Exploring the determinants of stress:
An examination using spatial and multilevel analysis methods in Philadelphia.

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Abstract:

Traditionally, studies of the predictors of stress are focused on the individual characteristics. In our study we also include ecological factors, particularly social and built environmental characteristics of neighborhoods. We combine multiple georeferenced data sets with the Philadelphia Health Management Corporation's Community Health database, a telephone survey of 4,095 respondents embedded in several hierarchical contexts; our results focus on 158 neighborhood areas. Exploratory Spatial Data Analysis suggests a moderate spatial autocorrelation and uncovers a spatial clustering of self-rated stress in Philadephia County. At the individual level few social factors appear to matter though self-rated neighborhood trust and food insecurity have independent effects on stress. At the neighborhood level, the presence of hazardous waste sites and traffic levels are determinants of self-rated stress even after controlling for other individual characteristics. The latter two factors are of relevance to public health policy as they are potentially modifiable.

Introduction

The proliferation of spatial data and the related techniques to analyze them have naturally given rise to increasing attention to relationships between place characteristics and health. The increasing array of spatial characteristics available for analysis has allowed researchers to be increasingly creative and broad minded in their inclusion of explanatory factors. Several recent studies have concluded that the neighborhood etiological factors for mental health, stress and depression in particular, have been underexplored (Cutrona et al., 2006; Kim, 2008). Specifically, relatively little is known about the effects of the built environment, services, and amenities of a neighborhood on mental health. Combining individual data with multiple spatial data sets, the goals of this study are to investigate how individual stress is shaped by the built environment, and to explore the spatial clustering pattern of stress across residences.

To reach these goals, this study attempts to answer the following research questions: First, do individuals exposed to the same environmental factors exhibit similar stress levels? If so, we should observe a clustering pattern across residences. Second, if people reporting comparable stress cluster together, is this phenomenon resulted from individual characteristics or is it caused by shared environmental factors? Third, if environmental factors are involved in stress evaluation, is it the social environment or the built environment that matters most? These questions demand an integrated analytic approach in which spatial and multilevel methods are included. Spatial analysis is not only capable of detecting the spatial pattern underlying the research area but also provides objective measures of the built environment of a neighborhood. Multilevel modeling can hence utilize these measures and estimate their impacts on stress.

Stress is a concept first introduced in 1936 (Selye, 1936) and has become a feature of modern life. It originally referred to a syndrome occurring in laboratory rats and gradually evolved into a concept of understanding the interaction between individuals and environment (Viner, 1999). Nowadays, stress is used to explain a wide range of social and health outcomes, such as cardiovascular diseases (Kristensen, 1996; Black and Garbutt, 2002), cancers (Sklar and Anisman, 1981; Reiche et al., 2004), deviant behaviors (Cohen and Lichtenstein, 1990; Wills et al., 2002), depression (Maddock and Pariante, 2001), and even biological reactions (Ader, 1980; Tausk et al., 2008). To effectively prevent these adverse outcomes, it is imperative to identify the determinants of stress.

Stress encompasses the following four dimensions: (1) a certain environmental exposure or experience; (2) an appraisal of a specific environmental condition; (3) a response to the environmental exposure; and (4) an interactive association between environmental demands and personal capability to fulfil these demands (Kasl, 1984). According to these definitions, environment should play a crucial role in assessing personal stress. However, due to the unavailability of proper methods and data sources, earlier research has been less capable of fully exploring the determinants of stress at the neighborhood level and the question of how stress distributes across space was rarely discussed. We endeavor to shed new light on the field of social stress research and demonstrate how the integration of spatial and multilevel methods can advance the literature. To frame our analysis we review the literature on individual level models of stress and follow this with a focus on ecological multilevel models. The purpose of the two-stage review is to establish the relationship between stress and environment, given the fact that stress is partially determined by social position.

Stress by Individual Social Hierarchy

Since the 1960s, the literature has reported the connection between social status and mental health problems (Turner and Marino, 1994). Low socioeconomic status, being unmarried

or previously married, and unemployment have been found to increase the risk for stress, mental disorder, and depression (Dohrenwend and Dohrenwend 1969; Turner et al., 1970; Turner et al., 1995; Turner and Lloyd, 1999). In addition, psychological stress and psychiatric distress differ by demographic features, i.e. gender and age (Kessler and McLeod, 1984; Nolen-Hoeksema, 1987; Turner and Avison, 1989; Turner et al., 1995; Pearlin and Skaff, 1996; Shields, 2004). These relationships have been regarded as the variations in the experience of individuals of divergent socioeconomic characteristics (social causation) rather than the outcomes of selecting individuals into different social positions (social selection) based on their mental health status (Aneshensel, 1992; Turner et al., 1995). Various positions of social structure could lead to different levels of stress. It is, therefore, important to consider these factors before taking neighborhood features into account.

Age: Various sources of stress may change with aging. Generally, unexpected life events are more likely to impose adverse effects on stress than scheduled ones (Pearlin, 1980; George 1980). The march of the life course exposes people to fewer unscheduled events and higher mastery of their lives, while aging also indicates the onset of health impairment and the potential loss of peers and friends (Pearlin and Skaff, 1996). Empirically, there is no sufficient support for the notion that stress is an inevitable consequence of aging (Baltes and Baltes, 1990; Gatz and Hurwitz, 1990). Instead, the elderly report lower stress than the young generations (Turner et al., 1995; Shields, 2004).

