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RESIDENTIAL PROXIMITY TO MAJOR ROADWAYS AND INCIDENT HYPERTENSION IN POST-MENOPAUSAL WOMEN

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Abstract

Living near major roadways has been associated with increased risk of cardiovascular morbidity and mortality, presumably from exposure to elevated levels of traffic-related air and/or noise pollution. This association may potentially be mediated through increased risk of incident hypertension, but results from prior studies are equivocal. Using Cox proportional hazards models we examined residential proximity to major roadways and incident hypertension among 38,360 participants of the Women's Health Initiative (WHI) Clinical Trial cohorts free of hypertension at enrollment and followed for a median of 7.9 years. Adjusting for participant demographics and lifestyle, trial participation, and markers of individual and neighborhood socioeconomic status, the hazard ratios for incident hypertension were 1.13 (95% CI: 1.00, 1.28), 1.03 (0.95, 1.11), 1.05 (0.99, 1.11), and 1.05 (1.00, 1.10) for participants living ≤50, >50-200, >200-400, and >400-1000 m versus >1000 m from the nearest major roadway, respectively (p_{trend}=0.013). This association varied substantially by WHI study region with hazard ratios for women living ≤50m from a major roadway of 1.61 (1.18, 2.20) in the West, 1.51 (1.22, 1.87) in the Northeast, 0.89 (0.70, 1.14) in the South, and 0.94 (0.75, 1.19) in the Midwest. In this large, national cohort of post-menopausal women, residential proximity to major roadways was associated with incident hypertension in selected regions of the U.S. If causal, these results suggest residential proximity to major roadways, as a marker for air, noise and other traffic-related pollution, may be a risk factor for hypertension.

Keywords

hypertension; women; blood pressure; traffic pollution; air pollution; noise pollution

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Despite recent medical advances and public health interventions, cardiovascular disease remains the leading cause of morbidity and mortality in the US (Go et al., 2014). Living near major roadways has been associated with higher prevalence of coronary heart disease (Hoffmann et al., 2007; Hoffmann et al., 2006), higher risk of acute myocardial infarction (Tonne et al., 2007), higher risk of death from cardiovascular disease, ischemic heart disease, and stroke (Cesaroni et al., 2013; Hart et al., 2014; Maheswaran and Elliott, 2003), and higher risk of death following stroke and acute myocardial infarction (Rosenbloom et al., 2012; Wilker et al., 2013). Moreover, observational studies suggest that moving away from major roadways is associated with decreased risk of myocardial infarction, coronary heart disease mortality and all-cause mortality (Gan et al., 2010; Hart et al., 2013). A growing body of evidence suggests that exposures associated with living near major roadways, including traffic-related air (Cesaroni et al., 2013; Chen et al., 2013; Gan et al., 2011; Raaschou-Nielsen et al., 2012) and noise (Beelen et al., 2009; Gan et al., 2012; Selander et al., 2009) pollution, are likely detrimental to cardiovascular health.

Living near major roadways (with concomitant residential exposure to higher levels of both air and noise pollution) may increase the risk of cardiovascular events through increased incidence of hypertension. A limited number of studies have evaluated this hypothesis and the evidence remains equivocal with most (Fuks et al., 2011; Fuks et al., 2014; Kirwa et al., 2014), but not all (Sørensen et al., 2012) prior studies suggesting an association between residential proximity to major roadways and hypertension. Of note, all but one (Kirwa et al.,

2014) of these studies have been conducted in Europe and only one (Sørensen et al., 2012) considered incident hypertension rather than prevalent hypertension. The association between long-term exposure to traffic-related air pollutants (e.g.: oxides of nitrogen or NO_2) and hypertension is also unclear with some studies finding a positive association (Chen et al., 2015; Coogan et al., 2012; Dong et al., 2013; Foraster et al., 2014b) and others finding no evidence of an association (Foraster et al., 2014a; Fuks et al., 2014; Sørensen et al., 2012). On the other hand, traffic-related noise has been positively associated with prevalence of hypertension (van Kempen and Babisch, 2012).

