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Residential Proximity to Major Roadway and Cognitive Function in Community-Dwelling Seniors: Results from the MOBILIZE Boston Study

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Abstract

Background/Objectives—Long-term exposure to ambient air pollution has been associated with decreased cognitive function, but the effects of traffic pollution on the elderly have not been studied in detail. Accordingly, the objective of this study was to evaluate the association between residential distance to major roadway, as a marker of long-term exposure to traffic pollution, and cognitive function in seniors.

Design, Setting, Participants—A prospective cohort study of 765 community-dwelling seniors with median follow-up of 16.8 months.

Measurements—We administered the Mini Mental State Exam (MMSE), Hopkins Verbal Learning Test-Revised (HVLT-R), Trail Making Test (TMT), category and letter fluency tests, and clock-in-the-box test (CIB) during home visits on 2 occasions. We calculated the residential distance to nearest major roadway and used generalized estimating equations to evaluate the

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Dr. Wellenius had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. Study concept and design: Wellenius, Mittleman. Acquisition of data: Milberg, Lipsitz, Gryparis. Analysis and interpretation of data: Wellenius, Boyle, Coull, Schwartz, Mittleman, Milberg. Drafting of manuscript: Wellenius, Boyle. Critical revision of the manuscript for important intellectual content: Wellenius, Boyle, Mittleman, Schwartz, Coull, Lipsitz. Obtained funding: Wellenius, Mittleman, Lipsitz.

association between performance on each test and residential distance to major roadway adjusting for participant demographics, education, socioeconomic status and past medical history.

Results—Decreasing distance to major roadway was associated with statistically significantly poorer performance on the immediate and delayed recall components of the HVLT-R, TMT part B, TMT delta, and the letter and category fluency tests. Generally, participants residing <100 m from a major roadway performed worst. Performance improved monotonically with increasing distance.

Conclusions—In this cohort of community-dwelling seniors, residential proximity to major roadways was associated with poorer performance on cognitive tests of verbal learning and memory, psychomotor speed, language and executive functioning. If causal, these results add to the growing evidence that living near major roadways is associated with adverse health outcomes.

Keywords

air pollution; traffic; roadway; cognitive function; elderly

INTRODUCTION

Long-term exposure to fine particulate matter air pollution has been associated with increased risk of cardiovascular mortality, coronary heart disease, and cerebrovascular events.[1, 2] These effects are likely mediated by a combination of pathophysiologic changes including increased systemic inflammation, oxidative stress, and vascular endothelial injury, with pollution from traffic identified as a key source.[3] Long-term exposure to traffic pollution has been associated with increased atherosclerosis of the carotid arteries[4] and narrowing of the retinal arterioles,[5] suggesting that traffic pollution can adversely affect both the large cerebral arteries and the cerebral microvasculature. Considering the importance of a vascular etiology in cognitive impairment,[6] it is plausible that long-term exposure to traffic pollution may be detrimental to cognitive function. However, few studies have specifically evaluated this hypothesis in the elderly.[7, 8] Given the increasing prevalence of mild cognitive impairment, the substantial impact even mild cognitive decline can have on the number of people unable to live independently, and the increasing urbanization of cities worldwide, further clarifying the potential effects of traffic pollution on cognitive function is important. Accordingly, we evaluated the association between residential distance to major roadway as a marker of long-term exposure to traffic pollution and cognitive function within a prospective, community-based cohort study of healthy aging.[9]

METHODS

Study Design

Between 2005 and 2008, the MOBILIZE Boston Study (MBS) recruited 765 non-institutionalized men and women aged ≥65 years, able to communicate in English, residing <5 miles (8.0 km) from the study clinic, able to walk 20 feet (6.1 m) without personal assistance, and having a Mini-Mental State Examination (MMSE) score of ≥18, as previously described.[9] All participants provided written informed consent. This analysis was approved by the Institutional Review Boards at Hebrew Senior Life and Brown University.