Gender: Females are found to have a higher level of stress than males (Turner and Marino, 1994; Turner and Lloyd, 1999). A study in Canada exhibits that women are more likely than men to observe and report recent negative life events, chronic strains, and childhood traumas (Shields, 2004). It has been suggested that women are socialized to be responsible for the well-being of family members and sensitive to nuanced changes in life, such as relationships (Turner and Avison, 1989). These features make females more stressed due to the greater exposure to stressors and the higher cost of caring (Kessler and McLeod, 1984).

Marital status: The married are believed to receive more emotional support from the stable relationship with their partners and encounter lower occurrence of undesirable events than do the unmarried (Kessler and Essex, 1982; Ross and Mirowsky, 1989; Turner and Marino, 1994). The previously married generally exhibit the highest stress level in contrast to others (Turner and Lloyd, 1999; Shields, 2004). The separated and divorced individuals tend to confront a disproportionate number of chronic problems and hence report higher stress, which contributes to the differences in mental health by marital status (Turner et al., 1995).

Employment status: The adverse impacts of unemployment on psychological functioning and physical health have been well documented (Kessler et al., 1989; Jin et al., 1997). Involuntary job loss is stressful because it leads to personal economic strain and possibly becomes a threat to families' well-being (Pearlin et al., 1981; Broman et al., 1990). However, being employed is not always beneficial. Work-related stress has been related to psychological disorders (Tennant, 2001) and cardiovascular diseases (Kristensen, 1996). The stress resulted from jobs could be buffered by the support from colleagues (LaRocco et al., 1980) but the stress caused by unemployment may not be easily alleviated.

Socioeconomic status: People with low socioeconomic status tend to have high stress (Turner and Marino, 1994; Turner et al., 1995). Specifically, stress decreases as income increases. This relationship holds even after age and gender are considered. In addition, being independent of the effect of income, whether or not completing secondary education becomes a significant predictor for stress (Shields, 2004). Individuals with high socioeconomic status not

only have rich resources and support to moderate the impacts of stressors, but also have low risk of confronting unexpected events, such as job loss or hunger.

Stress differs by position within the social hierarchy. As Aneshensel (1992) indicated: "The occurrence of social stress can be seen as an inevitable consequence of social organization" (p.33). While social position plays a crucial role in determining stress, relatively little attention has been paid to the importance of residential location in stress research.

Stress in different residential locations: built environment

By definition, environmental factors should contribute to stress assessment (Kasl, 1984). While the impact of the built environment on depression symptoms has been explored in psychology (Lawrence 2002; Evans 2003), social stress research has not well discussed how individuals incorporate the residential environment into their perceived stress. The literature has suggested that poor neighborhood resources, noise or busy traffic, and hazardous exposure have positive associations with stress or other psychiatric symptoms (Houston et al, 2004; Song et al 2007). Explicitly, stress and mental health are known in part to be determined by the residential locations and the related features should be included when exploring how stress is assessed.

Below we focus on two possible environmental factors: hazardous waste and traffic. First, perceived threats to personal health can result in stress, cause psychological trauma, and harm mental health. It has been found that neighborhood residents who realize that they have been exposed to toxic material tend to report more psychological distress symptoms than those who do not, such as stress disorders, fear, and loss of sleep (Edelstein, 2002). Clinically, the "hazardous waste syndrome" refers to the phenomenon that patients affected by very low doses of the chemicals but exhibit physical symptoms associated with the chemicals and subtle psychological disturbances (Task Force on Clinical Ecology, 1986). The residents living around hazardous waste sites are more likely to show this syndrome. Several studies in California, for example, did not find evidence indicating excessive rates in cancer or birth defects around the waste sites; however, the total number and the prevalence of many psychological problems, such as stress and anxiety, were higher in the areas near the sites (Neutra et al 1991; Smith and Rigau 1988; see also Schiffman et al 1995). The presence of potential threats to residents' well-being in a neighborhood does not necessarily result in adverse physical health outcomes, but may become a determinant of stress and mental health (Luginaah et al 2002). The environmental features related to hazardous sites could be considered as a source of stress.

The other factor is traffic. The dwellers in a neighborhood with high traffic exposure are found to report high self-rated stress (Gee and Takeuchi, 2004; Babisch et al., 2001). Noise is one of the problems brought by traffic. The disturbance and annoyance caused by noise could elevate individuals' stress perception. In addition, biologically, traffic noise will induce the release of the stress hormones (i.e. adrenaline), affecting both cognitive and emotional responses (Babisch et al., 2001). Moreover, high traffic volume brings congestion, which will easily increase drivers' stress and the perception of risk of injury to pedestrians (Song et al., 2007). A more implicit explanation of why neighborhood traffic might cause stress is that vehicle maintenance, insurance, parking, and unexpected damage may create pecuniary and mental hardship and thus result in high stress perceptions (Gee and Takeuchi, 2004). Perceived traffic danger not only has been reported as the second leading barrier to walking and biking in the U.S. (CDC, 2002), but also become a widely cited neighborhood problem (Balfour and Kaplan, 2002). As a consequence, we consider traffic as an important environmental factor related to stress.