Approximately 80% of US residents (and more than half of the world's population) now live in a city and this proportion is expected to grow (Kaiser Family Foundation, 2014). Therefore, understanding the potential health consequences of our physical environment is of increasing public health significance. Accordingly, we assessed the association between residential distance to nearest major roadway and the risk of incident hypertension in the Women's Health Initiative (WHI) Clinical Trial (CT) cohorts, a large, national US prospective study.

METHODS

Study Population

We obtained data from the WHI CT cohorts, which enrolled 68,132 post-menopausal women between 50 and 79 years of age from 1993-1998. We excluded participants with hypertension at baseline (n=29,118), defined as a systolic blood pressure (SBP) ≥140 mmHg, a diastolic blood pressure (DBP) ≥90 mmHg, self-reported use of antihypertensive medication at baseline, or use of an antihypertensive medication as determined at baseline via medical inventory. Medications in the following categories were considered antihypertensive agents: angiotensin-converting enzyme inhibitors, angiotensin receptor blockers, β-blockers, calcium channel blockers, diuretics, centrally acting antihypertensive agents, vasodilators, and combinations of these medications (Margolis et al., 2008). We excluded 17 women with missing data on residential distance to roadway and 637 participants with no follow-up data, yielding a final study population of 38,360 eligible women.

Exposure Assessment

We used ArcGIS (ESRI, Redlands, CA, USA) to calculate the distance from each participant's address to the nearest major roadway defined as those with US Census Feature Class Code A1 (primary highways with limited access) and A2 (primary road without limited access), which generally include interstate highways, US highways and some state or county highways. We used road network data from ESRI Data & Maps and from ESRI StreetMap and North American Atlas Products that spanned the study period. We used a Python script in ArcGIS using the *Generate Near Table* function to calculate the Euclidean distance and angle to the nearest major roadway for each participant address.

In a sensitivity analysis we additionally considered residential proximity to nearest A3 roadways (secondary or connecting roads), which are typically smaller and have less traffic compared to A1 and A2 roadways, but can still carry substantial local traffic in urban areas. We additionally considered the total miles of A1 and A2 roadways within 200 m of a geocoded participant's address. Data on traffic volumes or the composition of the local vehicle fleet are not available at the national level.

Outcome Assessment

Blood pressure was measured at WHI clinical centers by trained personnel using standardized procedures after participants had been seated for 5 minutes (Anderson et al., 2003; Margolis et al., 2008). Two blood pressure measurements were taken in the right arm ≥30 seconds apart with a conventional mercury sphygmomanometer and an appropriately sized cuff at baseline and at each following approximately annual visit (Anderson et al., 2003; Margolis et al., 2008). We averaged the two measurements from each visit for use in analyses. As in previous studies (Margolis et al., 2012) we defined incident hypertension as a SBP ≥140 mmHg, a DBP ≥90 mmHg, or a first self-report of medication prescribed for hypertension.

Covariate Data

Participants provided data on demographics and health behaviors using a self-reported questionnaire at baseline, as described previously (Anderson et al., 2003). Briefly, race/ethnicity was defined as Black/African-American (not of Hispanic origin); Hispanic/Latino; White (not of Hispanic origin); American Indian/Alaskan Native; Asian/Pacific Islander; and Other. Smoking status was categorized as never smoker (smoked <100 cigarettes in their lifetime); past smoker (smoked ≥100 cigarettes in lifetime but do not currently smoke); and current smokers (smoked ≥100 cigarettes and were currently smoking), and alcohol consumption was categorized as nondrinkers (<12 drinks of any kind in entire life); past drinkers (≥12 alcoholic beverages in lifetime but do not currently drink); and current drinkers (≥12 alcoholic beverages in lifetime and are currently drinking). Diabetes and high cholesterol at baseline were defined as a self-reported physician's diagnosis (Anderson et al., 2003). Employment status was based on the participant's current job, or if she did not currently have a job, the job she held the longest (Anderson et al., 2003). Information on household income was obtained through self-report.

Body mass index (BMI) was calculated from height (m) and weight (kg) measured at study enrollment using a wall-mounted stadiometer and a balance beam scale, respectively (Anderson et al., 2003). Waist and hip circumference were measured at study enrollment using a standardized measuring tape (Anderson et al., 2003).

