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Authors
Song, Yan
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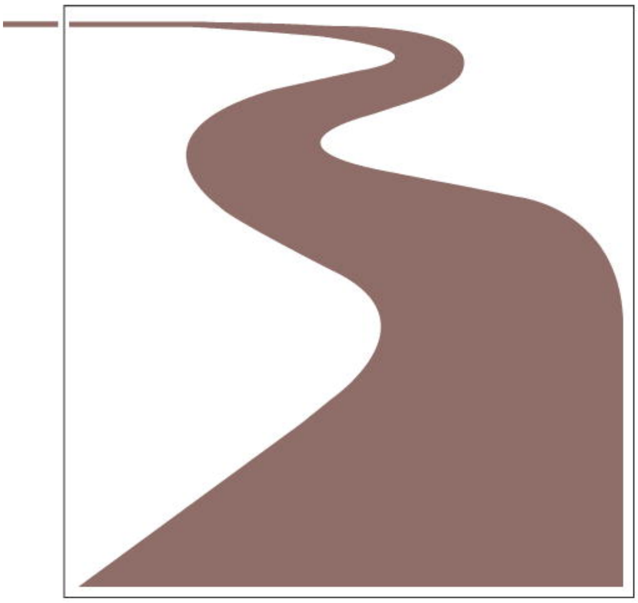

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Do physical neighborhood characteristics matter in predicting traffic stress and health outcomes?

Yan Song [a,*], Gilbert C. Gee [b], Yingling Fan [a], David T. Takeuchi [c]

[a] *Department of City and Regional Planning University of North Carolina at Chapel Hill East Bldg, CB# 3140, Chapel Hill, NC 27599-3140*

[b] *Department of Health Behaviour and Health Education School of Public Health, University of Michigan 1420 Washington Heights, Room M 5224 Ann Arbor, MI 48109-2029*

[c] *University of Washington 4101 15th Avenue, NE Seattle, WA 98105-6299*

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Abstract

This study examines whether social, and physical environment characteristics related to urban design interact with individual perceptions of traffic stress to influence individual well-being. The Chinese American Psychiatric Epidemiologic Study data, the US census data, and the Geographic Information System (GIS) data are employed. Analyses used hierarchical linear modeling. The results indicate that perceived traffic stress was associated with lower health status and higher depression. More importantly, higher density of major streets and greater vehicular burden in the neighborhood pose potential harm to health by reinforcing the negative impacts of perceived traffic stress. On the other hand, more park land in the neighborhood could alleviate the damage of traffic stress on individual's well-being. The implications of the results for future research are discussed.

Keywords: Traffic stress; Health; Neighborhood configuration; HLM analysis

1. Introduction

The number of motor vehicles is growing rapidly around the world. Between 1980 and 1995 – just 15 years – the global fleet of cars, trucks, and buses increased by 60% (Ingram & Liu, 1998). The increasing number of vehicles brings many benefits in enhancing people's mobility and accessibility to destinations but is also associated with worsening negative externalities brought by one of transportation's undesired consequences – traffic. Among these externalities includes the potentially harmful effects of stress and annoyance resulting from traffic (Ouis, 2001). Perceptions of stress due to traffic and transportation (hereafter called "traffic stress") may result from unintentional injuries, the exposure to traffic and to traffic-related noise, vibration and air

* Corresponding author. Tel.: +1 919 962 4761.
E-mail address: ys@email.unc.edu (Y. Song).

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pollution, the hassles of driving and parking, monetary hardships, inconveniences of vehicle maintenance and purchase, and reduction of street activities (Institute of Transportation Engineers [ITE], 1999; Gee & Takeuchi, 2004). Illness may result when stressors exceed one's ability to cope with these stressors (Lazarus & Folkman, 1984). Further, stressors may influence health, not only through individual perceptions, but also through an interaction between an individual and their environment (Gee & Payne-Sturges, 2004).

However, few formal analyses focus on understanding the interaction effects of an individual and the environment on health outcomes. Earlier stress models were developed to investigate individual's response to stress based on individual's differences in perceiving stress stimulus by focusing on appraising and coping behavior (Lazarus, 1966), organismic characteristics (Selye, 1976), and adaptive capacity (Jenkins, 1979). Most of these models can be regarded as individually based models since they emphasize individual's behavior of adaptation in the process of responding to stress. While early stress models do acknowledge the role of the environment in producing stressors, much of the empirical research has been criticized for neglecting the environmental context (Pearlin, 1989; Aneschensel, 1992). Given this background, the present study seeks to examine both individual perceptions of traffic stress, as well as objectively measured environmental characteristics related to traffic.

Several empirical studies suggest that structural features of the urban environment are associated with stress-related outcomes. For example, Taylor (1982) hypothesized three sets of physical neighborhood features – buildings, neighborhood facilities, and land uses – that could capture the influence of the environment on neighborhood social functions. Variables such as type and condition of housing, location and pattern of placement of amenities, traffic volume and circulation patterns are then used to quantify those three sets of physical neighborhood features. Brugge, Leong, Averbach, and Cheung (2000) found that the lack of open/green space has been a primary community concern through a survey of residents in Chinatown of Boston. Ewart and Suchday (2002) concluded that the number of vehicles speeding on neighborhood streets and the number of vacant houses are predictors of neighborhood disorder. Woldoff (2002) and Feldman and Steptoe (2004) examined the relationship between several physical neighborhood factors and presence of neighborhood problems. They found that perception of physical neighborhoods is associated with selected physical neighborhood factors and this association is through social and psychological experiences of the residents in neighborhoods.