Stress in different residential locations: social environment

Residential locations not only include the built environment characteristics, but also the social features of the environment. We introduce three possible factors associated with stress: neighborhood safety, residential stability, and socioeconomic composition. A wide range of stress symptoms, such as sleep disturbances and anxiety, are closely related to neighborhoo safety. Specifically, the residents in a neighborhood with high crime rates tend to have more signs of mental illnesses than their counterparts in a low-crime community (Osofsky, 1995; Berman et al., 1996; Ross, 2000; Ross and Mirowsky, 2001). It is more likely for the residents in a high crime neighborhood to be victims of violence or property loss, witness acts of crimes, or perceive potential threats to safety. The experience related to crimes will exacerbate psychological burdens resulting in stress. In addition to the direct impacts, crimes also have indirect effects on stress. The grief for the victims (especially the loved ones) may also lead to high stress and hypertension (Taylor and Repetti, 1997; Green and Pomeroy, 2007).

Unlike crimes, residential stability has been found to alleviate stress. Support for the argument is found in the literature on social support and social capital (Putnam, 2000; James et al., 2001; Glaeser et al., 2002). A stable neighborhood is good for residents' interaction, facilitates the development of social capital, and strengthens the degree of civil engagement. The collective efficacy will not only establish a sense of consistency and belonging, but also generate emotional support and access to resources. Therefore, when individuals are exposed to stressors, living in a stable neighborhood may bring sufficient support to get through (Berkman et al., 2000). This argument has been recently confirmed by a study examining the mediating role of residential stability between stress and health (Boardman, 2004). Though residential stability might not directly contribute to physical health, its beneficial impact on stress could be expected.

It has been argued that socioeconomic composition is the fundamental proxy describing the environment where people live (Sampson et al., 1997). Household income, education, and occupation are commonly used to measure socioeconomic composition. The members from a poor neighborhood are reported to experience more life stress events, i.e. hunger and loss of health (Fang et al., 1998; Krivo and Peterson, 1996). Falling infrastructure and discriminatory behaviors are associated with low socioeconomic neighborhoods (Schulz et al., 2000). These undesirable features may cause residents problems like difficulty in getting public services and thus lead to stress. A longitudinal study has reported that the characteristics of poor infrastructure in neighborhoods are sources of stress (Dalgard and Tambs, 1997) and the movement from high- to low-poverty communities improves mental health for both children and adults (Johnson et al., 2002).

Prior social stress research has well established the impacts of social positions on stress. By contrast, this study broadens the scope of predictors for stress by considering the built environment. Utilizing the burgeoning georeferenced data and the development of analytic methods, we will examine the related hypotheses as listed in the next section.

Hypotheses

To answer our research questions, we derive the following hypotheses from the discussion above:

(1) At the aggregate level, as neighborhood environment involves various dimensions of stress, people who are exposed to similar environmental factors should report similar stress. Explicitly, we hypothesize that *stress demonstrates a spatial clustering pattern by residence instead of random distribution*.

(2) The social stress literature has suggested that the uneven distribution of social support (and social capital) contributes to the difference in stress by social position (i.e. age and

marital status). If this argument holds, *the impacts of social structure on stress will be attenuated, if not eliminated, by social support/capital.*

(3) Beyond individual characteristics, the neighborhood environment where people live should explain the perceived stress. Specifically, (a) *the presence of potential threats to health or safety nearby is positively associated with individual stress*; (b) *busy neighborhood traffic leads to high stress among residents*; (c) *neighborhood crimes are positively associated with stress*; (d) *residents in a stable neighborhood report low stress*; (e) *individuals in a neighborhood of high SES tend to perceive less stress even after personal characteristics are controlled.*

Methods

Analytic Strategy

To test the first hypothesis, we employ exploratory spatial data analysis (ESDA). The objective of ESDA is to detect the spatial association in data and explore the relationships among variables. According to Anselin (2003), ESDA embraces a range of techniques to visualize data, capture spatial autocorrelations, unveil spatial clusters, and prepare for complex explanatory models. At this stage, we use the software, GeoDA$^®$, developed by Anselin (2003) to visualize data and determine both global spatial association (Moran's I) and spatial clusters of stress. Moran's I (Moran, 1950) is a correlation coefficient weighted by spatial structure for areal data and used to measure the departures from randomness. Usually, the value of the Moran's I falls between 1 and -1, but is not bounded in this interval. Positive spatial autocorrelation indicates the nearby areas have similar attributes and conversely, a negative Moran's I could be translated into the heterogeneity of a certain characteristic within an area.

To detect if a spatial clustering of stress exists, we use the local indicator of spatial association (LISA) introduced by Anselin (1995). LISA consists of a series of statistics that assess the spatial clustering of interest, and answers the question of whether the areas with high (or low) values flock by chance. Four types of spatial clusters are identified: high-high, low-low, high-low, and low-high. In this application, high-high clusters refer to places with high stress among residents clustering spatially. The high-high and low-low clusters exhibit the expected spatial clustering whereby areas with similar characteristics tend to be closer to each other. High-low and low-high clusters are considered as spatial outliers.

