3 being 'absolutely certain' (Spitzer et al., 2006). These stress indexes were included to determine if there was a possible mediation effect present between the analysis of residential proximity to roadways and hypertension.

Finally, each participant's residential address recorded during the baseline visit was geocoded using ArcGIS Version 10.5.1 (Environmental Systems Research Institute, Inc., Redlands, CA), using the Geocode Addresses process in Geocoding Tools. Of the 703 participants in the CHDWB database, we excluded 14 with incorrect or invalid address information and 2 with baseline residential address outside of Georgia. After excluding a further 43 participants with no blood pressure data, there were 635 participants included in the final cohort for this analysis.

Heart Medication Data

A complete listing of existing blood pressure medications by both brand and generic name was created using information from the American Heart Association website under the webpage titled “Cardiac Medications” (AHA 2018). This complete list was then merged with a listing of self-reported medications from the participants in order to identify participants taking blood pressure medication at baseline. Those that reported taking a blood pressure medication were coded with a “1” and those that did not were coded as a “0”.

Roadway Data and Roadway Proximity Metrics

Roadway data were procured from the United States Census’ Topologically Integrated Geographic Encoding and Referencing (TIGER) product database. The TIGER products are spatial extracts from the Census Bureau’s MAF/TIGER database and are a collection of shapefiles (.shp) and database files (.dbf) that contain features such as roads, railroads, and rivers available from 2007 to the present. Starting in 2010, TIGER roadway data were organized to include shapefiles focused exclusively on primary and secondary roads, which represent high traffic roadways considered most relevant to the current analysis. The US Census defines primary roads as roadways that are generally divided, limited access highways within the interstate highway system. They also include divided roads that are under state management that are distinguished by the presence of interchanges are accessible by ramps, including toll highways. These roads are classified by TIGER with the MAF/TIGER Feature Classification Code (MTFCC) of S1100. Secondary roads are main arteries that are a part of the US highway, state highway, or county highway system. These roads contain one or more lanes of traffic in each direction and may or may not be divided. Secondary roadways usually have both a local name and route number and are classified with a MTFCC code of S1200. For this analysis, we used shapefiles containing Georgia's primary and secondary roadway data (combined, and separate) for 2010, which best aligned with the timing of the majority of the CHDWB cohort baseline visits (Figure 1 and Figure 2).

The residential proximity to major roadways for each participant was calculated (in meters) using the "Generate Near Table" tool in ESRI's ArcGIS software version 10.5.1. The 'Transform' tool within ArcGIS was used to change the coordinate system of the roadway data (UGS 1984) into the same coordinate system as the geocoded addresses (UTM NAD 1983) points to ensure that the proximity from the point to the nearest roadway was accurate. The Euclidian distance from each geocoded point to the nearest primary roadway ('primary only') and nearest primary or secondary roadway ('primary or secondary') was then calculated and exported as a table. The table containing the distances was merged with the CHDWB cohort data by participant ID in SAS v.9.4 (SAS Institute).

In analyses, residential proximity to 'primary only' and to 'primary or secondary' roadways were considered as both continuous variables (in meters) and categorical variables. Two categorization methods were considered: a 3-category variable (0 to 100 m, 101 to 500 m, and >500 m) and a 4-category variable (0 to 50 m, 51 to100 m, 101 to 500 m, and >500 m). These categories reflect observed concentration gradients of TRAP around roadways. A meta-analysis comprised of over 700 air pollutant concentration measurements near roadways from over 40 studies found that, on average, common traffic-related pollutants such as $PM_{2.5}$, NO_2, NOx, and volatile organic compounds are elevated at the roadway and decay to background concentrations by about 115 m to 570 m away from a roadway; the highest concentration was found to be within 0 to 80 m of the roadway (Karner 2010). In Los Angeles, individuals living within 90 m of a major roadway were found to be exposed to a full spectrum of particle sizes (including a relatively greater proportion of ultrafine particles) compared to those living further than 90 m from a major roadway (Zhang et al., 2004). Compared to the 3-category metric, the 4-category metric divided the proximity <100 m into two categories to better reflect the rapid decay in pollution concentrations as well as the noise levels with increasing proximity from the roadway. A study investigating the 5-minute average noise levels of two major freeways in Los Angeles found that sound walls, such as buildings and houses, drastically reduced traffic noise in the 0 to 100 m range from the freeways (Shu 2014). With roadway impacts being strongest within the first 100 m of the roadway, we were specifically interested in analyzing the health impacts of living within this zone.

Air Quality Data

Estimates of participants' residential ambient traffic-related $PM_{2.5}$, CO, and NOx concentrations were made by Georgia Tech collaborators as part of previous research (Zhai et al., 2016, Pennington et al., 2017). Estimates were made using the Research

LINE-source dispersion model for near-surface releases (RLINE) from the Community Modeling and Analysis System (CMAS), which provided annual average ambient concentrations of primary $PM_{2.5}$, CO, and NOx from mobile sources at 250 m grid cell resolution in the Atlanta metropolitan area for 2002- 2011 (CMAS 2015). For the current study, 2010 RLINE estimates were assigned to each participant based on the values for the 250 m grid cell centroid located closest to each participant's residential geocoded address. These data were used to evaluate the residential roadway proximity measures with respect to TRAP levels and to assess the influence of TRAP in associations of roadway proximity with hypertension and blood pressure.

Statistical Analysis

Feature Selection

The baseline survey for the CHDWB cohort provided information on a broad range of demographic and lifestyle factors for participants. A literature review was conducted to determine the criteria for including specific factors as covariates in models with residential roadway proximity as the main exposure of interest. Once variables were selected *a priori*, a forward stepwise regression with an alpha of 0.05 was applied to filter covariates which did not have an association with hypertensive status, systolic or diastolic blood pressure.

Several demographic factors were consistently associated with hypertension and blood pressure outcomes throughout the literature, including gender, age, smoking, BMI and household income. As humans grow older, arterial stiffness increases and thereby the risk of hypertension increases (McEniery 2007, Benetos et al., 2002). Additionally, population studies have consistently found women to have higher odds of hypertension than men, with the comprehensive NHANES cohort showing this effect particularly in older women (Cornoni-Huntly et al., 1991). A possible explanation for this is an increased vulnerability to genetic alterations due to environmental stimuli among women compared to men, although the mechanism remains unknown (Tsai et al., 2009). Smoking has consistent evidence of adverse effects on cardiovascular function, including effects on hypertension and blood pressure, at both acute and chronic exposure levels (Primatesta et al 2001, Rhee et al., 2007). BMI has been linked to poor diet and exercise and is a measure of obesity; a positive correlation of BMI to blood pressure has been observed in diverse populations, including in the United States, China, and India (Wilson et al., 2002, Wang et al., 2015, Dua 2014). Finally, household income is a strong predictor of an individual’s ability to afford a healthy lifestyle as well as adequate preventative care. A CDC report illustrated that participants of the second NHANES survey with higher income indeed had lower blood pressure on average, and less with hypertension, than those with lower income (Gillespie et al., 2013). These five covariates had a strong relationship with the outcome variables of interest here in both epidemiological literature and succeeded in passing the stepwise regression filter in our feature selection analysis.