During an in-home interview, trained staff administered tests of cognitive function and obtained detailed information on participant age, race, sex, education, household income, medical history, current medications, physical activity, and smoking history. Performance of physical activities was determined using the Physical Activity Scale for the Elderly (PASE).[10] During a follow-up clinic examination, we measured height and weight, collected a venous blood sample, and measured supine blood pressure as previously described.[9] A second assessment consisting of an in-home interview and clinic examination was performed a median of 16.8 months after the baseline assessment.

Neuropsychological Measures

We administered six neuropsychological tests to each participant during the home interview, as previously described.[11]

The MMSE is widely used in clinical and research settings to screen for dementia and provides a global assessment of an individual's cognitive function. The MMSE is scored on a 30-point scale, with low scores indicating worse performance.

The Hopkins Verbal Learning Test-Revised (HVLT-R)[12] is a 12-item word list learning test in which individuals are presented three learning and recall trials followed by a delayed recall trail and a 24-item word recognition test. The HVLT-R produces three scores: the sum of correct responses in each of three learning trials (HVLT-R Learning); the number of items correctly recalled after the delay (HVLT-R Delayed Recall); and the number of recognition items correctly identified (HVLT-R Recognition). In older adults, the encoding procedure requires working and verbal memory processes and executive functioning.[13]

The Trailmaking Test (TMT) part A consists of number targets to be connected in order, providing an estimate of attention and psychomotor speed. TMT Part B includes number and letter targets that are to be connected in alternating sequence (e.g., 1-A-2-B-3-C), providing an estimate of set-shifting and executive function. Performance is based on the time required to complete each task up to a maximum of 5 minutes. Shorter times indicate better performance. The TMT is frequently applied in the clinical setting and is sensitive to the presence of frontal lobe pathology and cerebrovascular risk.[14] As in previous studies,[11] to control for the effect of motor function and information processing speed we calculated the TMT delta as the time to perform part B minus the time to perform part A.

The Clock-in-a-Box Test (CIB) requires participants to read and follow written directions by drawing a clock in a specific location on the response form and setting the clock to the correct time.[15] Performance on this test is based on eight features associated with working memory and organization and planning of the drawing, with higher scores indicating better performance. Performance on the CIB has been shown to be predictive of performance on standardized measures of working memory and executive function.[11, 15]

In the Letter Fluency test, participants were asked to name as many words as possible beginning with given letters (F, A, and S) for 60 seconds each. An additional 60-second trial was given to assess category fluency (animal naming). Performance was based on the number of items generated for each trial, with higher scores indicating better performance. Both tests assess language and executive functioning.[11]

Exposure Assessment

We calculated residential distance to major roadway as a marker of long-term exposure to traffic pollution. We used ArcGIS (version 9.2; ESRI, Inc., Redlands, CA) to geocode participant addresses and calculate the Euclidean distance from residence to the nearest major roadway, defined as roads having US Census Feature Class Code A1 (primary highway with limited access) or A2 (primary road without limited access), as in previous studies.[16] In a secondary analysis, we estimated daily outdoor black carbon levels (a marker of traffic pollution) at each participant's residential address using a validated spatial-temporal land-use regression model, as previously described.[17] To create a metric of long-term black carbon exposure for the present study, we average destimated residential black carbon over the 365 days preceding each cognitive assessment.

Statistical Analysis

As in a previous study,[7] we dichotomized MMSE scores as below or above the lowest quartile (MMSE <26 versus ≥26) and used generalized estimating equation (GEE) models with a logit link function and an exchangeable correlation matrix to estimate the association between residential exposure to traffic pollution and the odds of having an MMSE <26 while accounting for within-subject correlation. For all other outcomes, we used GEE models with an identity link function. In all analyses we adjusted for age, sex, race (white versus other), history of stroke, history of smoking (ever versus never), physical activity, education (3 categories), visit (baseline versus first follow-up) body mass index, household income (below versus above median), season of home interview (4 categories), and two census track-level indicators of neighborhood socioeconomic status (percent of population that is non-white and percent of population with college degree or above). Age, physical activity, and body mass index were each modeled using natural cubic splines with 3 degrees of freedom. We initially modeled residential distance to roadway as a linear continuous variable, but subsequently considered the following categories: ≤100, >100 to 250, >250 to 500, >500 to 1000, and >1000 m. Tests for linear trend were performed by assigning the median distance to each category and including the term as a continuous variable in the regression model.