Following the spatial analysis, we implement a series of hierarchical models using the statistical package HLM 6 (Scientific Software Inc, 2008). We first conduct a null model where no explanatory variable is considered to further confirm that stress varies by residence. This basic model is equivalent to a one-way ANOVA with two random effects (see Equation 1). γ_{00} is the grand mean of the stress measure. u_{0j} adjusts the grand mean for the *j*th neighborhood. For instance, if the average perceived stress of a neighborhood is greater than the grand mean, u_{0j} should be positive. Likewise, if the average stress is equal to the grand mean, u_{0j} should be zero. r_{ij} hence is the offset to the grand mean for the *i*th respondent in the *j*th neighborhood. If the Chi-square test for u_{0j} turns out to be statistically significant, we have evidence that the mean self-reported stress is not normally distributed across neighborhoods, suggesting multilevel analysis may be used.

$$Y_{ij} = \beta_{0j} + r_{ij} \qquad\qquad\qquad\qquad\qquad \text{Individual Level}$$
$$\beta_{0j} = \gamma_{00} + u_{0j} \qquad\qquad\qquad\qquad\qquad \text{Neighborhood Level}$$
$$Y_{ij} = \gamma_{00} + u_{0j} + r_{ij} \qquad\qquad\qquad\qquad\qquad (1)$$

, where Y_{ij} is the reported stress of the ith individual in the jth neighborhood and r_{ij} is the random effect for this respondent; γ_{00} is the unadjusted average stress level in the data and u_{0j} is the random effect for the jth neighborhood.

Next, the relationships between stress and both social and built environment are examined. The individual characteristics are introduced in the models before the environmental factors are considered. To examine their impacts on stress, the neighborhood level variables are included in the intercept and hence the Equation 1 could be expanded into Equation 2 as below:

$$Y_{ij} = \gamma_{00} + \sum \gamma_{0l} w_{lj} + \sum \beta_{kj} x_{ijk} + u_{0j} + r_{ij} \qquad\qquad\qquad (2)$$

, where γ_{00} is the adjusted average stress level; γ_{0l} is the impact of neighborhood feature l; w_{lj} is the feature l of the jth neighborhood; x_{ijk} is the characteristic k of the ith respondent in the jth neighborhood and β_{kj} indicates the impact of that characteristic.

Data

The Philadelphia Health Management Corporation's (PHMC) 2006 Southeastern Pennsylvania Household Health Survey provides the individual data. It includes comprehensive data on individual health behaviors and health care experience in southeast Pennsylvania (PHMC 2006). We employ data on the 4,095 respondents in Philadelphia County. The 2006 PHMC is a telephone survey, and the participants are interviewed in English or Spanish. A random-digit dial methodology based on a stratified sampling frame was used to ensure representation within smaller geographic areas across the southeast Pennsylvania. The 2006 PHMC over-sampled individuals aged 60 and above and Latino population in order to provide a sufficient number of interviewers for analysis related to these sub-populations. These sampling methods ensure the statistical results could be generalized to the populations of the area (PHMC 2006).

We use 360 census tracts as well of aggregations of these tracts to form 158 neighborhoods (with aggregations based on spatial and numerical similarities on salient socio-economic characteristics as well as physical (rivers) and built environment characteristics). In addition, we test different weight matrices and use a Queen's first-order spatial weights (or contiguity) matrix (discussed in greater detail later). The connectivity profiles of the spatial weights matrices are normally distributed and there are no 'islands.' The neighborhood level data are from multiple sources and will be detailed in the next section.

Measures

Individual Level

The dependent variable in this study is individual self-reported stress. Generally, the sources of stress can be divided into childhood traumas, acute and chronic stressors (Wheaton, 1999). An event happening in childhood, such as parental divorce and domestic violence, may have a lingering impact on stress. If a change in life requires an immediate emotional adjustment, it can be regarded as an acute stressor, i.e. job loss. Situations that persist and might develop or change over a period of time are chronic strains. Being parents and working, for instance, are well-known sources of chronic stress (Pearlin, 1989; Turner and Lloyd, 1995). Despite the classification of stressors, assessing stress with a satisfactory objective perspective is extremely difficult, if not impossible, because whether an event leads to stress is subject to individual

perception and interpretation of that event. A similar event occurring at a different stage of life or to different people could result in different outcomes. On the contrary, subjectivism can provide precisely what a researcher needs (Lazarus, 1990). Self-assessed stress summarizes the equilibrium of environmental demands and individual coping capability, and reflects the day-to-day stress.

The respondents in the PHMC were asked to use a scale from 1 to 10 to assess how much day-to-day stress they experienced, where 1 meant "no stress" and 10 indicated "an extreme amount of stress." Following Lazarus' argument (1990), the subjective assessment should be the stress measure in which researchers are really interested and avoid the potential problem of having an incomplete inventory of stressful events. The reported stress are aggregated by neighborhoods and analyzed. In hierarchical models, the reported stress will be treated as a continuous variable and its relationships with other explanatory variables will be investigated.

The individual level independent variables include not only the social positions but also related factors. Four demographic variables are first considered. *Age* is an ordinal variable from 1 to 5 (age 18-39, 40-49, 50-59, 60-74, and 75 or above). *Gender* is a dummy variable where males are coded 1 and females are 0. *Race* is coded 1 if respondents self-identified as African-Americans and 0 otherwise. *Marital status* is trichotomized into married/cohabited, widowed/separated/divorced (previously married), and single (reference group). In addition, three covariates related to socioeconomic status are included. *Employment status* is dichotomized into full time employed and others (reference group). *Education* is a dummy variable coded 1 if respondents completed high school, 0 otherwise. *Poverty* is captured by a dummy variable and coded 1 if the family income is below the federal poverty level, 0 otherwise. In addition to the variables aforementioned, *food insecurity* has been used to predict perceived stress recently (BeLue et al., 2008). It is coded as 1 if the respondents have cut the size of meals or skipped meals because of the lack of budget for food, otherwise 0.