Five additional covariates were selected due to their strong statistical association with the outcome variables in our study data, but held weaker evidence within the scientific literature. These covariates included sodium intake , trans fats intake, education level, and ethnicity. These all have contradictory results in the literature when it comes to their relation to hypertension and blood pressure, or the finding that they are risk factors for only a niche population. For example, high sodium intake has long been associated with high blood pressure, and decreasing sodium intake has produced cardiovascular benefits across a multitude of study populations and was even included in a World Health Organization review (Karppanen and Mervaala 2006, Ha 2014). However, a recent cohort study focusing on 2,600 American men and women for 16 years found no association between sodium intake and blood pressure after controlling for other risk factors (Moore et al., 2017). For consumption of trans, or saturated, fats, their ability to adversely affect systemic blood flow has been demonstrated in an adult European cohort and another cohort study following 13,000 US women followed for 13 years (Wang et al., 2010, Oomen et al., 2001). However, a meta-analysis combining the data of 21 studies and over 340,000 subjects found that there was no effect of trans fat consumption on blood pressure and hypertension when controlling for other factors (Siri-Tarino et al., 2010). Education level determines a person's knowledge of healthy habits and lifestyle choices, and indeed this has been determinant of heart health and hypertension in a clinical setting in Europe (Chiara et al., 2017, Tedesco et al., 2001). However, the first NHANES epidemiological follow-up study that observed an American population only found an association of education level with hypertension in white men and women, possibly suggesting that this phenomenon is only present in certain ethnicities in more diverse countries (Vargas et al., 2000). Regarding ethnicity, US studies have found higher odds of hypertension among the black population compared to other races (Hicken et al., 2014, Bell et al., 2010). The effect levels could point to SES as being the main variable of interest, and even studies that demonstrate an association between perceived stress scores (PSS), a standardized index of stress, hint that stress management techniques between those in contrasted SES classes could be driving the how stress affects hypertension (Suter et al., 1997, Hobbs and Aycock 2017).

Given support from the literature and in analyses of the CHDWB cohort data, we considered all 10 variables as covariates to control potential confounding in adjusted analyses of residential proximity to roadways and hypertension and blood pressure outcomes.

Modeling Framework

We estimated crude and adjusted odds ratios for hypertension with the categorical roadway proximity measures using logistic regression. We also estimated crude and adjusted associations of both the categorical and continuous roadway proximity measures with continuous blood pressure outcomes using generalized linear models. In these analyses, roadway proximity measures were for both the ‘primary only’ and ‘primary or secondary’ roadways, and the categorical measures included both the 3-level and 4-level variables.

The adjusted models controlled for the 10 covariates described above: gender (female, male), age (continuous), smoking status (Never, Former, Current), BMI (Normal, Overweight, Obese, Extreme Obesity), household income (<\$50,000, \$50,000- <\$100,000, \$100,000- <\$250,000, ≥\$250,000), highest level of education (High School, College Degree, Graduate School, Post-Graduate School), sodium consumption (continuous, mg per day), trans-fat consumption (continuous, mg per day), as well as hypertension medication use (yes/no). To assess the potential mediating roles of TRAP and stress in associations of residential roadway proximity and hypertension and blood pressure, we compared associations with and without inclusion of RLINE air pollution estimates and stress variables (GAD-7, PSS) in the models.

III. Results

Descriptive Analysis

Demographics

The demographic data for CHDWB cohort participants are presented in Table 1 and Table 2 with respect to the 3-level and 4-level roadway proximity metrics, respectively. In this cohort, 66% of participants were female; and 71.8% were white, 23.2% where African American, and 5% were of other races. A higher proportion of non-Hispanic whites lived within 100 meters of a roadway than further from roadways; in contrast, a higher proportion of African Americans lived away from major roadways than close to them.

The CHDWB cohort was comprised of Emory University employees. As a result, the level of education was high among participants, with over 50% of the cohort having a graduate degree or higher. This observation corresponds well with national trends showing white populations typically having a higher education than other races, particularly African Americans (US Census 2003). The distribution of education levels between proximity categories was relatively consistent. The high average level of education among the cohort was consistent with its high household income levels; cohort members on average earned well over Georgia's median household income of $51,307 USD (US Census 2017), with over half (58.43%) of the cohort living in households with income over $250,000 per year. More than 70% of the cohort reported earning over

$100,000 dollars annually per household. This distribution of income did not change significantly over the proximity categories, although all of those who had less than $50,000 household income lived greater than 100 m from a primary or secondary roadway; and, the highest proportion of those in the highest income category was among participants living less than 100 m from major roadways. This pattern is in contrast to that observed nationally by the CDC, with a higher proportion of lower earners living near major roadways (Boehmer 2013).

A reason for this disparity could be the unique urban environment of Atlanta, or perhaps the age distribution of the study population. The mean age was 48, suggesting a mature, working population. This is not surprising given the income and education distribution of this cohort. Those who lived within 50 meters of a major roadway were much older than those who lived further from major roadways, perhaps indicating that there is a preference for convenience of transportation in those who are older.

Lifestyle Factors

A vast majority of cohort members were never smokers: about 6% of the study population were self-reported current smokers, while 93.2% of cohort members reported that they had never smoked in their lifetime. The distribution of smokers vs. nonsmokers was relatively consistent across proximity categories, however the highest proportion of current smokers lived within 0 to 100 meters of major roadways.

Given the age of the population, it is not surprising to see that the majority of the population was overweight, with roughly 31% of cohort members being obese. There was little deviation in the distribution of BMI between proximity categories. However, the generally high BMI was taken as a potentially influential factor for the level of hypertension seen in the cohort, and thus included in adjusted models of roadway proximity. Among the food intake categories, average consumption of sodium and trans fats among cohort members exceeded the daily recommended amounts and these foods are known to adversely affect cardiovascular health (USDA 2015).

As a whole, this study group experienced average to below average stress and anxiety. The Perceived Stress Score and the Generalized Anxiety Order – 7 scores were included to understand if stress or anxiety were mediators in any potential association between roadway proximity and hypertension or blood pressure outcomes. For PSS, we observed a very consistent score across all proximity categories with a mean of 19.8, placing the study population at a level of 'moderate perceived stress' according to the survey (APA 2014). The GAD-7 scores were considerably low (with a mean of 3.5), as 5 is the benchmark for moderate anxiety (Spitzer 2006); no significant variation between proximity categories was observed.

The majority of participants did not report taking blood pressure medication at baseline. It is important to note that during the date of the baseline measurements, hypertension was still defined at 140/90 versus the more updated 130/80. Thus, it is possible that while many participants were hypertensive, the definition in use at the time did not lead their primary care providers to suggest blood pressure medication.

Environmental Factors

Levels of annual average primary traffic-related $PM_{2.5}$, NOx, and CO at participant residences (based on closest 250 m grid cell centroid) all decreased in concentration as the residential proximity from a primary roadway increased. A clear inverse relationship was observed that suggests TRAP could serve as a mediating factor for the association between residential proximity to roadway and hypertension status.