We calculated population density defined as the mean population per square meter within a 3-mile buffer zone of a participant's address from 2000 and 2010 Census Tiger/Line files. We used data from the US Census and American Community Survey to calculate an index of neighborhood socioeconomic status (NSES) for each participant based on her address, as previously described (Diez Roux et al., 2001). We calculated z-scores for 4 NSES variables: median household income, percent high school diploma, percent professional occupation, and median value of owner-occupied housing units. We summed each of the z-scores to calculate a z-sum, which we used to control for potential confounding by NSES.

Statistical Analyses

We used stratified Cox proportional hazards models to estimate the hazard ratio (HR) and 95% confidence interval (CI) for incident hypertension associated with living ≤50, >50-200, >200-400, >400-1000 m from nearest major roadway compared to >1000 m, stratified by WHI study region. In our primary analyses, we adjusted for age, race (White, non-Hispanic versus others), smoking status, alcohol consumption, education, household income, employment status, insurance coverage, high cholesterol, participation in the hormone replacement therapy trial, and z-sum of NSES, in addition to WHI study region. We used multiple imputation by chained equations to create 10 datasets with all covariates imputed (Su et al., 2011). Most variables were missing in <1% of participants, except education, income and physical activity which were each missing in ≤10% of participants and employment status, history of high cholesterol, population density and distance to A3 roadways which were each missing in ≤16% of participants.

We performed several sensitivity analyses to assess the robustness of our findings. First, we additionally adjusted for physical activity, diabetes, and BMI. These factors were not included in the main analysis as they may represent causal intermediates between traffic pollution and incident hypertension. Second, in separate models we repeated the main analysis additionally adjusting for population density, waist circumference and waist-to-hip ratio, and distance to A3 roadways. Third, we repeated the primary analyses using a time-varying Cox model and considering the following metrics of exposure: distance to roadway at most recent address, and averaged over the 3, 6, 12, and 24 months prior to the clinic visit, in order to better estimate residential distance to roadway over time. Fourth, we repeated the primary analyses considering instead the total length of A1 and A2 roadways within a 200 m buffer of residential address. Fifth, we repeated the primary analyses using pooled logistic regression rather than a Cox model to better account for interval censoring. Sixth, we used linear mixed effects models to explore the association between residential distance to major roadway at baseline and repeated measures of SBP and DBP treated as continuous outcomes.

We evaluated whether the association between distance to nearest major roadway (comparing those ≤200 m versus >200 m from a major roadway) and incident hypertension varied according to subgroups defined by smoking status (never vs former vs current), BMI (<30 vs ≥30), education level (less than college degree vs college degree or more), race (white, non-Hispanic versus non-white), age at baseline (below vs above median of 61), physical activity (below vs above median of 7.5 MET hours per week), diabetes (yes vs no), population density within a 3-mile buffer (below vs above median of 3,044) , NSES z-score sum (below vs above median of 0) and prehypertension (dichotomous, defined as baseline SBP/DBP of 120/80 to 139/89 mmHg). We performed these analyses overall and by WHI study region. All analyses were conducted in the R statistical environment (version 3.0.0.) and a 2-sided p-value of <0.05 was considered statistically significant.

RESULTS

The 38,360 study participants free of hypertension at enrollment were predominantly White, non-Hispanic (84.8%) with a mean age of 61.6 ± 6.9 years (mean ± SD) (Table 1) and had a median follow up time of 7.9 years (range: 3.3-14.3 years). Participants lived a median of 1,154 m from a major roadway with 2.2% living ≤50 m of a major roadway. Participants living closest to a major roadway were more likely to be older, non-minority race/ethnicity, college graduates, lower income, obese, currently working, and have a history of diabetes compared to women living further away. A total of 12,051 participants developed incident hypertension during 267,775 person-years of follow-up, yielding an overall crude incidence rate of 4.5 per 100 person years.