There has been scant empirical investigation of the environmental features that could be associated with traffic stress-related outcomes, although there is a vast literature on good physical urban qualities and good urban forms that suggest these relations (for example, Calthorpe, 1993; Jacobs, 1984; Kostof, 1992; Lynch, 1960, 1981; Wheeler, 2003). The literature suggests the following set of favored physical features which can be associated with traffic stress, including: *Permeability*, the connectiveness of places, prescribes that a successful movement system ensures the easiness of how people make their journey; *variety*, the appropriate mix of compatible land uses and housing types, generates greater opportunities for social interactions; *robustness*, the accessibility of development, boosts healthy vehicle and pedestrian activities. In this paper, we quantify these dimensions of built environment by developing measures of street network design, land use mixture, and density. These measures have been demonstrated to be efficient measures of connectiveness, variety, and accessibility of the environment (Song & Knaap, 2004a). The main aim of this study is then to investigate whether these dimensions of neighborhood configuration are associated with traffic stress and can be used to predict individual's well-being.

This study uses a more refined technique and more comprehensive assessment on urban characteristics to revisit a previous study which examined whether traffic stress could be associated with well-being. Gee and Takeuchi (2004) found that persons reporting traffic stress had greater illness and that neighborhood traffic moderated the association between traffic stress and illness. In particular, the relationship between traffic stress and illness was stronger for people living in areas where more residents drove their cars to work. However, their analysis considered only two environmental characteristics – vehicular burden and neighborhood poverty, raising questions as to whether other neighborhood characteristics may be relevant in explaining or expanding their findings. In addition to traffic environment measured by vehicular burden in the neighborhood, traffic stress may also arise from an interaction between an individual and other dimensions of built environment of the residential neighborhood such as street design, land use mixture, and density. We thus go beyond prior work by considering additional characteristics of neighborhood built environment that have been developed in the planning literature. In addition, whereas the Gee and Takeuchi (2004) study used census tracts, this current study uses census block groups. This smaller unit of analysis allows for a more fine-grade examination of the proximal neighborhood environment.

2. Methods

2.1. Conceptual Model

Fig. 1 portrays the conceptual model concerning the relationship between individual characteristics, neighborhood level factors, traffic stress and individual health outcomes. Adapted from the model of the stress process in neighborhood context developed by Elliott (2000), this model shows that individual differences as well as neighborhood factors influence traffic stress and health outcomes. Individual perceptions of traffic stress and objective neighborhood conditions may influence health directly (links *a* and *b*, respectively). Additionally, in line with arguments that subjective perceptions may be moderated by objective conditions, perceptions of traffic stress may be moderated by neighborhood characteristics (link *c*). For example, individuals who perceive a high level of traffic stress who live on streets with a high vehicular burden may be at greater risk of illness than individuals who perceive similar levels of stress, but who live on streets with a lower vehicular burden. Similarly, individual perceptions of traffic stress may be buffered by the presence of parks and other "restorative" properties of the environment. In addition to these moderating effects, finally, other personal characteristics (e.g. age, income) that may influence well-being (link *d*) are included as controls.

2.2. Data

Three major data sources are used for this study: (1) Chinese American Psychiatric Epidemiologic Study (CAPES) survey; (2) 1990 Census data, and; (3) 1995 Geographic Information System (GIS) data purchased from the GIS Center in the City of Los Angeles. The CAPES was a population-based survey of Chinese Americans living in the greater Los Angeles area. The study's multistage sampling scheme has been described previously (Gee & Takeuchi, 2004; Gee, 2002; Takeuchi et al., 1998) and is only summarized here. In 1993–1994, a sample of 1747 Chinese American respondents aged 18–65 years was produced. The response rate among eligible respondents was 82%. Of these respondents, 1503 were reinterviewed at a 15-month follow-up. This article focuses on the reinterview because all respondents were asked about perceived traffic stress. Respondents were linked to census data from the 1990 US Census of Population, allowing for analysis of neighborhood social-economic compositions. Respondents were further linked to the 1995 GIS data on land parcels,