We evaluated whether the association between residential distance to major roadway and test performance varied by age (≤77 versus > 77) or education (high school or less versus some college or more) by adding an interaction term to the main effects model.

Analyses were performed using SAS (v9.2; SAS Institute Inc., Cary, NC) and R statistical software (R v2.10). A two-sided p value of <0.05 was considered statistically significant.

RESULTS

MOBILIZE Boston Study participants were elderly, and predominantly white and female (Table 1). Residential distance to major roadway varied from near 0 meters to just over 3 km, with 10% of participants living within 100 m of a major roadway.

In models adjusting for participant demographics, medical history, education, and socioeconomic status, decreasing residential distance to major roadway was associated with poorer performance on the immediate and delayed recall components of the HVLT-R, TMT part B, TMT delta, and both the letter and category fluency tests (Table 2, Supplemental Table 1). Generally, performance on these tests was worst for those participants residing within 100 m from a major roadway and improved monotonically with increasing distance (Table 3). Distance to major roadway was not associated with performance on the HVLT-R recognition, TMT part A, or CIB tests, nor with risk of having an MMSE score <26 (odds ratio (OR): 1.07; 95% confidence interval (CI): 0.84, 1.36; p=0.60).

Proximity to major roadway was associated with increased risk of having an MMSE score <26 among participants with at least some college education (OR: 1.54; 95% CI: 1.10, 2.17) and participants aged ≤77 years (OR: 1.34; 95% CI (1.01, 1.76), but not among older participants or those with less formal education (Supplemental Table 2). The association between distance to roadway and performance on the HVLT-R delayed recall and category fluency tests varied according to age with the larger association observed among participants aged ≤77 years.

Annual residential black carbon levels ranged from 0.15 to 0.98 $\mu g/m^3$ with a median of 0.36 $\mu g/m^3$. An interquartile range increase in residential black carbon levels (0.11 $\mu g/m^3$) was associated with a higher risk of having an MMSE score <26 (OR: 1.15; 95% CI: 0.99, 1.34; p=0.063), and worse performance on the HVLT-R immediate recall (p=0.046), but was not associated with statistically significant changes in performance on any other neuropsychological tests (Supplemental Table 3).

DISCUSSION

In this cohort of community-dwelling seniors, residential distance to major roadway was associated with poorer performance on cognitive tests of verbal learning and memory, psychomotor speed, language and executive functioning, with most tests showing evidence of a graded dose-response relationship. To put these results into context, the decrease in performance associated with an interquartile range decrease in distance to major roadway was similar to that associated with an increase in age of 2 (for tests of verbal memory) to 4 years (for the TMT and category naming tests). Some of the observed associations differed across subgroups defined by achieved education, but we found no statistical evidence that the associations differed by age. Results were generally in the same direction but not statistically significant when we instead considered residential black carbon levels as a marker of traffic pollution.

Prior studies suggest that traffic pollution[18, 19] is likely deleterious to neurodevelopment in children and that urban air pollution is associated with cognitive decline in older adults.[20] However, fewer studies have evaluated the effects of traffic pollution on cognitive impairment in the elderly. Ranft et al.[8] found that among 399 women aged 68–79 years in Germany those living <50 m from a busy roadway performed worse on the total score calculated from the CERAD-Plus test battery, as well as the Stroop color word test and a test of olfactory function. The observation that performance on the Stroop test – which provides an assessment of executive function and selective attention – is reduced is consistent with the findings in the current study. Power et al.[7] found that predicted 1-year average residential black carbon was associated with higher risk of having an MMSE score in the lowest quartile among 680 men from the Normative Aging Study. We similarly found an association between performance on the MMSE and long-term average residential black carbon levels. We also found that MMSE performance was associated with distance to roadway among participants with at least some college education. Power et al.[7] also found that residential black carbon levels were associated with a lower summary score derived from a battery of 7 cognitive tests, but did not report the results for individual tests making further comparison to the current study difficult.