Participants living ≤50 m of a major roadway had a 13% (95% CI: 1%, 28%) higher rate of incident hypertension compared to those living >1000 m from a major roadway, adjusting for a number of participant demographics, past medical history, and markers of individual and neighborhood socioeconomic status (Table 2, Model 1). This association was similar in sensitivity analyses including additional adjustment for the potential causal intermediates physical activity, diabetes, and BMI (Table 2, Model 2), further adjusting for population density (Table 2, Model 3), further adjusting for waist-to-hip ratio and waist circumference (data not shown), and in analyses using a time-varying Cox model (data not shown). In sensitivity analyses additionally adjusting for residential distance to nearest A3 roadway, the association with incident hypertension was further attenuated and no longer statistically significant (Table 2, Model 4). When examining residential distance to nearest major roadway and SBP and DBP, we found that participants living ≤50 m of a major roadway tended to have slightly higher SBP and DBP versus participants living >1000 m, but these differences did not reach statistical significance after adjustment for potential confounders (Supplemental Material Tables S1 and S2).

Participant demographic, socioeconomic, and health characteristics varied across WHI study regions (Supplemental Table S3). The association between residential distance to nearest major roadway and incident hypertension varied significantly by WHI study region (Figure 1; $P_{homogeneity}$<0.001). Specifically, participants living ≤50 m versus >1000 m had a 61% (95% CI: 18%, 120%) and a 51% (95% CI: 22%, 87%) higher rate of incident hypertension in the West and Northeast, respectively. In contrast, in the South and Midwest, living ≤50 m of a major roadway was not associated with an increased rate in incident hypertension.

The above results were similar in models additionally adjusted for population density (data not shown) or in models that considered total length of major (A1 or A2) roadways within a 200 m radius of each participant's home as an alternative exposure metric (Supplemental Material Table S4). Results were similar when we used pooled logistic regression instead of a Cox model (data not shown).

We evaluated whether the association between residential proximity to a major roadway (dichotomized as ≤200 m versus >200 m from a major roadway to simplify presentation of results) and incident hypertension differed according to participant characteristics. We observed no evidence of statistically significant heterogeneity by smoking status, BMI, race, physical activity, diabetes, population density within a 3-mile radius, NSES, or the presence of pre-hypertension at baseline, overall or within a WHI study region (Supplemental Material Table S5). There was some evidence of statistically significant heterogeneity by education level in the West ($P_{homogeneity}$=0.001), and by age at baseline in the Northeast ($P_{homogeneity}$=0.021).

DISCUSSION

In this national prospective study of more than 38,000 post-menopausal women with a median follow-up time of 7.9 years we found that living close to a major roadway was associated with higher rates of incident hypertension, with women living ≤50 m from a major roadway at greatest risk. These findings were generally robust to alternative modeling strategies, adjustment for a number of individual and neighborhood characteristics, and alternative exposure metrics. The magnitude of the observed association varied considerably across WHI study region, with strong, positive associations observed in the West and Northeast, some evidence of a negative association in the South, and no association observed in the Midwest.

Direct comparison to prior publications is challenging given the use of different exposure metrics across studies. Of the comparable previously published studies, only Sørensen et al(Sørensen et al., 2012) considered incident hypertension. Among 33,275 participants in the Danish Diet, Cancer and Health cohort study, Sørensen et al. (2012) found that living ≤50 m from a major roadway was associated with an incidence rate ratio for hypertension of 1.13 (95% CI: 0.97, 1.32). This estimate is remarkably close to the hazard ratio for incident hypertension of 1.13 (95% CI: 1.00, 1.28) for women living ≤50 m from a major roadway observed in the present study. Sørensen et al. (2012) separately considered the association between residential proximity to major roadways and prevalent hypertension and found no evidence of an association. We are aware of three other published studies that have focused on prevalent rather than incident hypertension. Among 4,291 participants of the Heinz Nixdorf Recall Study in Germany, living ≤50 m versus >200 m from a roadway with high volumes of heavy-duty traffic was associated with an odds ratio for prevalent hypertension of 1.51 (95% CI: 0.98, 2.34), which did not quite reach statistical significance. In a pooled analysis of 13 European cohorts with >100,000 participants, Fuks et al. (2014) subsequently found that cumulative traffic density within 100 m of the home was associated with prevalent hypertension, although the association again did not quite reach statistical significance (OR: 1.05 [95% CI: 0.99, 1.11] per 4 million vehicles x meter/day). In a study of 5,401 WHI participants in the San Diego area, we previously found that those living within <100 m vs >1000 m from a major roadway had a 22% higher (95% CI: 7, 39%) risk of prevalent hypertension (Kirwa et al., 2014).