Residential Roadway Proximity Metrics

There was a clear difference in the distribution of residential proximity measures between consideration of ‘primary or secondary’ roadways and ‘primary only’ roadways (Figures 3 and 4). For the proximity calculation for ‘primary or secondary’ roadways (Figure 3), we observed a greater number of participants that lived within 0 to 100 m, which was vital to the analysis given that the body of literature suggests most roadway impacts with respect to air and noise pollution levels occur within this range. Conversely, when the residential proximity was calculated using ‘primary only’ roadways, there were few participants that lived within the 0 to 100 m distance and a far greater number living >1000m away. This did not provide the resolution nor the study power needed to conduct a meaningful analysis, and as a result, the proximity to ‘primary only’ roadways was only compared to the blood pressure measurements as a continuous variable in secondary analyses.

Epidemiologic Analyses of Categorical Roadway Proximity Metrics & Outcomes

Associations of 3-Level Roadway Proximity Metric with the Outcomes

We observed clear inverse patterns in estimated associations between the 3-level categorical residential proximity to the nearest primary or secondary roadway metric and all three outcome variables of interest (Table 3). In adjusted models, for example, the odds of hypertension among participants living within 100 m of a major roadway was

2.322 (0.980, 5.502), and the odds among participants living 100-500 m of a major roadway was 1.407 (0.849, 2.325) compared to the furthest proximity category. When the air pollution estimates were included in the statistical model, odds ratios were slightly weakened, which could indicate TRAP as a mediating factor in the association between roadway proximity and hypertension. There was no discernable difference in the odds ratios when the stress covariates were added to the models, perhaps suggesting that stress was less of a mediating factor in the association between roadway proximity and hypertension compared to TRAP. Stress has been seen as a crucial contributing factor to blood pressure and hypertension within clinical health literature, however, given the lack of variation of self-reported stress within Table 1 it did not affect the outcome of this analysis. The possibility exists that because this cohort included so many participants with high household income, the stress associated with low SES was not evident in this cohort.

The trend in effect estimates across the 3-level roadway proximity measures was also evident with systolic and diastolic blood pressure outcomes (Table 3). In adjusted models, those living within 100 m of primary or secondary roadways had an elevated systolic BP [by 4.91 (95% CI: 0.22, 9.60) mmHg] and an elevated diastolic BP [by 2.92 (95% CI: -0.52, 6.35) mmHg] compared to those living greater than 500 m from a major roadway. Those living at a proximity of 100m to 500m showed no differences in BP measures compared to those living greater than 500 m of a major roadway, highlighting that the first 100 m from a roadway are particularly impactful for health. The uniformity of this trend across all models suggests a strong plausibility that living further away from a major roadway in this cohort could be protective for lowering blood pressure and preventing hypertension.

Associations of 4-Level Roadway Proximity Metric with the Outcomes

Roadway air pollution literature suggests that the dynamics and movement of pollutants varies greatly within 100 m of the source, and this extends to noise pollution as well. A secondary analysis was conducted with the 0 to 100 m proximity category split into 0 to 50 m and 50 to 100 m strata (Figure 3). Given very low sample size of participants living within the 0 to 50 m proximity category (n=13) (Table 2), the association with hypertension did not run for this strata. However, adjusted odds for hypertension among participants living in the 50 to 100 m category was 6.139 (2.305, 16.349) compared to those living greater than 500 m from a major roadway. Analyses of the continuous BP outcomes showed similar results, with those living between 50 to 100 m from a major roadway had significantly elevated systolic [9.34 (95% CI: 3.90, 14.79) mmHg] and diastolic [5.00 (95% CI: 1.00, 9.01) mmHg] blood pressures compared to those living greater than 500 m from a major roadway. Thus, those living in this proximal range accounted for the effects observed in the broader 0 to 100 m categorization approach for all outcomes.

An examination of Table 2 reveals the probable cause of this stark difference found in the model results between those living within 50 m and those living within 50 to 100 m of a major roadway. Those living within the closer proximity category had the highest proportion of those who reported not having hypertension (92.31%) whereas those living in the 50 to 100m category had the highest proportion of participants who had hypertension (59.26%). It is also important to note that this group had the highest proportion of participants living in households with income greater than $250,000 annually and was the most educated compared to the other categories (23% with post graduate education). Other major differences include this group being the only one with a male majority (61.54%) as well has having the lowest proportion of obese participants (18% cumulative). Finally, there were only 13 participants living within 50 meters of a primary or secondary roadway, which decreases the study power available for the calculated measures of association.

Epidemiologic Analyses of Continuous Proximity Measures and Outcomes

Residential proximity to major roadways as a continuous variable was examined for potential linear relationships with blood pressure outcomes (Table 4). The results were overwhelmingly weak and nonsignificant; the only marginally significant association was with roadway proximity using the ‘primary only’ roadways and diastolic blood pressure [0.23 (95% CI: -0.01, 0.46) mmHg decrease in diastolic BP with every 1000 m increase in roadway proximity, p-value of 0.055]. The weak results of this analysis were likely due to the assumption of linearity, which given the categorical roadway proximity results was likely not a valid assumption. The relationship between residential proximity to roadway and blood pressure is more likely non-linear and therefore requires a non-parametric analysis, which can be evaluated in future work.

IV. Discussion

Few studies have evaluated the potential harm of living close to a major roadway with respect to blood pressure related outcomes. With a need to understand the relationship between human health and the built environment, this analysis provides insight into one of the adverse effects of living in an American metropolis with a healthy, educated cohort. Overall, the results support the hypothesis that residing closer to a major roadway can adversely impact blood pressure and possibly cardiovascular health, with observations of elevated odds of hypertension and elevated systolic and diastolic BP among individuals residing within 100 m (and particularly in 50 to 100 m) of a major roadway compared to those living greater than 500 m from a major roadway.

The results observed in this study are in close agreement with a study by Kirwa et al. examining the relationship between proximity and blood pressure in post-menopausal women in San Diego (Kirwa et al., 2014). A clear inverse relationship between proximity and blood pressure, and a decrease in odds of hypertension was observed as study participants lived further away from major roadways. In their study, an adjusted odds ratio of 1.36 (1.16, 1.60) was found for those living within 50 meters of a major roadway and it decreased to 1.04 (0.95, 1.14) for those living between 50 to 200 meters, compared to >400m. Similar patterns of effect were found in a cohort of 113,926 Europeans by Fuks et al. In a meta-analysis of 15 cohorts, the authors found that those living within 100 m of a major roadway were exposed to more vehicular traffic related air pollution and had higher adjusted odds of having hypertension of 1.05 (0.99, 1.11) than those living further from a major roadway (Fuks et al., 2014). In addition, with a residential proximity within 100 meters, study participants had an increase of 0.35 mmHg systolic BP and an increase of 0.22 mmHg diastolic BP per 4,000,000 vehicles passing on the roadway (Fuks et al., 2014).