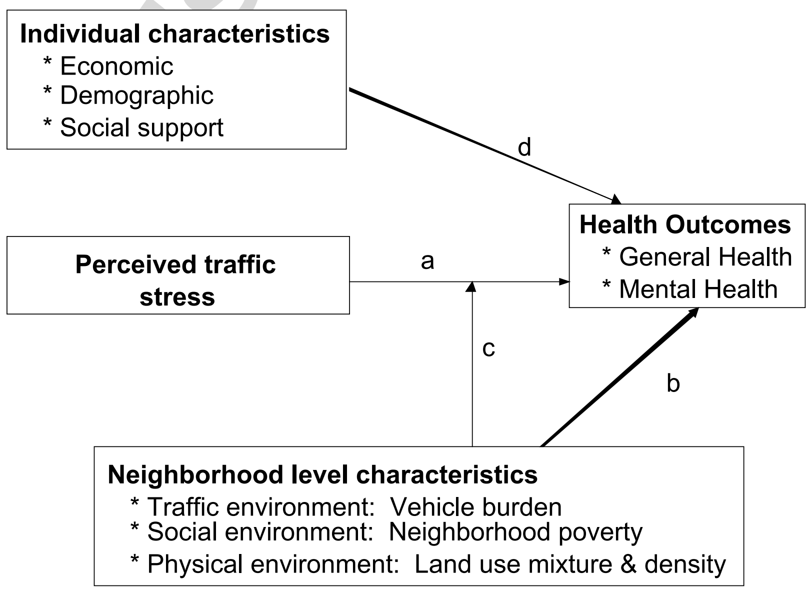

Fig. 1. Proposed model of traffic stress process in neighborhood context.

street networks, land use types, and employment activity centers collected for the 137 census block groups, allowing for analysis of physical neighborhood features such as street connectivity, land uses and density.

It is notable that this study focuses on the experiences of the Chinese American population in Los Angeles. Focusing on Chinese Americans raises questions as to how representative the study population can be of the US general population. As one check, CAPES respondents' general health scores (mean = 70.4) were similar to those of US national norms (mean = 72.0) (Ware, 1993).

2.3. Measures

Based on the conceptual model described above, our dependent variables include indicators of individual well-being: general health and mental health. Independent variables include individual level characteristics, neighborhood level features, and traffic stress. We provide more information of all variables below and in Table 1.

2.3.1. Dependent variables

General and Mental health. We adopt measures of mental health and general health of individuals as our dependent variables in this study. General health status is measured with a five-item scale derived from the Medical Outcomes Study Short Form 36 (SF-36). The range is 0–100, with higher scores indicating better health status. This scale is widely used and has been correlated with several health outcomes (Ware, 1993).

Table 1
Definition of variables

Categories	Variable name	Description (data source)
Dependent variables		
Individual well-being	Mental health	A depression scale with a range from 0–2.9, higher scores indicating more depressive symptoms (Survey)
	General health	a five-item scale with a range from 0–100, higher scores indicating better health status (Survey)
Independent variables		
Individual characteristics	Marital	Respondent's marital status (Survey)
	Age	Respondent's age (Survey)
	Education	Respondent's education achievement (Survey)
	Income	Respondent's income category (Survey)
	Employed	Respondent's employment status (Survey)
	Acculturation	Adjusted average of several measure items about respondent's acculturation (Survey)
	Social support	Individual perceived social support from friends (Survey)
Traffic environment	Vehicular burden	% of residents age 16 year or older who drive alone to work in the census blockgroup (US Census)
Physical neighborhood environment	Internal connectivity	Number of street intersections divided by the number of intersections plus the number of cul-de-sacs; the higher the ratio, the greater the internal connectivity of the neighborhood (GIS)
	Major street	Length of major street in feet per acre in the blockgroup; major street is defined by highway and arterial road (GIS)
	Land use diversity	A diversity index with a higher value indicating more evenly distribution of land uses (GIS)
	Green parkland ratio	Percent of park land area in the census blockgroup (GIS)
	Density	Number of housing units per ace (GIS)
Social environment	Neighborhood poverty	% persons meeting the federal poverty threshold in the block group (US Census)
Traffic stress	Traffic stress	A 3-to-11 scale measuring how the reaspondent was concerned of traffic, auto maintenance, and accidents within the last month (Survey)

The mental health indicator is the depression subscale from the Revised Symptom Checklist 90 (SCL-90-R) (Derogatis, 1994). The range is 0–2.9, with higher scores indicating more depressive symptoms.

2.3.2. Independent variables

(1) *Individual level characteristics.* Several other characteristics are included as confounders that may explain the association between traffic stress, neighborhood conditions and health. Demographic controls include age, gender, education, and employment. We also include two measures of social relationships, marital status and social support. Social support is measured with 6 items measuring instrumental and emotional aid (e.g. how much can you rely upon your friends for help if you have a serious problem); Cronbach's alpha = 0.87 for this scale within this sample. We also control for acculturation, a 14-item scale measuring language, ethnic interaction, and cultural traditions (e.g. How often do you celebrate Chinese festivals? What is your language of thinking?) adapted from (Burnam, Hough, Karno, Escobar, & Telles, 1987); Cronbach's alpha = 0.81 for this scale within this sample.

(2) *Neighborhood level characteristics.* Neighborhoods were operationalized as census block groups ($n = 137$) where CAPES respondents resided at the time of the study. We hypothesize three sets of pertinent neighborhood level characteristics in relation to the perception of traffic stress and associated health outcomes: traffic environment, neighborhood social environment and physical environment features. For each neighborhood, we compute the following measures.