While residential black carbon and distance to nearest major roadway both serve as markers of traffic pollution, they are not equivalent. Between-person differences in estimated residential black carbon predominantly reflect differences in air pollution from traffic on roads within 100 m of the home which is dominated by automobiles moving at slower speeds. On the other hand, residential distance to major roadway likely reflects pollution originating from automobile and truck traffic on busy highways. Thus, our results might suggest that cognitive function is more strongly associated with pollution arising from automobiles and trucks on busy highways than that arising from automobile traffic on local roads. Indeed, independent effects of traffic pollution over different spatial scales have been previously reported.[21]

Short-term and long-term exposure to ambient particulate matter has been associated with increased risk of cerebrovascular events, and traffic pollution seems to be particularly important.[2, 22, 23] Traffic pollution exposure has also been associated with increased systemic inflammation and oxidative stress,[24, 25] which may in turn promote cerebral micro vascular dysfunction and increase the brain’s susceptibility to injury.[6] Histologic evidence of cerebral micro vascular damage, vascular inflammation, and disruption of the blood brain barrier has been observed in dogs from areas with high versus low levels of urban air pollution.[26,27] Excess prefrontal white matter hyperintense lesions on magnetic resonance imaging have been observed in dogs and children residing in high versus low pollution areas of Mexico.[27] Whether long-term exposure to ambient pollutants is associated with other vascular pathologies remains unknown.

Non-vascular mechanisms of cognitive impairment are also plausible. Toxicologic studies suggest that inhaled ultrafine particles (diameter <100nm, primarily from traffic) and/or transition metals may translocate from the respiratory system directly to the central nervous system via the olfactory neuronal pathway.[28, 29] Dogs from the polluted areas also showed increased DNA damage in the olfactory bulb and hippocampus, as well as increased expression of injury-responsive proteins (NFκB, iNOS, amyloid precursor protein and amyloid β) in neurons and/or glial cells.[29]

Our study has some potential limitations. First, despite controlling for socioeconomic status at both the individual and neighborhood levels, we cannot exclude the possibility of residual confounding. Second, since participants with MMSE <18 were excluded from the study our results may not be generalizable to individuals with impaired cognitive function. Third, the length of time at the current address for each study participant is unknown, possibly leading to some exposure misclassification which would have biased our health effects estimates towards the null. Additionally, indoor levels of pollutants of ambient origin may be substantially lower than outdoor levels, likely further biasing our health effect estimates towards the null. Finally, our study is unable to separate the effects of traffic air pollution from traffic noise, which has also been associated with cognitive impairment in children.[30] On the other hand, important strengths of our study include a large, representative cohort of community-dwelling seniors, repeated measures within individuals, and a comprehensive battery of neuropsychological assessments administered in the home.

In conclusion, in this cohort of community-dwelling elderly participants, markers of long-term exposure to traffic pollution were associated with cognitive impairment across a number of different domains, suggesting that traffic pollution could be exerting effects on specific areas of the brain. Additional studies are needed to confirm these findings, to identify the components of traffic pollution most responsible, and to identify the pathophysiologic changes in brain structure or function underlying these associations. If causal, these results add to the growing evidence that living near major roadways is associated with adverse health.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Table 1

Baseline characteristics of 765 participants from the MOBILIZE Boston Study.

Characteristic	n (%) or mean ± SD
Female	489 (63.9)
Age, years	78.1 ± 5.4
White	593 (77.5)
Educational Level	
High School or Less	261 (34.2)
College or Vocational School	266 (34.8)
Graduate School	237 (31.0)
Ever Smoker	427 (55.8)
Body Mass Index, kg/m^2	27.3 ± 5.1
History of Stroke	76 (9.9)
Dyslipidemia	361 (47.2)
Diabetes Mellitus	153 (20.0)
Hypertension	598 (78.2)
Physical Activity *	104.7 (66.4)

*assessed using the using the Physical Activity Scale for the Elderly (PASE) [10].