In comparison to the Kirwa et al. and Fuks et al. studies, our effect estimates were much larger (e.g., odds of hypertension among those living within 100 m of a major roadway was 2.322 (0.980, 5.502). The two other studies were able to recruit an ample number of participants which aided their study power. Perhaps this is why their odds ratios were closer to the null and their 95% confidence intervals had a much narrower range than the analysis performed here. The small sample size of this analysis (n=635 participants) may have contributed to the extreme findings. Nonetheless, the importance of the similarities between the trend of each of the odds ratios is consistent between all three of the studies. For example, Kirwa et al. observed a weakening of odds ratios with increasing proximity categories: ORs of 1.23 for participants living within 100 m, 1.11 for 100 to 200 m, 1.05 for 200 to 1000 m, compared to the reference category of >1000 m. Fuks et al. observed a similar pattern, with 1.05 times the odds of having hypertension among participants living within 100 m and a null finding for anyone living greater than 100 m from a roadway. This consistency is promising in suggesting that these results are replicable amongst different metropolitan areas, and that there is a strong possibility that the findings observed among the CHDWB cohort are externally valid.

This analysis also sought to determine if air pollution and stress, which have been demonstrated to have relevance to hypertension and residential proximity to roadways in the literature (Jakubiak-Lasocka et al., 2015, Gan et al., 2014, Sunyer et al., 2015, Wellenius et al., 2012), could function as mediators for the effect of living close to a roadway. For hypertension status, a slight weakening of effects in the adjusted odds ratio was observed when the RLINE air pollution estimates were included. Additional studies that elucidate the explicit relationship between air pollution distribution from a traffic related source such as roadways is crucial to understanding if the effect observed here is truly mediation by air pollution, or a contribution by other correlated factors.

One drawback from this study and those conducted by Fuks et al. and Kirwa et al. is that this was only a 2-dimensional analysis that sought to find an association between blood pressure and proximity on a single geometric plane. Research in this area has already shown that 3-dimensional air pollution models that track the distribution of pollutants through distance and altitude are able to capture more complex, nuanced patterns of pollutant dispersion that follow non-linear patterns (Hakami et al., 2003, Berkowicz 2000, Sandu et al., 2005). This is especially important considering that apartment complexes are occupying a larger proportion of the American housing market annually, and single-family home ownership dropping to all-time lows (Harvard University 2018). Increasing prevalence in apartments that are typically taller in height and more bountiful in urban settings complicates the traditional approaches to 2D understanding of air, noise, and sound pollution that could contribute to the increase of blood pressure seen in a study population.

Limitations

There are several limitations to this analysis, one of the most prominent being the study power of only 635 participants and having cross-sectional data that was not able to consider measures of association over time. Future analyses utilizing follow-up measures in this cohort are warranted. The nature of this cohort also does not adequately cover the full spectrum of socio-economic status that is often found in urban settings, particularly in Atlanta. The 2010 US Census found that the metropolitan area of Atlanta is predominantly African American with 54% of the population reporting that their household is either black or African American (US Census 2017) whereas this study's population was predominantly (71.8%) non-Hispanic white. Perhaps one of the starkest contrasts in the difference in household income between this study population and the general population of Atlanta. The majority (58.4%) of the participants in this study reported a household income of over $250,000, suggesting an over representation of wealthy individuals in this analysis. Wealth has an established link with better health outcomes across a vast variety of populations (Liu 2017, Woolf et al., 2015, Kendall et al., 2017), suggesting that these results may not be fully externally valid despite similar patterns of effect across proximity categories as previous studies (Kirwa et al., Fuks et al.).

The distribution of the residential proximity from primary or secondary roadways also proved to be a limitation. Only 40 participants resided in the 0 to 100 m strata compared to 410 participants residing in the reference strata of >500 m of a major roadway. The analysis could have greatly benefited from a larger sample size at the closer proximity. Furthermore, the types of residences were not recorded, thus it was not clear what living conditions that each participant was exposed to which could impact their level of air, noise, and light pollution. For example, those living in tall apartment complexes could have had a lower exposure to noise pollution but a greater exposure to air pollution.

This study was able to procure air pollution and stress measures in an attempt to discern if either were mediating the effect encompassed by the distance to roadway metrics. Effectively, the RLINE estimates, GAD-7, and PSS were proxies for the closest accurate representation of air pollution and stress. Given that air, noise, and light pollution are the three exposures that proximity to roadway could encompass, having measures for all three could have greatly enhanced the mediation analysis. Future studies could benefit from having measures of all three environmental factors in either a 2D or 3D space in order to understand which influence the hypertensive effect and at which distance are they the most influential. Proximity to roadway is ultimately a complex exposure which encompasses many elements. Increasing the capacity to explicitly identify which elements are important will further the understanding of the biological mechanism of how the urban environment affects blood pressure.

Finally, the possibility exists that there remained uncontrolled residual confounding within this analysis. While we conducted a thorough analysis of covariates and assessment of potential confounders, using available detailed CHDWB survey data, it may be that some unmeasured factor(s) contributed to the observed patterns of effect across roadway proximity categories.

V. Conclusions and Future Recommendations

In sum, there are clear gaps of knowledge which future studies could fill in regards to understanding whether living closer to major roadway adversely affects blood pressure, and in turn, cardiovascular health. However, the results of this analysis were consistent with the literature that had similar methodology. Results of this analysis support a clear inverse relationship between the odds of having hypertension and residential proximity to a major roadway.

Detailed 3D and 2D modeling of air pollution dispersion from roadways could inform future statistical models developed to measure the effect of residential proximity on blood pressure. Linear regression in this study was unable to explain the variation of blood pressure, likely due to a nonlinear relationship. Both pollution modeling, and machine learning techniques could inform the type of transformation needed to build an accurate predictive model.

This type of study will need to be replicated in different metropolitan settings on a cohort with a broader socioeconomic background. Sociologists have long held the notion that urbanization is heterogeneous and differs between cultures and geography (Bloom et al., 2008, Gollin et al., 2016, Marcotullio 2017). While this current analysis was for an Atlanta-based cohort, cohorts in other major American metropolitan areas should also be assessed. Built environments differ between American cities, and can nuance the current understanding between residential proximity to roadways and blood pressure (Jackson 2003). What applies in Atlanta may not hold true in New York City or Boston due to differences in climate, city planning, and population density. Ultimately, this study supports the work done by previous studies and offers a research design that could be easily replicated with other cohorts that can further work in this field.

VI. Works Cited

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VII. Tables and Figures

Table 1. Summary of CHDWB cohort participant characteristics, overall and by 3-level residential roadway proximity.

			Residential Proximity to Nearest Major Roadway			
		Overall (n=635)	**≤100 m (n=40)**	**>100 to 500 m (n=185)**	**>500 m (n=410)**	**p-value***
OUTCOME VARIABLES						
Hypertension, %	Has Hypertension	20.5	30.0	23.2	18.3	0.12
	No Hypertension	79.5	70.0	76.8	81.7	
Systolic blood pressure, Mean (SD)		121.3 (15.7)	126.0 (15.5)	121.2 (16.7)	120.9 (15.3)	0.14
Diastolic blood pressure, Mean (SD)		76.7 (10.8)	78.5 (10.7)	76.0 (10.3)	76.9 (11.0)	0.37
LIFESTYLE FACTORS						
Smoking Status, %	Never Smoker	93.2	90.0	92.4	93.9	0.55
	Former Smoker	0.9	0.0	1.6	0.7	
	Current Smoker	5.8	10.0	6.0	5.4	
Body Mass Index, %	Normal	31.1	27.8	33.1	30.5	0.54
	Overweight	37.4	44.4	34.3	38.1	
	Obese	26.3	19.4	25.6	27.4	
	Extreme Obesity	5.2	8.3	7.0	4.0	
Diet, Mean (SD)	Daily servings of milk, yogurt, cheese	1.06 (0.79)	1.28 (0.83)	1.05 (0.82)	1.04 (0.77)	0.20
	Saturated fat, gms	19.98 (9.86)	21.44 (8.50)	20.59 (11.09)	19.56 (9.38)	0.32
	Trans fats, total, gms	1.97 (1.24)	2.12 (0.95)	1.99 (1.34)	1.95 (1.22)	0.74
	Daily svgs fats & oils, sweets, sodas	3.01 (1.52)	3.28 (1.40)	3.11 (1.76)	2.94 (1.41)	0.23