Traffic Environment. The neighborhood traffic environment is measured with *Vehicular Burden*, defined as the percent of persons age 16 or older who drive to work in a given census block group. Vehicular burden provides information on potential traffic volume and exposure to traffic in the immediate neighborhood where the respondent resides. Previous studies concluded that exposure to vehicle traffic could trigger worse health outcomes (for example, Peter et al., 2004) and exacerbate the relation between traffic stress and health.

Social Environment. Because neighborhood socioeconomic characteristics may influence vulnerability to stress and health, Elliott (2000) suggests that they be included in studies of environmental stressors. We include the *Neighborhood Poverty* rate to account for neighborhood socio-economic characteristics. In an empirical evaluation, Krieger et al. (2002) report that neighborhood poverty is one of the most robust of the socioeconomic measures available. Neighborhood poverty is operationalized as the percent of persons meeting the federal poverty threshold.

Physical Environment. We include a set of variables of physical environmental characteristics that have been previously reported as efficient quantifications the physical environment, including street design and circulation system, level of mixed land use and density (Song & Knaap, 2004a, 2004b).

To quantify street design and circulation system, the first measure is *Major Streets*. It is measured by length of major streets (highway and arterial road) in feet per acre in the census block group. Existence of major streets is hypothesized to increase traffic stress and health risks for problems associated with heavy traffic. For example, highway pollution, being linked to health risks by at least more than twenty four scientific studies, has been a major concern in public health (Sierra Club, 2004). The health risks include increased likelihood of asthma, cancer, premature and low-birth weigh babies, and general higher risk or death (Sierra Club, 2004). Consequently, we expect that more major streets in the neighborhood would lead to poorer health outcomes. The second measure of street design and circulation system is *Internal Connectivity* which is measured by number of street intersections divided by the number of intersections plus the number of cul-se-sacs. The higher is the ratio, the greater the internal connectivity of the neighborhood. According to Benfield, Raimi & Chen (1999), better connectivity leads to more walking and biking, fewer vehicle miles travelled, and better air quality. These features of connectivity might contribute to the alleviation of traffic stress.

To quantify level of mixed land uses, the first measure we adopted is *Land Use Diversity* which is measured by a diversity index $H = \frac{-\sum_{i=1}^{s}(p_i)\ln(p_i)}{\ln(s)}$ where $H =$ diversity, $p_i =$ proportions of each of the four land use types such as residential, light industrial (such as office use), public, and commercial uses, and s is the number of land uses (in this case s equals to four). The higher the value, the more even the distribution of land uses. Prior research has indicated that this is a valid and reliable measure of land use mixture (Song & Knaap, 2004b). Additionally, studies find that although consumers prefer that neighbourhoods be dominated by single family residential land use, consumers also like to see some non-residential land uses such as commercial, public, and light industrial uses be evenly distributed in the neighbourhood (Song & Knaap, 2004b). According to the American Planning Association (1998), greater mixing of uses and destinations facilitates walking and biking, lowers vehicle miles travelled, and hence lessens traffic stress (1998). The second measure used to measure land use mixture is G *reen Parkland Ratio*, measured by percent of parkland area in the neighbourhood. Researchers suggested that nature accelerates human beings' recovery from stress (Kaplan & Talbot, 1983; Ulrich, 1984, 1999, 2001). We therefore assume green park land has a restorative power on human beings and hypothesize a negative association of depression but a positive relationship with general health status.

Finally, *Density* is measured by the number of housing units per acre for each neighbourhood. Higher density development puts different destinations in proximity to each other and thus facilitates walking and biking, lowers vehicular burden in the neighborhood, and may lessen traffic stress (American Planning Association, 1998).

(3) *Traffic stress.* Perceived traffic stress is measured with a three-item indicator asking respondents how often they were bothered (1 = none of the time to 4 = most of the time) within the last month by traffic, auto maintenance, and accidents. The range of this measure within our sample is 3–11, with higher values indicating greater concerns. An exploratory factor analysis suggested a single factor (eigenvalue 1.6; factor loadings from 0.68 to 0.78). Cronbach's alpha was 0.58 for this measure within this sample. To further explore the properties of this indicator, we divided the sample based on a median split of neighborhood vehicular burden, major streets and green parkland ratio respectively. We find a single-factor structure and similar reliabilities within the subsamples with median splits respectively. Thus, although the inter-item reliability of this scale is suboptimal, there is indication that the measure performs similarly between subpopulations for variables of interest such as neighborhood vehicular burden, major streets and green parkland ratio.

2.4. Analysis plan

Hierarchical linear modeling (HLM) is performed to examine the association between individual and neighborhood level characteristics, traffic stress, and health outcomes. The data are hierarchically arranged, with individuals nesting within census block groups. HLM is a multivariate regression technique that allows for the analysis of nested data (Raudenbush & Bryk, 2002).

We show two HLM models for each dependent variable. The first model focuses on the individual level predictors, allowing for an investigation of traffic stress on health, conditional on individual level covariates. The second model adds the neighborhood factors in order to examine the main effects of neighborhood factors and the cross-level interactions between neighborhood factors and traffic stress.