Derived from the discussion on the impact of age, individual *health* is considered in the analysis. It is operationalized as a composite score based on physical health conditions and self-rated health. Respondents were asked if they had any of the following problems: asthma; heart problems; diabetes; arthritis; high blood pressure; or high cholesterol. We summed and standardized the number of "no" responses in order to build a measure of positive health indicator. Participants were also asked to evaluate their overall health from "excellent" to "poor." This indicator is consistent with the physical health (Cronbach's alpha = 0.653). The final health score is generated by standardizing the self-rated health score and averaging the physical condition measure within individuals (where higher scores indicate better health).

To examine if social support attenuates the impacts of social structure on stress, we used two variables as the proxy of social support. One is *religiosity,* which is measured with the frequency of attending religious services. Those who participate weekly are coded as 1, in contrast to others coded 0. The other variable is *neighborhood trust*. Respondents were asked if they agreed that most people in the neighborhood can be trusted, ranking from 1 to 4 (strongly disagree, disagree, agree, strongly agree). We standardized the ranking and used in the future analysis. Higher scores indicate higher neighborhood trust.

Neighborhood Level

Neighborhood crimes are not only associated with the sense of safety but can have an adverse impact on residents' physical and mental health (Taylor and Repetti, 1997; Green and Pomeroy, 2007). We utilized tract-level crime data for 2004 from the Philadelphia Police Department to define neighborhood safety. Three crime data were summed for each

neighborhood and converted into rates per 1,000 population: Part I violent crimes, property crimes, and missing persons. We used the principal component analysis to create a crime score for each neighborhood and the factor loadings for the three crimes were .94, .93, and .53, respectively, with 67.71 percent of the total variance was explained. The regression method was applied to generate the neighborhood crime score used in the analysis.

We also extracted six social condition variables from 2000 census data and followed the previous data reduction approach to identify one socioeconomic factor. The factor loadings on socioeconomic situation are: percent of female-headed household (.83), unemployment rate (.92), poverty (.94), percent of people receiving public assistance (.94), median household income (-.91), and percent of people with at least a bachelor's degree (-.88). This socioeconomic situation factor explained 81.35 percent of the total variance. Based on the factor loadings, higher scores could be interpreted as lower socioeconomic status.

The third social environment variable is residential stability. The percent of house ownership and the percent of residents living in the same address at least five years were calculated from 2000 census tract-level data. We aggregated the raw data for each neighborhood and standardize these two variables. Because these two characteristics are highly correlated (0.68 ($p < 0.01$)), we averaged the standardized scores to yield a single indicator of residential stability.

One strength of our study is to employ a spatial perspective and use GIS to create objective measures of neighborhoods' built environments. We introduced the first measure: daily vehicle miles traveled (DVMT). Stimulated by Houston et al (2004), we constructed this variable using Pennsylvania Department of Transportation (2008) geo-referenced data on traffic volume (based on the amount of vehicle traffic that traveled sections of road). Each segment of road had a DVMT calculated by multiplying the length of road (in miles) by average daily traffic estimate. The neighborhood boundaries were overlaid with the traffic network in a GIS and then we averaged the DVMT of each road segment within a neighborhood, generating the traffic volume measure for each neighborhood. To avoid small estimates, we standardized the DVMT and used the z-scores later.

With respect to the hazardous exposure, two variables were obtained from Pennsylvania Department of Environment Protection (2006) – the number of toxic release inventory (TRI) sites and the presence of a residual waste operation (RWO) site. The TRI site is a facility that manages chemicals released from industries such as manufacturing, mining, electric utilities, and commercial hazardous waste treatment (Environmental Protection Agency, 2008). The RWO is a primary facility handling the materials and products that cannot be reused, recycled, or composted and require disposal technologies such as landfill and incineration (EnviroCentre 2007). These facilities were geocoded by the Pennsylvania Department of Environment Protection and we overlaid these with neighborhood boundaries. The number of TRI sites within a neighborhood was used as the variable. In contrast to TRI, RWO was relatively rare in Philadelphia, we coded the neighborhoods with RWO sites as 1, 0 if without.

Results

Table 1 shows the descriptive statistics of the variables used in this study. The average reported stress is 5.3, which is close to the mean of this stress scale, 5.5. While almost 13 percent of the respondents reported no stress at all, there was a similar proportion (12.1%) of people characterizing life as extremely stressful (results not shown). Stress is a common experience for the residents in Philadelphia County. Furthermore, about 40 percent of the respondents are black. Two out of three participants are either married or previously married. 53 percent of respondents in the data are full time employees and more than 40 percent completed at least secondary

education. The PHMC data exhibit a poverty rate of 17 percent and indicate that more than 40 percent of the respondents attend religious activities weekly.

[Table 1 Insert Here]

At the neighborhood level, the Moran's I of stress is 0.16 and statistically significant at .001 level (see Figure 1 and Table 1). As discussed previously, a positive spatial autocorrelation indicates that neighborhoods with similar stress levels tend to be geographically close to one another. In other words, we now have evidence that stress is not randomly distributed across space. We test four weight matrices and show the selected results in the last panel of Table 1. The Moran's I of stress is only significant with the Queen's first order, which is the main reason why we choose it as our weighting scheme. In addition, the Moran's I of other environmental variables decreases with the increase of orders, showing a trend suggested by Tobler (1970).