			Residential Proximity to Nearest Major Roadway			
		Overall (n=635)	**≤100 m (n=40)**	**>100 to 500 m (n=185)**	**>500 m (n=410)**	**p-value***
	Daily frequency of fruits & fruit juices	1.52 (0.94)	1.47 (0.89)	1.57 (1.03)	1.5 (0.91)	0.65
	Daily svgs breads, cereals, rice, pasta	4.55 (2.4)	4.36 (1.98)	4.53 (2.5)	4.58 (2.40)	0.84
	Daily svgs meat, fish, poultry, beans, eggs	2.20 (1.25)	2.29 (1.21)	2.24 (1.39)	2.17 (1.19)	0.69
	Daily servings of vegetables	3.95 (2.29)	4.60 (2.63)	4.11 (2.32)	3.82 (2.24)	0.07
	Average daily servings of whole grains	0.69 (0.73)	0.75 (0.68)	0.74 (0.82)	0.66 (0.69)	0.43
	Average daily sodium intake, mg	2918.70 (1223.84)	3098.81 (940.71)	2991.65 (1391.84)	2868.22 (1165.22)	0.33
Stress, Mean (SD)	GAD7 Anxiety Score	3.5 (3.7)	4.0 (4.7)	3.8 (3.8)	3.4 (3.6)	0.32
	PSS Stress Score	19.8 (7.4)	19.6 (6.3)	19.9 (7.5)	19.8 (7.5)	0.96
BP Medications Use, %	Currently Taking	4.3	0.0	4.3	4.6	0.38
	Not Taking	95.8	100.0	95.7	95.4	
DEMOGRAPHIC FACTORS						
Gender, %	Male	33.7	37.5	32.4	33.9	0.82
	Female	66.3	62.5	67.6	66.1	
Age, Mean (SD)		48.5 (10.2)	50.3 (11.6)	48.6 (10.4)	48.4 (10.0)	0.54
Ethnicity, %	White non-Hispanic	71.8	80.0	75.1	69.5	0.05

			Residential Proximity to Nearest Major Roadway			
		Overall (n=635)	**≤100 m (n=40)**	**>100 to 500 m (n=185)**	**>500 m (n=410)**	**p-value***
	American Indian or Alaska Native	0.8	5.0	0.5	0.5	
	African American	23.2	15.0	21.1	24.9	
	Other	4.3	0.0	3.2	5.1	
Highest Level Education, %	High School	2.7	0.0	3.8	2.4	0.29
	College Degree	38.6	32.5	36.8	40.0	
	Graduate School	37.3	52.5	39.5	34.9	
	Post - Graduate School	21.4	15.0	20.0	22.7	
Household Income, %	<\$50,000	3.2	0.0	1.6	4.2	0.40
	\$50,000 - <\$100,000	24.6	30.0	27.6	22.7	
	\$100,000 - <\$250,000	13.9	12.5	12.4	14.6	
	≥\$250,000	58.4	57.5	58.4	58.5	
ENVIRONMENTAL FACTORS						
RLINE Pollution, Mean (SD)	$PM_{2.5}$ ($\mu g/m^3$)	1.88 (0.84)	2.66 (1.08)	2.18 (0.91)	1.67 (0.68)	<0.001
	NOx (ppb)	66.65 (33.46)	95.74 (48.91)	78.26 (38.68)	58.58 (25.00)	<0.001
	CO (ppb)	789.21 (380.75)	1113.81 (549.63)	922.39 (439.70)	697.44 (286.65)	<0.001

*p-values for categorical variables were calculated using Chi-Squared tests, while continuous variables utilized an ANCOVA calculation.

Table 2. Summary of CHDWB cohort participant characteristics, overall and by 4-level residential roadway proximity.

			Residential Distance to Nearest Major Roadway				
		Overall (n=635)	**≤50 m (n=13)**	**>50 to 100 m (n=27)**	**>100 to 500 m (n=185)**	**>500 m (n=410)**	**p-value***
OUTCOME VARIABLES							
Hypertension, %	Has Hypertension	20.5	7.7	59.3	23.2	18.3	0.02
	No Hypertension	79.5	92.3	40.7	76.8	81.7	
Systolic Blood Pressure, Mean (SD)		121.3 (15.7)	120.7 (10.1)	128.6 (17.1)	121.2 (16.7)	120.9 (15.3)	0.16
Diastolic Blood Pressure, Mean (SD)		76.7 (10.8)	76.6 (7.3)	79.4 (12.0)	76.0 (10.3)	76.9 (11.0)	0.38
LIFESTYLE FACTORS							
Smoking Status, %	Never Smoker	93.2	92.3	88.9	92.4	93.9	0.79
	Former Smoker	0.9	0.0	0.0	1.6	0.7	
	Current Smoker	5.8	7.7	11.1	6.0	5.4	
Body Mass Index, %	Normal	31.1	18.2	32.0	33.1	30.5	0.57
	Overweight	37.4	63.6	26.0	34.3	38.1	
	Obese	26.3	9.1	24.0	25.6	27.4	
	Extreme Obesity	5.2	9.1	8.0	7.0	4.0	
Diet, Mean (SD)	Daily servings of milk, yogurt, cheese	1.06 (0.79)	1.42 (0.82)	1.21 (0.84)	1.05 (0.82)	1.04 (0.77)	0.27
	Saturated fat, gms	19.98 (9.86)	23.28 (9.96)	20.55 (7.75)	20.59 (11.09)	19.56 (9.38)	0.40
	Trans fats, total, gms	1.97 (1.24)	2.07 (0.83)	2.14 (1.02)	1.99 (1.34)	1.95 (1.22)	0.87