In notation:

$$Y_{ij} = \beta_{0j} + \beta_{ij}X(\text{Traffic Stress})_{1ij} + \cdots + \beta_{Qij}X_{Qij} + r_{ij}, \quad \text{where } r_{ij} \sim N(0, \sigma^2)$$

and

$$\begin{aligned}\beta_{0j} &= \gamma_{00} + \gamma_{01}(\text{poverty}) + \gamma_{02}(\text{vehicular burden}) + \gamma_{03}(\text{connectivity}) + \gamma_{04}(\text{major street}) \\ &\quad + \gamma_{05}(\text{land use mixture}) + \gamma_{06}(\text{green parkland}) + \gamma_{07}(\text{density}) + u_{0j}, \\ \beta_{1j} &= \gamma_{10} + \gamma_{11}(\text{poverty}) + \gamma_{12}(\text{vehicular burden}) + \gamma_{13}(\text{connectivity}) + \gamma_{14}(\text{major street}) \\ &\quad + \gamma_{15}(\text{land use mixture}) + \gamma_{16}(\text{green park land}) + \gamma_{17}(\text{density}) + u_{ij},\end{aligned}$$

where Y_{ij} are the health outcomes for the ith individual in the jth census blockgroup. Here, X_1 is the measure of traffic stress, and X_Q refers to other covariates. The error terms u_{0j} and u_{0j} are assumed multivariate normal with means of zero, and variances τ_{00} and τ_{11} and covariance τ_{01}. The model considers how neighborhood conditions may be directly associated with health, independent of the interaction with traffic stress. Those direct associations are modeled in the intercept (β_{0j}). For example, γ_{01} refers to the conditional association between neighborhood poverty and health. Additionally, the model examines how the slope of traffic stress (β_{1j}) is itself a function of the neighborhood variables – poverty (γ_{11}), vehicular burden (γ_{12}), connectivity (γ_{13}), major streets (γ_{14}), land use mixture (γ_{15}), green parkland (γ_{16}), and density (γ_{17}). This allows for an examination of the hypothesis that individually perceived traffic stress and health may be moderated by objectively measured neighborhood conditions.

3. Results

Table 2 summarizes 1503 CAPES respondents' individual characteristics and 137 neighborhoods' traffic, social and physical environment features. Results show that respondents are fairly healthy and well educated – 62.3% of respondents have a degree higher than high school. However there is also a sizable low-income population. Almost one third of the respondents earn less than $20,000 a year in household income. On average, respondents report a fairly low level of stress due to traffic. The average perceived traffic stress is 4.04, measured on a 3–11 scale. For the neighborhoods in study area, the population below the poverty line is 14%, which is higher than the national level of 12%. On average, 81% of residents in neighborhoods drive to work. Neighborhoods have a relatively high average (0.87) in internal connectivity, homogenous land use distribution (0.36), medium level of densities in housing units (7), and a low average green park land ratio (4%). Summary statistics also show that there are variations in physical environment features.

Simple correlations for variables at the individual level and at the neighborhood level are listed in Tables 3 and 4, respectively. General health is negatively correlated with gender, age and education and positively correlated with social support, employment and acculturation. Depressive symptoms is negatively correlated with social support and employment and positively correlated with gender, lower education and traffic stress. Most relevant for the topic at hand, traffic stress is negatively correlated with gender, age, education and social support, positively correlated with employment and acculturation and uncorrelated with income. Further, the neighborhood factors also present correlations between study measures. The strongest correlation is between neighborhood poverty and vehicular burden ($r = -0.49$) and for major streets and connectivity ($r = -0.41$). These correlations suggest the importance of using a multivariate and multi-level modeling approach and

Table 2
Characteristics of respondents ($n = 1503$) and neighborhoods ($n = 137$)

	Estimate		Min	Max
Individual level characteristics				
General health status, mean (SD)	70.4	(19.0)	0	100
Depression, mean (SD)	0.2	(0.3)	0	2.9
Traffic stress, mean (SD)	4.0	(1.4)	3	11
Acculturation, mean (SD)	2.1	(0.7)	1	4.6
Age, mean (SD)	38.9	(11.5)	18	65
Social support, mean (SD)	3.3	(0.5)	1	4
Female, no. (%)	797	53		
Education, no. (%)				
0–11 years	288	19		
High school	277	19		
Some college	308	21		
College graduate	628	41		
Income, no. (%)				
<$10,000	120	8		
$10,000–$19,999	348	23		
$20,000–$34,999	354	24		
$35,000–$49,999	254	17		
$50,000–$69,999	234	16		
$70,000 and above	193	13		
Employed, no. (%)	972	65		
Neighborhood level characteristics				
Neighborhood poverty, mean (SD)	14	(9.3)	0	42
Vehicular burden (% drive to work), mean (SD)	81	(13.0)	19	100
Connectivity, mean, (SD)	0.87	(0.10)	0.63	1.00
Major streets (length of major streets per acre in feet), mean (SD)	108	(48.8)	31	434
Land use diversity, mean (SD)	0.36	(0.21)	0.09	0.89
Green Parkland ratio (% Park in the neighborhood), mean (SD)	4	(0.1)	0	46
Density, mean (SD)	7	(5.2)	5	22

SD = standard deviation; min = minimum; max = maximum.