Although not entirely consistent, these results suggest the presence of a variable association between living very close to major roadways and risk of hypertension. Indeed, we observed considerable heterogeneity by WHI study region, with pronounced positive associations observed in the West and Northeastern US, some evidence of a negative association in the South, and no association in the Midwestern US. The magnitude of the association likely varies depending on: the relationship between area roadways and nearby traffic-related noise and air pollutants (eg: vehicle fleet and fuel characteristics, topography), the relationship between outdoor and indoor residential pollution levels (eg: housing characteristics, prevalence of air conditioning), region-specific characteristics (eg. meteorological conditions, typical time-activity patterns), and potentially a number of other location specific characteristics. In particular, geocoding errors are known to vary in magnitude and direction depending on the properties of the local street network (Zandbergen et al., 2012), raising the possibility that the regional variability observed is partly an artifact of variable quality spatial data. Heterogeneity across studies may be driven by any or all of these factors in addition to differences in study-specific assessment of the outcome (eg: self-reported vs measured or incident vs prevalent hypertension).

We evaluated whether the association between residential distance to nearest major roadway and incident hypertension varied across strata defined by individual and neighborhood characteristics, nationally and within each of the four WHI study regions. We found statistically significant heterogeneity by education in the West (with the association more pronounced among those with at least a college degree), and by age at baseline in the Northeast (with the association more pronounced among younger participants). Associations appeared to be stronger among current smokers everywhere except the Midwest, but the test for heterogeneity did not reach statistical significance. However, it is unclear from these data whether any apparent heterogeneity is due to increased biological susceptibility, differences in behaviors that may lead to different exposures (eg: younger participants may spend more time outside), or chance findings.

In sensitivity analyses we evaluated the association between residential proximity to major roadways and repeated measures of SBP and DBP treated as continuous outcomes. Although we found that those living very near major roadways tended to have slightly higher SBP and DBP, these differences did not reach statistical significance after adjusting for a number of potential confounders. However, the magnitude of our effect estimates were similar to those from the larger European ESCAPE study (which did reach statistical significance) (Fuks et al., 2014), suggesting that perhaps our analyses of SBP and DBP were underpowered to detect associations of the expected magnitude.

Distance to major roadway is an imperfect surrogate marker for residential exposure to traffic-related air and noise pollution which has been used in a number of prior studies of cardiovascular health (Cesaroni et al., 2013; Fuks et al., 2011; Fuks et al., 2014; Gan et al., 2010; Hart et al., 2013; Hoffmann et al., 2007; Hoffmann et al., 2006; Maheswaran and Elliott, 2003; Rosenbloom et al., 2012; Sørensen et al., 2012; Tonne et al., 2007; Wilker et al., 2013). Support for use of this surrogate marker is provided by studies showing that levels of traffic-related air pollutants are highest immediately adjacent to roadways, decrease with increasing distance, and are close to background levels approximately 200 m from a major roadway (Zhu et al., 2002). Noise follows a similar decay pattern (Hothersall and Chandler-Wilde, 1987), such that outdoor levels of traffic-related noise and air pollutants are both correlated with proximity to major roadways as well as with each other (Allen et al., 2009). Clearly, future studies with spatial-temporal predictions of residential levels of both traffic-related noise and air pollutants would be needed to fully disentangle the effects of these two exposures. On the other hand, the use of residential proximity to major roadways has a significant advantage in that it allows consideration of the joint effects of air pollution and noise originating from this ubiquitous source.