To further identify the hotspots/cold spots of stress, the LISA map could provide detailed information. Among the 158 neighborhoods, fifteen are of the high-high (red neighborhoods) clustering. The hotspot demonstrates that these neighborhoods have comparably high stress level sand they do *not* happen to be geographically close to each other by chance (the p-values of the LISAs are at least below .05). Most of them could be observed in the middle of Philadelphia County. On the other hand, only 8 neighborhoods are categorized into the low-low group (blue neighborhoods) and they can be observed in two conspicuous clusters. One sits in the northeast of this county and the other is northwest of the stress hotspot. The residents living in these neighborhoods tend to report low stress, which aggregately reflects on the LISA map.

[Figure 1 Insert Here]

As the ESDA results suggest that the distribution of stress is correlated spatially, the hierarchical modeling can further help to determine if the environmental factors proposed in this study really matter. We first investigate the impacts of social structure on stress (see Table 2). The null model echoes the ESDA results and indicates that stress differs by neighborhood (variance component = 0.0689 and significant at .01). The demographic variables are included in Model I. While the literature suggests that stress varies by these fundamental social locations, our results can only provide the evidence for the effect of age. While the estimated coefficients of gender and marital status follow the theoretical expectation, they fail to reach the statistical significance. Take marital status for instance, in contrast to the single, those who are married have lower stress and those who are previously married report higher stress. Model II further comprises socioeconomic variables. Being employed or completing secondary education do not necessarily impose a beneficial effect on self-rated stress. However, the impoverished exhibit a higher stress than those whose family income is above the poverty line.

[Table 2 Insert Here]

When religiosity and neighborhood trust are included in Model III, the adverse effect of poverty becomes insignificant. Though attending religious activities weekly does not have a protective effect on stress, neighborhood trust exhibits the expected influence. Social support could alleviate the stress resulting from poverty. Respondents who have high trust in their neighbors report a significantly lower stress than their counterparts with distrust. High neighborhood trust could facilitate the interaction and collaboration among residents. When people confront stressors related to poverty, neighbors might provide appropriate resources to counter stress. These resources are either tangible or invisible, such as monetary support or disseminating useful information. Based on Model III, the inclusion of social support does not alter the impact of age on stress greatly.

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Model IV further considers food insecurity and individual health. While health is negatively associated with self-reported health, its impact is marginally significant. It should be noted that the impacts of age and neighborhood trust shrink from Model III to Model IV. Apparently, the inclusion of food insecurity and health explain, in part, why age and social support affect stress. To maintain regular contacts with people, being physically healthy might be a crucial factor, especially for the elderly. While a recent study in South Africa did not find a significant relationship between stress and food insecurity (BeLue et al., 2008), the residents in Philadelphia County are influenced by food insecurity adversely even after demographic and socioeconomic covariates are controlled.

To avoid the potential multi-collinearity problem, we examine the variance inflation factors (VIF) among the independent variables at the individual level. Menard (2002) noted that many of the diagnostic statistics for multi-collinearity can be obtained by implementing an OLS regression with the same dependent and independent variables. "Because the concern is with the relationship among the independent variables, the functional form of the model for the dependent variable is irrelevant to the estimation of collinearity (Menard 2002, p. 76)." Generally, a VIF greater than 10 is problematic. All the VIFs in Table 2 are smaller than the stricter cut-off value, 4. We are confident that the results here should not be biased by collinearity.

Table 3 demonstrates the results of models including the environmental factors. Model V considers the neighborhood's socioeconomic composition only. Although it is believed that the residents from a neighborhood with low socioeconomic status tend to report high stress, the results fail to support this argument. We further add crimes and stability into Model VI. Residential stability shows a beneficial, but marginal, effect on stress as found in the previous studies (Berkman et al., 2000; Boardman, 2004). A neighborhood with low turnover rates and high homeownership can be interpreted as a stable social structure. This stable environment can develop a sound social network, which is responsible for determining individual behaviors and emotional responses and hence affects self-reported stress (Berkman et al., 2000). However, neighborhood crimes are not related to stress. Despite the suggestion that lack of sense of safety could lead to undesirable mental health outcomes, in Philadelphia County, the difference in residents' stress level between high- and low-crime neighborhoods is not substantial.

[Table 3 Insert Here]

We finally take the built environment into account. Model VII comprises two measures of hazardous waste exposure. The number of TRI sites within a neighborhood is positively correlated with individual stress, even after controlling for other covariates. This relationship echoes the hazardous waste syndrome and reflects that a more visible potential menace (in contrast to crimes) to individual safety does burden mental health with more stress. Nonetheless, unlike TRI, the presence of RWO is not a predictor of stress in our results. In addition, in Model VII, the beneficial effect of stability becomes insignificant. It seems that residential stability is confounded with hazardous waste. It has been reported that "wanting to move but cannot" is among the five most common sources of stress for both females and males in Canada (Shields, 2004). Assuming this finding holds in Philadelphia County, those who wanted to move out of the neighborhoods with hazardous waste sites but cannot might, on one hand, increase residential stability at the neighborhood level and on the other hand report high individual stress. Explicitly, whether high residential stability is a result of voluntarily staying or incapability of moving might affect the relationship between stress and residential stability, especially for the respondents from neighborhoods with poor built environment.

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Traffic volume is added in Model VIII. Following the theoretical expectation, busy traffic leads to high stress. Since 1990s, traffic has been identified as a salient source of stress (Gulian et al., 1990; Novaco et al., 1990; Hennessy and Wiesenthal, 1997). The number of automobiles has increased steadily but the expansion of public roads and highways has been relatively slow. Residents, especially in urban areas, are hence more likely to experience stress caused by the competition for parking space, congestion, and accidents. Moreover, while the impact of TRI on stress has been reduced due to the inclusion of traffic, it remains significant, indicating both environmental factors contribute to stress independently.