			Residential Distance to Nearest Major Roadway				
		Overall (n=635)	**≤50 m (n=13)**	**>50 to 100 m (n=27)**	**>100 to 500 m (n=185)**	**>500 m (n=410)**	**p-value***
	Daily svgs fats & oils, sweets, sodas	3.01 (1.52)	3.31 (1.62)	3.26 (1.32)	3.11 (1.76)	2.94 (1.41)	0.40
	Daily frequency of fruits & fruit juices	1.52 (0.94)	1.43 (1.21)	1.48 (0.72)	1.57 (1.03)	1.5 (0.91)	0.83
	Daily svgs breads, cereals, rice, pasta	4.55 (2.4)	4.49 (2.19)	4.3 (1.91)	4.53 (2.5)	4.58 (2.4)	0.94
	Daily svgs meat, fish, poultry, beans, eggs	2.2 (1.25)	2.63 (1.34)	2.13 (1.14)	2.24 (1.39)	2.17 (1.19)	0.54
	Daily servings of vegetables	3.95 (2.29)	3.25 (1.56)	5.25 (2.81)	4.11 (2.32)	3.82 (2.24)	0.01
	Average daily servings of whole grains	0.69 (0.73)	0.68 (0.77)	0.78 (0.65)	0.74 (0.82)	0.66 (0.69)	0.60
	Average daily sodium intake, mg	2918.70 (1223.84)	3213.55 (1053.08)	3043.57 (897.66)	2991.65 (1391.84)	2868.22 (1165.22)	0.49
Stress, Mean (SD)	GAD7 Anxiety Score	3.5 (3.7)	3.8 (4.4)	4.1 (4.9)	3.8 (3.8)	3.4 (3.6)	0.51
	PSS Stress Score	19.8 (7.4)	19.4 (5.6)	19.6 (6.8)	19.9 (7.5)	19.8 (7.5)	0.99
BP Medications Use, %	Currently Taking	4.3	0.0	0.0	4.3	4.6	0.59
	Not Taking	95.8	100.0	100.0	95.7	95.4	0.99
DEMOGRAPHIC FACTORS							
Gender, %	Male	33.7	61.54	25.93	32.43	33.9	0.15
	Female	66.3	38.46	74.07	67.57	66.1	
Age, Mean (SD)		48.5 (10.2)	57.1 (9.8)	47.0 (11.1)	48.6 (10.4)	48.4 (10.0)	0.02

			Residential Distance to Nearest Major Roadway				
		Overall (n=635)	**≤50 m (n=13)**	**>50 to 100 m (n=27)**	**>100 to 500 m (n=185)**	**>500 m (n=410)**	**p-value***
Ethnicity, %	White non-Hispanic	71.8	76.9	81.5	75.1	69.5	0.13
	American Indian or Alaska Native	0.8	7.7	3.7	0.5	0.5	
	African American	23.2	15.4	14.8	21.1	24.9	
	Other	4.3	0.0	0.0	3.2	5.1	
Highest Level Education, %	High School	2.7	0.0	0.0	3.8	2.4	0.42
	College Degree	38.6	38.5	29.6	36.8	40.0	
	Graduate School	37.3	38.5	59.3	39.5	34.9	
	Post - Graduate School	21.4	23.1	11.1	20.0	22.7	
Household Income, %	<\$50,000	3.2	0.0	0.0	1.6	4.2	0.67
	\$50,000 - <\$100,000	24.6	23.1	33.3	27.6	22.7	
	\$100,000 - <\$250,000	13.9	15.4	11.1	12.4	14.6	
	≥\$250,000	58.4	61.5	55.6	58.4	58.5	
ENVIRONMENTAL FACTORS							
RLINE Pollution, Mean (SD)	$PM_{2.5}$ (µg/m^3)	1.88 (0.84)	2.58 (0.92)	2.69 (1.17)	2.18 (0.91)	1.67 (0.68)	<0.001
	NOx (ppb)	66.65 (33.46)	94.16 (46.03)	96.5 (51.07)	78.26 (38.68)	58.58 (25.00)	<0.001
	CO (ppb)	789.21 (380.75)	1100.3 (520.15)	1120.32 (572.83)	922.39 (439.70)	697.44 (286.65)	<0.001

*p-values for categorical variables were calculated using Chi-Squared tests, while continuous variables utilized an ANCOVA calculation.

Table 3. Associations of 3-level categorical residential roadway proximity and hypertension and blood pressure outcomes.

Model*	**≤100 m**		**>100 to 500 m**		**>500 m (ref)**
Hypertension Status	**OR**	**(95% CI)**	**OR**	**(95% CI)**	**OR**
Crude	1.91	(0.93, 3.94)	1.35	(0.89, 2.07)	1
Adjusted	**2.32**	**(0.98, 5.50)**	**1.41**	**(0.85, 2.33)**	**1**
Adjusted w/ RLINE PM2.5	2.11	(0.86, 5.19)	1.32	(0.78, 2.25)	1
Adjusted w/ RLINE CO	2.20	(0.90, 5.37)	1.36	(0.80, 2.30)	1
Adjusted w/ RLINE NOx	2.18	(0.89, 5.32)	1.35	(0.80, 2.28)	1
Adjusted w/ GAD7 Anxiety Score	2.34	(0.98, 5.56)	1.37	(0.82, 2.29)	1
Adjusted w/ PSS Stress Score	2.31	(0.98, 5.48)	1.37	(0.83, 2.27)	1
Systolic Blood Pressure	**Estimate**	**(95% CI)**	**Estimate**	**(95% CI)**	**Estimate**
Crude	5.12	(0.01, 10.24)	0.30	(-2.43, 3.03)	0
Adjusted	**4.91**	**(0.22, 9.60)**	**-0.41**	**(-2.87, 2.04)**	**0**
Adjusted w/ RLINE PM2.5	5.57	(0.65, 10.49)	-0.06	(-2.64, 2.51)	0
Adjusted w/ RLINE CO	5.42	(0.56, 10.28)	-0.13	(-2.68, 2.43)	0
Adjusted w/ RLINE NOx	5.39	(0.52, 10.25)	-0.15	(-2.71, 2.40)	0
Adjusted w/ GAD7 Anxiety Score	4.92	(0.23, 9.61)	-0.45	(-2.91, 2.01)	0
Adjusted w/ PSS Stress Score	4.86	(0.16, 9.56)	-0.41	(-2.86, 2.05)	0
Diastolic Blood Pressure	**Estimate**	**(95% CI)**	**Estimate**	**(95% CI)**	**Estimate**
Crude	1.65	(-1.86, 5.15)	-0.85	(-2.72, 1.03)	0
Adjusted	**2.92**	**(-0.52, 6.35)**	**-0.96**	**(-2.76, 0.84)**	**0**
Adjusted w/ RLINE PM2.5	3.03	(-0.57, 6.63)	-0.90	(-2.79, 0.99)	0
Adjusted w/ RLINE CO	2.99	(-0.57, 6.55)	-0.92	(-2.79, 0.95)	0
Adjusted w/ RLINE NOx	2.96	(-0.60, 6.52)	-0.94	(-2.81, 0.93)	0
Adjusted w/ GAD7 Anxiety Score	2.93	(-0.50, 6.36)	-1.00	(-2.80, 0.80)	0
Adjusted w/ PSS Stress Score	2.97	(-0.47, 6.40)	-0.97	(-2.77, 0.83)	0

*Main adjusted model results for each outcome in bold font; adjusted models control for gender, age, smoking status, BMI, household income, highest level of education, sodium consumption, trans-fat consumption, and hypertension medication use.