Long-term exposures to traffic-related noise and traffic-related air pollution have each been associated with hypertension in prior studies. The evidence of such an association is strongest with regard to traffic-related noise, as summarized in a recent meta-analysis (van Kempen and Babisch, 2012). The association between traffic-related air pollution and hypertension remains unclear with some studies reporting a positive association (Chen et al., 2015; Coogan et al., 2012; Dong et al., 2013; Foraster et al., 2014b), and others finding no evidence of an association (Foraster et al., 2014a; Fuks et al., 2014; Sørensen et al., 2012). Again, future studies with high quality estimates of residential exposures to both traffic-related noise and air pollutants would be needed to fully disentangle the effects of these two exposures. The available direct evidence remains mixed, but emerging studies suggest that the effects of traffic-related noise and traffic-related air pollution on hypertension risk are likely independent (Babisch et al., 2014; Foraster et al., 2014b).

Other limitations of our study warrant discussion. First, although we systematically collected address history from participants over the duration of follow-up, there is still potential for misclassification of exposure from inaccurate address information, geocoding errors, or errors in the GIS data layers describing the geographic position of roadways. These sources of exposure misclassification are expected to be relatively small in urban areas, although potentially larger in suburban and rural areas (Whitsel et al., 2006). Second, we did not collect information on the amount of time participants spent away from home. However, the utility of exposure measures based on home address is supported by national surveys showing that Americans spend an average of 68% of their time at home (Klepeis et al., 2001). Third, major roadways in the US carry a combination of truck (diesel) and car (predominantly gasoline in the US) traffic, with potentially different effects on cardiovascular health. However, in this study we were not able to consider traffic type. Fourth, although we controlled for a number of markers of both individual and neighborhood socioeconomic status, we cannot exclude the possibility of residual confounding by socioeconomic factors. Fifth, our study was limited to post-menopausal women participating in one or more of the WHI clinical trials, potentially limiting the generalizability of these findings to other geographic areas, younger individuals, or men. Sixth, our definition of incident hypertension excludes women diagnosed with hypertension who were not pharmacologically treated.

On the other hand, our study has important strengths, including a well-characterized, national, prospective cohort with assessment of incident hypertension, large sample size, geographic diversity, and the ability to adjust for potential confounding by multiple individual and neighborhood characteristics.

CONCLUSIONS

Hypertension affects approximately 78 million adults in the US and 1 billion adults worldwide (Go et al., 2013), and has been consistently associated with increased risk of adverse cardiovascular events independent of other risk factors. Our results suggest that among post-menopausal women in the US, living near major roadways may be an important novel risk factor for incident hypertension. If causal, these results suggest that regulatory efforts to reduce traffic emissions (noise and/or air pollution) may reduce the public health burden of hypertension. Given the increasing proportion of the world's population living in urban environments and chronically exposed to potentially high levels of traffic-related air and noise pollution, as well as the high global rates of hypertension, additional studies are needed to confirm or refute these results.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Highlights

- Residential proximity to major roadways may increase the risk of hypertension.

- We examined this hypothesis in a large prospective cohort of post-menopausal women.

- Living very near a major roadway was associated with incident hypertension

- The magnitude of this association varied significantly by region of the country