Table 3
Individual level variables: correlations

		1	2	3	4	5	6	7	8	9	10	11
1	General health	1										
2	Depressive symptoms	−0.36**	1									
3	Gender (1 = Female)	−0.13**	0.07**	1								
4	Age	−0.22**	0.04	0.04	1							
5	0−11 grade	−0.20**	0.09**	0.10**	0.19**	1						
6	High school	−0.03	−0.02	0.05*	0.11**	−0.23*	1					
7	Income	0.02	−0.01	0.03	0.01	−0.10**	−0.04	1				
8	Social support	0.21**	−0.24**	0.01	−0.16**	−0.10**	−0.05*	0.03	1			
9	Employed	0.19**	−0.12**	−0.20**	−0.04	−0.16**	−0.07**	0.07**	0.03	1		
10	Acculturation	0.23**	−0.00	−0.12**	−0.29**	−0.35**	−0.19**	0.05*	0.16**	0.23**	1	
11	Traffic stress	−0.02	0.21**	−0.05*	−0.10**	−0.11**	−0.02	0.03	−0.14**	0.20**	0.13**	1

* $p < 0.05$.
** $p < 0.01$.

Table 4
Neighborhood level variables: correlations

		1	2	3	4	5	6	7
1	Neighborhood poverty	1						
2	Vehicular burden	−0.49**	1					
3	Connectivity	0.31**	−0.18**	1				
4	Major streets	−0.30*	0.28**	−0.41*	1			
5	Land use diversity	0.27*	−0.20**	0.15*	0.04	1		
6	Green parkland ratio	−0.16**	0.06	−0.05	0.12**	0.13**	1	
7	Density	−0.29*	0.11*	−0.13**	0.16**	0.09**	0.04	1

* $p < 0.05$.
** $p < 0.01$.

for the inclusion of these sociodemographic characteristics as factors that may confound the association between perceived traffic stress and health.

HLM allows for the examination of health outcomes as a neighborhood level (i.e., Level 2) phenomena instead of an exclusively individual level (i.e., Level 1) phenomena. Goodness-of-fit statistics from the resulting hierarchical linear models for general health and depressive symptoms both demonstrate strong improvement in model fit, compared with the Level 1 model alone ($\chi^2(7) = 76.35$, $\chi^2(7) = 88.47$, $p < 0.001$, respectively). HLM can also describe the extent to which the variability in depressive symptoms and general health occurs at the individual level versus the neighborhood level. Specifically, fully unconditional random intercepts models (i.e., no independent variables) were conducted to estimate the amount of variance attributable to each level. The results indicate that health status is more strongly weighted toward individual level sources of variability. Nevertheless, a relatively substantial of the variability in health is between neighborhoods. Variance due to neighborhood effects (i.e., Level 2) is 8% for general health status and 12% for the depressive symptoms.

Table 5 presents regression results from the hierarchical linear models for general health status (columns A and B) and depressive symptoms (columns C and D). Column A shows that most of the individual level covariates were significantly associated with depressive symptoms in the expected directions. For example, traffic stress was positively associated with depressive symptoms ($\beta_{1j} = 0.04$, SE = 0.01, $p <= 0.001$), indicating that persons perceiving greater traffic stress reported more depressive symptoms. Education, employment, income, and social support were negatively associated with depression, indicating that persons with higher education and income, stable employment, and more social support were more likely to have fewer depressive symptoms.

Column B includes the neighborhood factors. As shown in the middle panel, there are no significant main effects between any neighborhood factor and depressive symptoms. However, as seen in the bottom panel, there are significant cross-level interactions between individually perceived traffic stress and neighborhood vehicular burden, major streets and parks. Specifically, the associations between traffic stress and depressive symptom was amplified for individuals living in neighborhoods with a greater vehicular burden ($\gamma_{12} = 0.002$,