Table 4. Associations of continuous residential roadway proximity ('primary or secondary' roadways and 'primary only' roadways) and blood pressure outcomes.*

	Primary or Secondary Roadways Estimate (95% CI) per 1000 m		Primary Only Roadways Estimate (95% CI) per 1000 m	
Systolic Blood Pressure	0.49	(-0.72, 1.69)	0.26	(-0.06, 0.58)
Diastolic Blood Pressure	0.59	(-0.29, 1.47)	0.23	(-0.01, 0.46)

*Models adjusted for gender , age, smoking status, BMI, household income, highest level of education, sodium consumption, trans-fat consumption, and hypertension medication use covariates; effect estimates expressed per 1000 m increase in roadway proximity

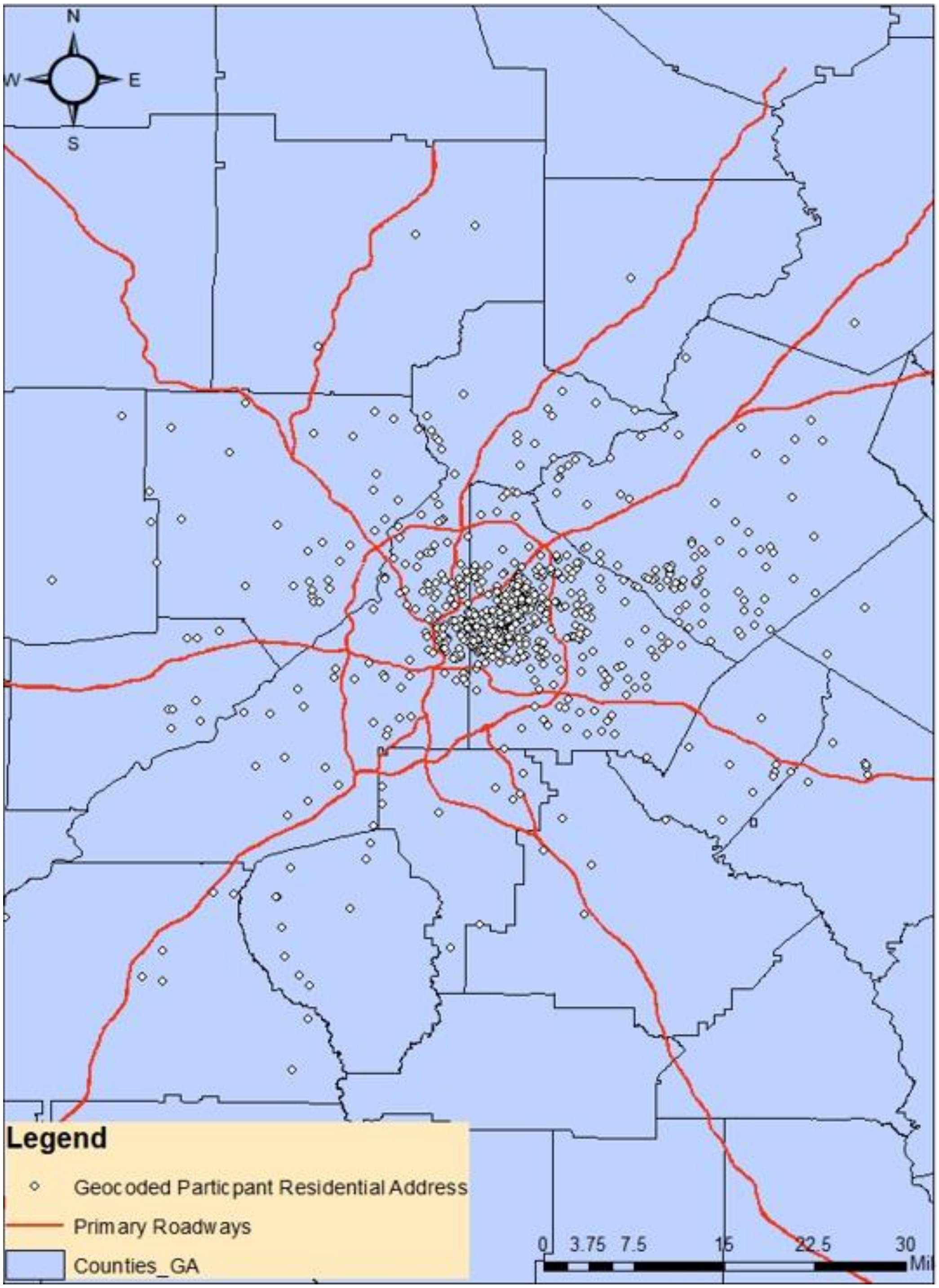

Figure 1. Location of CHDWB cohort residences and ‘primary only’ roadways in the Atlanta, GA metropolitan area.

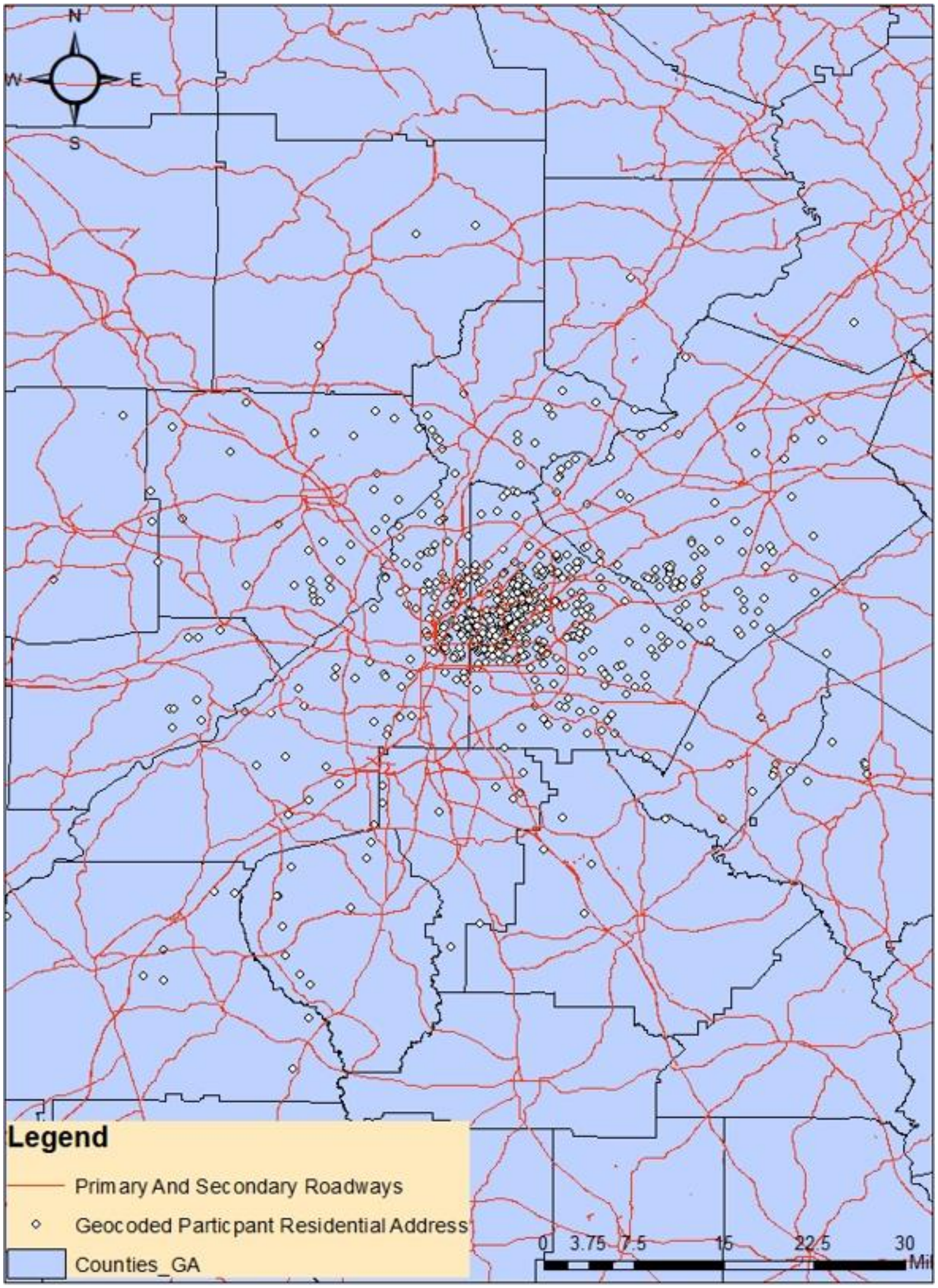

Figure 2. Location of CHDWB cohort residences and 'primary or secondary' roadways in the Atlanta, GA metropolitan area.