Table 2

Change in score on tests of cognitive function associated with an interquartile range decrease (851.2 m) in residential distance to major roadway.*

	Mean Score ± SD	Change in Score (95% CI)	p-value
Lower Scores Indicate Poorer Performance			
Hopkins Verbal Learning Test			
Immediate Recall	20.8 ± 5.8	−0.6 (−1.1, −0.1)	0.015
Delayed Recall	6.3 ± 3.5	−0.4 (−0.7, −0.1)	0.011
Recognition	11.4 ± 2.2	0.07 (−0.12, 0.25)	0.47
Letter Fluency	37.5 ± 14.7	−1.4 (−2.7, −0.2)	0.022
Category Fluency	15.6 ± 5.3	−0.7 (−1.1, −0.3)	0.002
Clock in the box	6.4 ± 1.5	−0.04 (−0.15, 0.07)	0.47
Higher Scores Indicate Poorer Performance			
Trailmaking Test, seconds			
Part A	56.3 ± 34.2	2.1 (−0.7, 4.9)	0.14
Part B	141.1 ± 78.1	10.5 (4.0, 17.1)	0.002
Delta†	87.9 ± 63.7	7.5 (2.2, 12.8)	0.006

*All models are adjusted for age, sex, race, history of stroke, history of smoking, education, visit number, body mass index, physical activity, household income, percent of neighborhood population that is non-white, and percent of neighborhood population with college degree or above.

†Trailmaking Test Delta is calculated as the time to complete Part B minus the time to complete Part A of the test.

Table 3

Change in score on tests of cognitive function associated with categories of residential distance to major roadway.

	Residential Distance to Major Roadway					P_{trend}
	<100 m (n=77)	**100–250 m (n=85)**	**250–500 m (n=133)**	**500–1000 m (n=224)**	**>1000 m (n=237)**	
Lower Scores Indicate Poorer Performance						
Hopkins Verbal Learning Test						
Immediate Recall	−1.6 (−2.9, − 0.3)	−0.8 (−2.0, 0.4)	−1.0 (−2.0, 0.1)	0.1 (−0.8, 1.0)	0	0.011
Delayed Recall	−1.1 (−1.9, − 0.3)	−0.8 (−1.6, −0.1)	−0.3 (−1.0, 0.3)	−0.1 (−0.7, 0.4)	0	0.006
Recognition	0.2 (−0.3, 0.8)	0.1 (−0.4, 0.5)	0.2 (−0.2, 0.7)	0.2 (−0.2, 0.6)	0	0.27
Letter Fluency	−1.5 (−4.7, 1.8)	−2.4 (−5.4, 0.5)	−2.4 (−5.0, 0.2)	−1.9 (−4.2, 0.4)	0	0.053
Category Fluency	−0.8 (−1.9, 0.3)	−1.2 (−2.4, 0.0)	−0.9 (−1.8, 0.1)	−0.3 (−1.1, 0.5)	0	0.016
Clock-in-the-Box	−0.1 (−0.4, 0.2)	−0.1 (−0.4, 0.2)	0.0 (−0.2, 0.3)	0.0 (−0.3, 0.2)	0	0.66
Higher Scores Indicate Poorer Performance						
Trailmaking Test						
Part A	7.4 (−2.2, 16.9)	1.9 (−5.7, 9.5)	−0.6 (−5.8, 4.5)	4.1 (−1.2, 9.5)	0	0.26
Part B	15.2 (−1.6, 32.0)	13.7 (−4.5, 31.8)	11.0 (−3.2, 25.2)	9.5 (−2.0, 21.0)	0	0.025
Delta†	6.9 (−6.5, 20.3)	12.4 (−2.6, 27.5)	10.2 (−1.3, 21.8)	5.0 (−4.4, 14.4)	0	0.041

P_{trend} denotes the P-value from the test for linear trend.

†Trailmaking Test Delta is calculated as the time to complete Part B minus the time to complete Part A of the test.