Revisit Hypotheses

We can test the research hypotheses based on the results presented above. First, we expected that stress is not randomly distributed across the research area. The ESDA confirms this hypothesis. Moran's I indicates a moderate spatial autocorrelation of stress in Philadelphia County and the LISA map demonstrates one hotspot and two coldspots. Obviously, the neighborhoods with comparable stress level tend to be geographically close to each other. That is, residents who are exposed to similar environments are more likely to assess stress in the same vein. Confirming this hypothesis is crucial to this study. We argued that social stress research has not paid enough attention to the potential environmental effects. This exploratory analysis primarily supports this argument and further bolsters the explanatory analyses including both social and built neighborhood environment.

Second, earlier social stress research clearly suggested that social locations play an imperative role in determining stress and social support might account for the differences in stress by social locations (i.e. age). Therefore, we hypothesized the impacts of social structure on stress will be attenuated by social support. However, the hierarchical modeling provides little evidence to sustain this hypothesis. Among various demographic and socioeconomic covariates at individual level, only "age" is found to have a persistent impact on stress. Though poverty imposes an adverse effect on stress, this relationship can be eliminated by social support. Generally, we fail to depict how social structure affects self-reported stress with our data. While social support, as expected, is negatively related to stress, there are not enough indications that social support can attenuate the effects of social location on stress (except poverty). In addition, food insecurity has an impact on stress, which is independent from social structure and not regularly discussed in the literature.

Finally, beyond individual characteristics, we anticipated that environmental factors could explain how people assess their stress. With respect to social environment, socioeconomic composition and neighborhood crime do not exhibit any significant effects on stress in our results. Residential stability has a marginal influence but this impact seems to be confounded with the presence of hazardous waste sites. It requires more detailed data to unveil the intertwined relationships among stress, stability, and the exposure to hazardous waste sites. Furthermore, this study endeavors to fuse a spatial perspective into mental health research by using georeferenced data and GIS. According to the results, two built environment factors drawn on spatial data sets demonstrate anticipated effects on stress. In contrast to crimes, these more visible or sensible threats to individual safety (or health) could better explain why stress differs by neighborhood.

Discussion and Conclusion

This study is motivated by the question of whether stress is a spatially-clustered phenomenon and attempts to explore the determinants of self-rated stress at both individual and neighborhood levels. The most significant contribution of this study is to establish the

association between self-reported stress and the perceived environmental threats, hazardous waste sites and traffic in particular. The built neighborhood factors should play a role as crucial as social locations, if not more important. As Healthy People (DHHS, 2000) indicated, health is not only determined by individual features but also by the environmental characteristics to which people are exposed. With the proliferation of spatial data and analytic tools, social stress research should expand the focus by embracing a spatial perspective and adopting related data sets. Moreover, while social structure has been suggested to affect stress, we find limited evidence to substantiate the literature. One explanation for this conclusion is that we employ self-rated stress as our dependent variable but earlier studies usually adopted an inventory of life events to measure stress. While a subjective stress measure has been argued to be the one stress research should be interested in (Lazarus, 1990), few studies have explored whether the impacts of social structure differ by subjective and objective measures.

Several policy implications could be drawn on the findings above. As the presence of hazardous waste sites might induce high stress, it is important to make residents realize the potential advantages and disadvantages these facilities might bring. Reducing residents' misgiving about the TRI sites and disseminating useful information might make these facilities less dangerous in residents' mind and hence improve mental health. In addition, to minimize the adverse impact of traffic on stress, encouraging the usage of public transportation and developing a more walker and biker friendly environment would decrease the traffic volume and stressors related to traffic. Because neighborhood trust is beneficial for stress, enhancing the collaboration and communication among residents should facilitate the development of trust. Clearly, not only should an individual-oriented policy be considered, but also a neighborhood-based health promotion plan needs to be undertaken.

Using both spatial analysis and hierarchical modeling, this study shares several limitations with earlier research. First, we realize the definition of neighborhood might alter the findings aforementioned. Openshaw (1983) has identified the modifiable areal unit problem (MAUP) and the influence of different levels of geographic aggregation on stress should be noted (Soobader and LeClere, 1999). Second, this study assumes that respondents are only affected by the neighborhood where they live. That is, we only take the residential environment into account but, in fact, other places where people stay for a significant amount of time daily, such as working neighborhood, should also have implications for stress. While methodologically a cross-classified model can solve this problem (see Raudenbush and Bryk 2002), the PHMC data sets do not support this approach. Third, this study is a cross-sectional analysis. The causal associations between stress and environmental factors are not fully examined. A longitudinal research design that collects information on the changes in individual stress and residential environment would further clarify the causality and the dynamics between stress and environmental factors.

In sum, this study sheds new light on investigating the determinants of self-rated stress with an emphasis on environmental factors. Although stress has been defined to be related to environment, insufficient efforts have been made to simultaneously take both social and environmental features into account and the spatial clustering pattern of stress has not been uncovered yet. This study has tried to fulfill this gap by incorporating several built environment characteristics that typically receive little attention into statistical models and analyzing them with a spatial perspective. In doing so, the questions of whether and how environmental factors matter in social stress research can be more fully addressed.