Table 5
Hierarchical linear models (HLMs) of health outcomes

	HLMs of depressive symptoms				HLMs of general health status			
	A (individual variables only)		B (with neighborhood variables)		C (individual variables only)		D (with neighborhood variables)	
	Coeff.	SE	Coeff.	SE	Coeff.	SE	Coeff.	SE
Intercept	0.18	$(0.02)^{***}$	0.18	$(0.02)^{***}$	70.02	$(1.38)^{***}$	68.39	$(1.34)^{***}$
Female (vs. male)	0.04	$(0.02)^{*}$	0.05	$(0.02)^{*}$	−2.65	$(1.01)^{**}$	−2.26	$(0.09)^{**}$
Age	1.81E−03	$(0.00)^{*}$	1.81E−03	$(0.00)^{*}$	−0.30	$(0.05)^{***}$	−0.31	$(0.05)^{***}$
0–11 grade	0.05	$(0.03)^{*}$	0.04	$(0.03)^{*}$	−4.10	$(1.24)^{***}$	−3.32	$(1.31)^{*}$
High school	−0.04	(0.02)	−0.05	(0.02)	0.51	(1.53)	0.63	(1.53)
Any college	1.0		1.0		1.0		1.0	
<$19,999	0.08	$(0.03)^{**}$	0.08	$(0.03)^{**}$	−3.02	$(1.22)^{*}$	−3.11	$(1.26)^{*}$
$20,000–$34,999	0.08	$(0.03)^{**}$	0.06	$(0.03)^{**}$	−1.03	(1.51)	−0.57	(1.64)
#35,000 and more	1.0		1.0		1.0		1.0	
Social Support	−0.17	$(0.03)^{***}$	−0.16	$(0.03)^{**}$	5.12	$(1.17)^{***}$	5.03	$(1.12)^{***}$
Employed	−0.07	$(0.02)^{**}$	−0.07	$(0.02)^{**}$	5.91	$(1.48)^{***}$	5.75	$(1.34)^{***}$
Acculturation	0.08	$(0.02)^{***}$	0.06	(0.02)	1.73	$(0.79)^{*}$	1.55	$(0.71)^{***}$
Traffic Stress	0.04	$(0.01)^{***}$	0.03	$(0.01)^{**}$	−1.01	$(0.47)^{*}$	−1.05	$(0.42)^{**}$
	Main effects of neighborhood factors on depressive symptoms				*Main effects of neighborhood factors on general health status*			
Vehicular burden			9.31E−04	(0.00)			−0.01	(0.09)
Neighborhood poverty			2.14E−03	(0.00)			−0.09	(0.08)
Connectivity			8.91E−03	(0.00)			0.00	(0.08)
Major streets			1.14E−03	(0.00)			−0.01	(0.01)
Land use diversity			1.40E−03	(0.00)			0.00	(0.02)
Green parkland ratio			1.37E−03	(0.00)			0.11	(0.10)
Density			3.72E−03	(0.00)			0.06	(0.04)
	Cross-level interaction between neighborhood variables and traffic stress on depressive symptoms				*Cross-level interaction between neighborhood factors and traffic stress on general health status*			
Vehicular burden			1.60E−03	$(0.00)^{**}$			−0.13	$(0.04)^{*}$
Neighborhood poverty			0.01	(0.00)			0.01	(0.08)
Connectivity			0.01	(0.10)			0.02	(0.04)
Major streets			3.08E−03	$(0.00)^{***}$			−0.19	$(0.08)^{***}$
Land use diversity			2.39E−03	(0.00)			0.00	(0.01)
Green parkland ratio			−0.01	$(0.01)^{***}$			0.37	$(0.04)^{**}$
Density			0.01	(0.00)			0.09	(0.02)
Random effects			$\chi^2(129) = 472.53$, $p < 0.001$			$\chi^2(129) = 675.38$, $p < 0.001$		
			SD	Variance component			SD	Variance component
Intercept			0.15	0.07			1.59	2.54
Level 1 effects			1.08	1.94			8.01	29.35

*, **, and *** indicate significance level at the 0.1, 0.05 and .001 levels, separately. Standard errors are shown in parenthesis. Estimates are unstandardized.

SE = 0.001, $p <= 0.01$) and who live in neighborhoods with major streets ($\gamma_{14} = 0.003$, SE = 0.001, $p <= 0.001$). Further, the association between traffic stress and depressive symptoms appears to be dampened in neighborhoods with a higher green parkland ratio ($\gamma_{16} = -0.006$, SE = 0.011, $p <= 0.001$). There are no cross-level interactions between traffic stress and neighborhood poverty, connectivity, land use diversity or density. As seen earlier, several of the neighborhood factors were fairly correlated. Because these correlations may introduce multi-collinearity and may mask the effects of some variables, we performed additional analyses (available from authors) that examined the neighborhood factors individually (not entered simultaneously). Those results were consistent with the full model reported in this manuscript.

The associations reported for depressive symptoms are also found for general health status. When comparing results across the two outcomes, the signs are expected to be reversed (as a reminder, *lower* values of general health status indicate greater morbidity, whereas *higher* values of depressive symptoms indicate greater morbidity).

Column C shows that individually perceived traffic stress is negatively associated with general health status ($\beta_{1j} = -1.01$, SE = 0.47, $p <= 0.01$), indicating that persons with more traffic stress are worse off than those who report less. Further, being female, older, less educated, of lower income, unemployed, less acculturated and reporting less social support was associated with decreased health status.

Column D includes the neighborhood factors. The associations for general health status also mirrored those for depression. Again, there were no significant main effects for any of the neighborhood variables, but there were cross-level interactions between individually perceived traffic stress, vehicular burden, major streets and green parklands. Specifically, the association between traffic stress and general health status was amplified by vehicular burden ($\gamma_{12} = -0.13$, SE = 0.04, $p <= 0.05$) and major streets ($\gamma_{14} = -0.19$, SE = 0.08, $p <= 0.001$), but dampened by the ratio of green parklands ($\gamma_{16} = 0.37$, SE = 0.04, $p <= 0.01$).