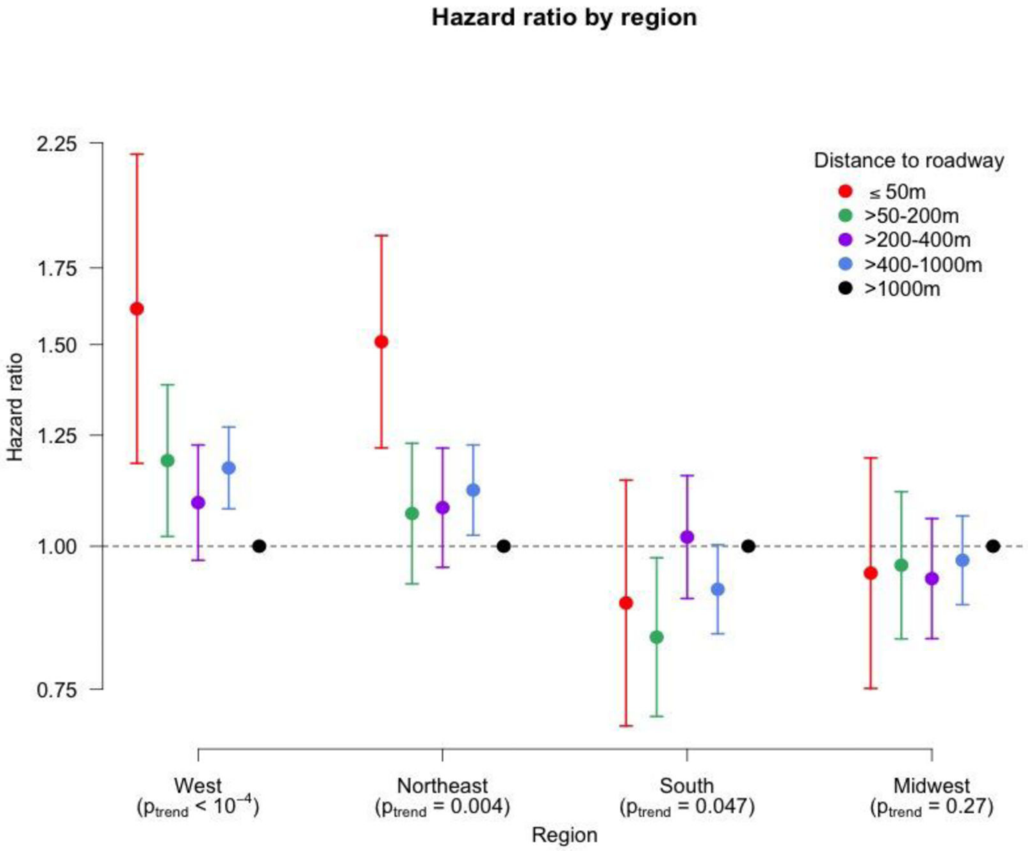

Figure 1.

Hazard ratios and 95% confidence intervals of the association between residential distance to nearest major roadway and incident hypertension among WHI CT participants, stratified by WHI study region.

Table 1

Baseline characteristics of 38,360 WHI clinical trials participants free from hypertension at baseline.*

		Residential Distance to Nearest Major Roadway (m)				
Characteristics	**All (N=38,360)**	**≥50 (N=851)**	**50-200 (N=2593)**	**200-400 (N=4172)**	**400-1000 (N=9594)**	**>1000 (N=21150)**
Age, years, mean ± SD†	61.6 ± 6.9	62.1 ± 7.1	61.6 ± 7.1	61.5 ± 6.9	61.6 ± 6.9	61.5 ± 6.8
Race, %						
White, Non-Hispanic	84.8	86.8	78.2	80.4	82.6	87.4
Black, Non-Hispanic	6.9	6.8	11.1	9.6	8.5	5.1
Hispanic/Latino	4.6	3.4	4.9	5.9	4.6	4.3
Asian or Pacific Islander	2.1	1.4	3.8	2.6	2.4	1.6
Other	1.1	0.9	1.3	1.1	1.3	0.9
Education, %						
< College degree	54.9	52.8	54.6	54.9	54.1	55.5
College graduate	36.8	39.8	36.5	36.2	37.3	36.4
Household income, %						
<$20,000	14.0	18.3	17.4	15.1	14.4	13.0
$20,000-<$50,000	42.7	44.3	42.5	43.8	42.7	42.5
≥ $50,000	37.7	32.9	34.7	35.2	37.2	39.0
Body mass index, %						
≤ 25 kg/m^3	33.7	35.1	32.8	32.6	33.6	34.0
25-<30 kg/m^3	36.9	30.2	35.8	36.2	37.1	37.3
≥ 30 kg/m^3	29.9	34.1	30.9	30.8	28.8	28.3
Alcohol drinks/week, %						
None or < 1	60.2	60.5	61.2	60.8	59.6	60.3
1-6	27.0	26.6	26.9	27.2	27.2	26.8
≥ 7	11.1	10.6	10.0	10.6	11.4	11.2
Ever Smoker, %						
Never	49.8	49.5	47.1	50.0	49.0	50.5
Past	40.9	39.6	41.3	40.5	41.2	40.8
Current	8.6	10.6	11.1	8.8	9.1	8.0
Currently working, %	39.0	41.4	39.7	40.3	39.9	38.1