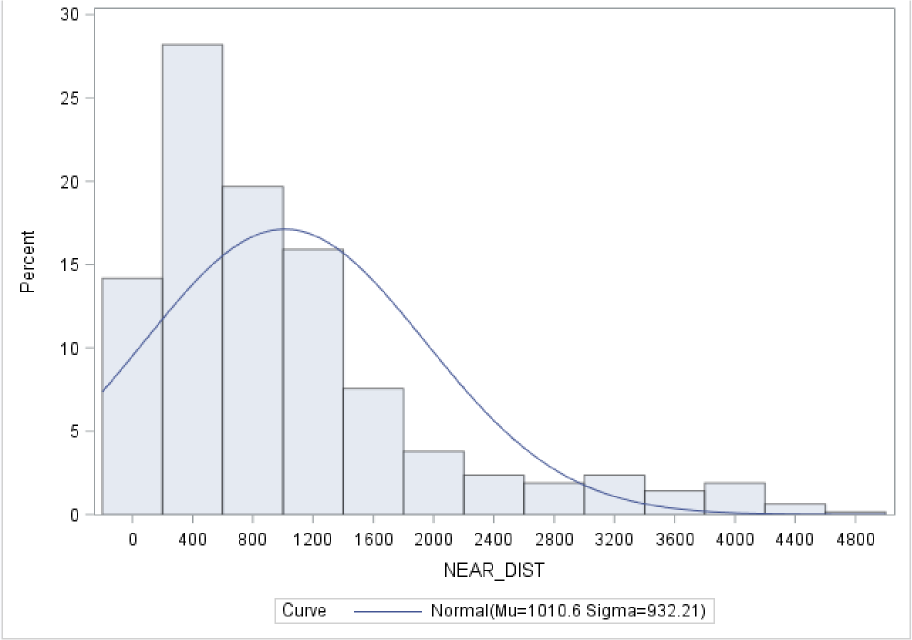

Figure 3. Distribution of residential proximity measures in meters from 'primary or secondary' roadways.

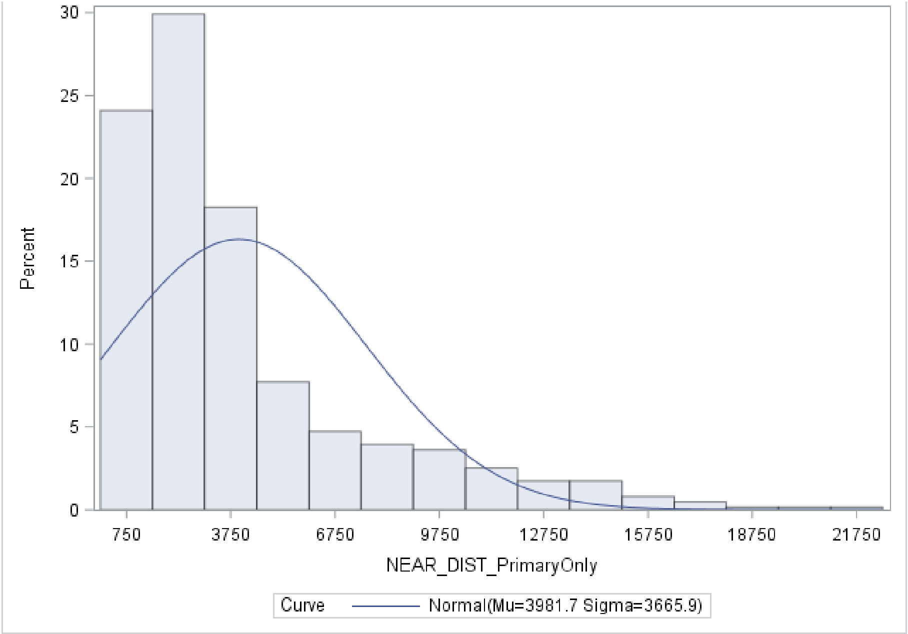

Figure 4. Distribution of residential proximity measures in meters from 'primary only' roadways.

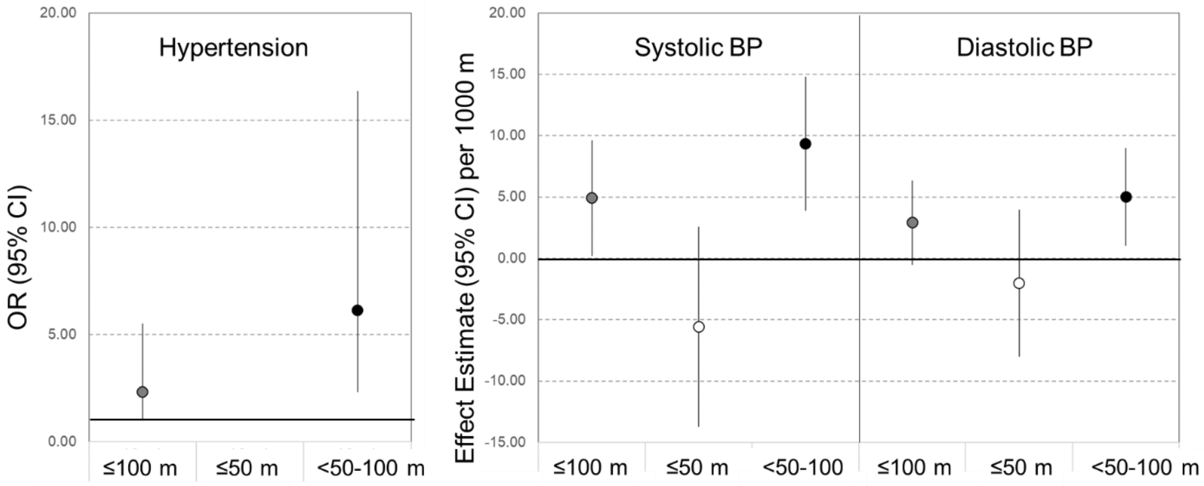

Figure 5. Associations of residential roadway proximity and hypertension and blood pressure outcomes: comparing associations within first 100 m vs. reference category of >500 m from 3-level and 4-level roadway proximity categorizations. (note: the model for hypertension in the ≤50 m roadway proximity category did not run)