4. Discussion

While it is important to move people through the transportation systems, it is also important to provide healthy places to live. Increasing mobilization around the world is associated with concerns of worsening negative externalities brought by heavy traffic. Although congestion and air pollution are among the most cited issues, there is mounting concern regarding traffic's undesired impact on the public's health. Of main interest in this study is the exploration of whether perceptions of traffic stress are associated with well-being, whether objective markers of the built environment may influence well-being, and whether individual perceptions are moderated by the built environment.

Using multi-level models, we found that reports of traffic stress were associated directly with general health status and depressive symptoms, controlling for a variety of individual and neighborhood factors. Further, we found that these individual perceptions were moderated by characteristics of the built environment. Specifically, the relationship between perceived traffic stress on health was stronger for individuals who lived in areas with a greater burden of vehicles and also for those who lived with a major street or arterial highways in their neighborhoods. Further, these two aspects of the built environment were only significant when interacted with individual perceptions, not as independent main effects. This study extends prior work on this topic by incorporating a more detailed analysis of neighborhood conditions. A prior study by Gee and Takeuchi (2004) examined similar issues, but only analyzed 36 census tracts. The current analysis of 137 block groups has the advantage of not only examining a smaller spatial unit that may be more proximal to respondents' actual homes, but further includes several important measures of the built environment not available in the prior study. The general conclusions of the prior study that neighborhood vehicular burden can deepen the potential harm of individual perceptions of traffic stress are held in this new analysis. Further, the current analysis also suggests that factors of the built environment, including parks and other recreational facilities, may help protect individuals from the harmful effects of traffic stress. That is, green parklands in one's community may protect against traffic stress. These findings are consonant with stress theory that posits that the impact of stressors may be buffered by resources.

The research also revealed that street network connectivity, land use mixture, and neighborhood housing unit density were not associated with traffic stress and health outcomes. The findings may have been the result of the inability of the measures in distinguishing counteracting effects. For example, higher connectivity might encourage people to drive shorter distances, which may foster less traffic stress, but these shorter drives may themselves lead to greater noise and air pollution. The net effect might be null. We are unable to tease apart these explanations with the present data. However, if valid, the findings rebut the fear that residents have on more internally connective streets with more intersection and less cul-de-sacs, more mixed land uses, or denser neighborhoods for their potential association with heavier traffic (Snow, 1999).

The aforementioned findings should, however, be tempered with several additional caveats. First, because this is secondary analysis, our measures of traffic stress are far from perfect, including a sub-optimal inter-item reliability. There is a need to develop more robust measures of environmental stressors (MacArthur, 2005) and our data suggest that traffic stress is a construct that deserves further exploration. Our three-item measure appears to measure one factor, but future work should consider the development of a more robust measure that captures the multi-dimensionality of experiences, including stressors associated with commuting, road rage, parking, noise, pollution, and vehicle maintenance.

Second, our analysis considers neighborhoods as defined by census block groups. These blocks do not fully capture participants' commuting experiences (e.g. to work) and may not conform to the subjective neighborhood boundaries as defined by study participants. Hence, future research should measure driving experiences, perhaps incorporating global positioning system (GPS) technology. Additionally, future studies should consider using subjectively defined neighborhoods. That said, one advantage of using block groups is that the neighborhoods are defined and replicable by other investigators.

Third, the data are cross-sectional and associations should not be taken as causal. Longitudinal studies are needed to establish the causal ordering between study measures. For example, although we presume that traffic stress causes health conditions, we are unable to rule out the competing explanation that health conditions cause individuals to perceive to traffic stress.

Fourth, the data files come from different years: the 1994–1995 CAPES, the 1995 GIS data and the 1990 census. The census data may not conform to the experiences of the study participants because of temporal change. Nevertheless, examination of census data suggests some stability over time. For example, 70.1% of persons in Los Angeles drove to work in 1990, compared to 70.5% in 2000 (US Census Bureau, 2002). Future research using Census data will benefit from more timely estimates from the American Community Survey.

With these caveats in mind, the findings suggest that major roads with heavy traffic are injurious but parks are curative. This has implications for transportation planners in regard to incorporation of health considerations into neighborhoods planning and designing processes.

Although preliminary, our research suggests that the following factors might be considered in building healthier neighborhoods: First, although it is important to provide residents convenient street network to access other destinations, major streets with heavy traffic could be minimized in residential areas. Second, measures might be taken to encourage alternative travel modes such as mass transit, biking and walking and to reduce vehicular burden in the neighborhoods. There is a vast literature in urban planning of promoting alternative travel modes by new urbanists and smart growth proponents (APA, 1998). These proponents argue that, rather than building neighborhoods that are solely reliant on private automobiles, we could develop our neighborhoods with alternative travel modes. These arguments are made citing concerns over environment quality, sustainability and energy consumption. Here we show that less reliance on vehicles may have health implications as well. Third, restorative neighborhood open spaces should be provided to benefit human well-being by mitigating mental fatigue and stress which can arise from prolonged exposure to some aspects of environments such as traffic.

In conclusion, this study suggests that more research should be conducted on the relationships between traffic stress and the built environment. Future research could examine these same relationships in other populations and areas, develop measures of traffic stress and similar constructs, and evaluate natural experiments related to the redesign of transportation. This work could then inform policies that help to promote the public health.

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