		Residential Distance to Nearest Major Roadway (m)				
Characteristics	**All (N=38,360)**	**≥50 (N=851)**	**50-200 (N=2593)**	**200-400 (N=4172)**	**400-1000 (N=9594)**	**>1000 (N=21150)**
Health insurance, %	93.5	93.4	92.6	92.4	93.5	93.8
Physical activity, %						
<3.00 MET[†] hr/wk	27.3	29.1	28.5	27.5	27.9	26.7
3.00 - <11.75 MET hr/wk	30.1	28.2	29.9	30.5	30.1	30.1
≥ 11.75 MET hr/wk	32.7	34.9	31.4	32.6	32.4	32.9
Diabetes ever, %	3.3	4.2	3.3	3.6	3.5	3.0
High cholesterol ever, %	7.6	7.3	9.2	8.6	8.1	7.6
Married or living with partner, %	64.7	53.0	56.1	59.9	62.6	68.1
WHI Study Region, %						
Northeast	22.7	30.2	28.2	26.9	24.5	20.0
South	24.8	26.2	22.1	21.9	23.6	26.2
Midwest	22.3	28.6	25.1	23.5	22.4	21.5
West	30.2	15.0	24.7	27.7	29.5	32.3
Census-level variables, mean ± SD						
Median neighborhood household income ($1000's)	56.6 ± 24.6	51.5 ± 22.0	52.3 ± 23.6	53.5 ± 23.2	54.5 ± 24.0	58.9 ± 25.1
Percent residents with high school diploma	86.1 ± 10.9	85.0 ± 11.3	83.8 ± 12.4	84.4 ± 11.8	85.1 ± 11.5	87.2 ± 10.0
Percent of residents with professional occupation	41.0 ± 15.7	41.7 ± 17.0	40.5 ± 16.7	40.4 ± 16.2	40.7 ± 16.1	41.4 ± 15.2
Median value of owner-occupied housing unit ($1000's)	196 ± 144	187 ± 137	192 ± 139	192 ± 136	195 ± 145	197 ± 145
Population density within 3-mile radius (population/miles^2)	4318 ± 5442	6372 ± 8509	6366 ± 7829	5815 ± 7157	5056 ± 6277	3321 ± 3523

[*] Some percentages do not add up to 100% due to missing data

[†] Abbreviations: SD= standard deviation, MET = metabolic equivalents

Table 2

Hazard ratios (95% confidence intervals) of the association between categories of residential distance to nearest major roadway and incident hypertension among 38,360 WHI CT participants.

	Residential Distance to Nearest Major Roadway (m)					
Model	**≤50**	**>50-200**	**>200-400**	**>400-1000**	**>1000**	**p-trend**
1*	1.13 (1.00, 1.28)	1.03 (0.95, 1.11)	1.05 (0.99, 1.11)	1.05 (1.00, 1.10)	1.0 (Ref.)	0.013
2†	1.14 (1.01, 1.28)	1.02 (0.94, 1.10)	1.04 (0.98, 1.10)	1.04 (1.00, 1.09)	1.0 (Ref.)	0.034
3‡	1.12 (0.99, 1.26)	1.02 (0.95, 1.10)	1.04 (0.98, 1.11)	1.05 (1.01, 1.10)	1.0 (Ref.)	0.016
4§	1.09 (0.95, 1.24)	1.02 (0.94, 1.10)	1.04 (0.97, 1.11)	1.03 (0.98, 1.08)	1.0 (Ref.)	0.096

[*] Model 1 is adjusted for age, race, smoking status, alcohol consumption, education, household income, employment status, insurance coverage, high cholesterol, study arm, and markers of neighborhood socioeconomic status.

[†] Model 2 is model 1 additionally adjusted for the potential causal intermediates physical activity, diabetes, and BMI.

[‡] Model 3 is model 1 additionally adjusted for population density.

[§] Model 4 is model 1 additionally adjusted for categories of residential distance to nearest A3 roadways.