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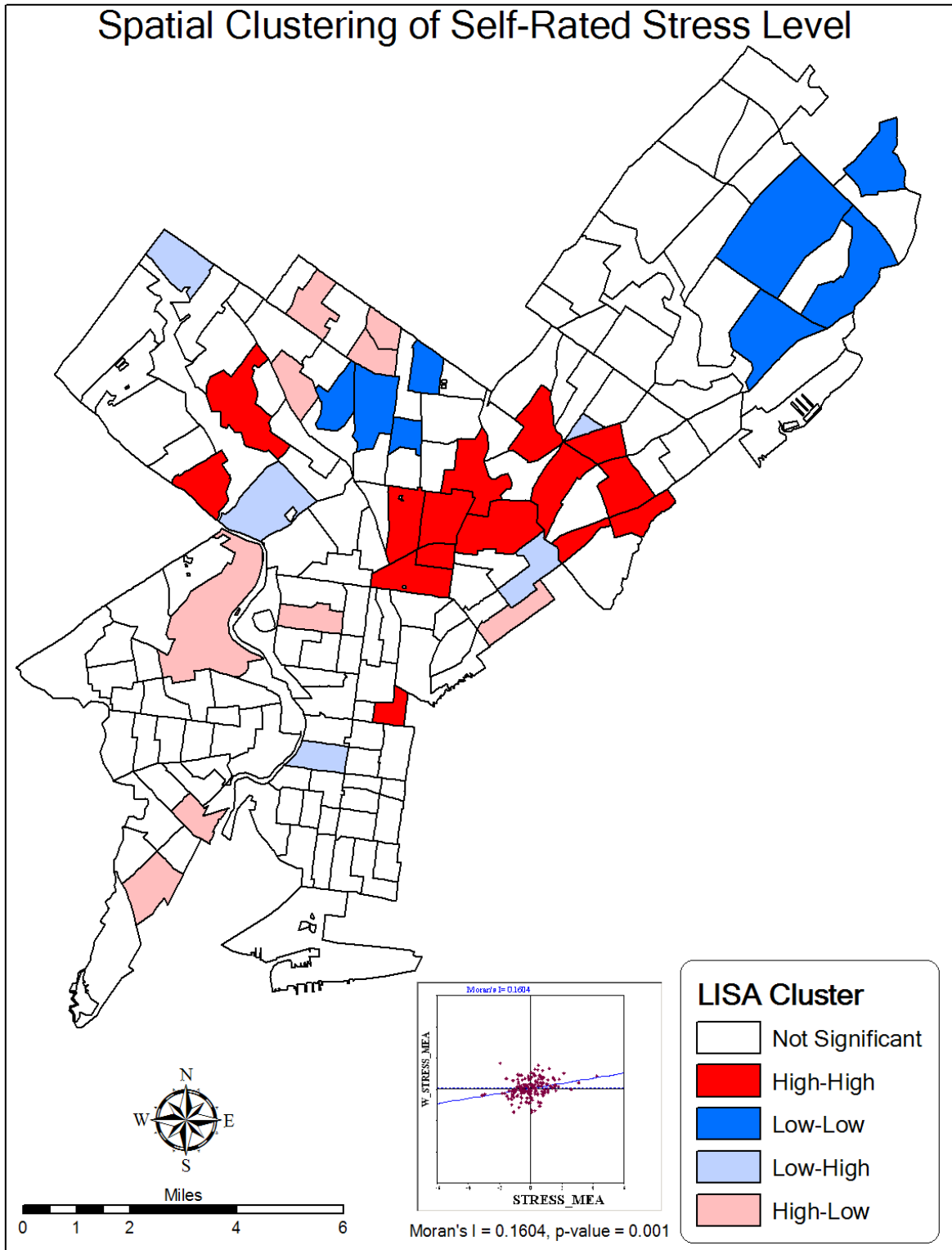Figure 1. Spatial clustering of self-rated stress in the Philadelphia County

Table 1. Descriptive statistics of the variables used in analysis

	Minimum	Maximum	Mean	S.D
Individual Level (N=4095)				
Stress	1.0000	10.0000	5.2909	2.8705
Age Group	1.0000	5.0000	2.5909	1.3710
Gender	1.0000	0.0000	0.2963	0.4567
Race (Black = 1, else 0)	0.0000	1.0000	0.4139	0.4926
Marital Status				
Married	0.0000	1.0000	0.3942	0.4887
Previously Married	0.0000	1.0000	0.2825	0.4503
Employed	0.0000	1.0000	0.5329	0.4990
Education (Over high school =1, else 0)	0.0000	1.0000	0.4499	0.4975
Poverty (Poor = 1, else 0)	0.0000	1.0000	0.1740	0.3791
Religiosity (weekly =1, else 0)	0.0000	1.0000	0.4129	0.4924
Neighborhood Trust	-2.9792	1.7036	0.0004	0.9940
Food Insecurity	0.0000	1.0000	0.1365	0.3433
Health	-2.7182	1.2496	0.0029	0.8604
Neighborhood Level (N=158)				
Socioeconomic Composition	-1.7173	2.6668	0.0000	0.9968
Neighborhood Crimes	-0.8443	9.5688	0.0026	1.0026
Residential Stability	-3.5638	1.7274	0.0000	0.9170
TRI	0.0000	7.0000	0.4304	0.9264
RWO	0.0000	1.0000	0.1329	0.3406
DVMT	-0.8754	4.1086	0.0000	1.0000
Moran's I for Selected Variables	Queen 1st	Queen 2nd	Queen 3rd	Queen 4th
Stress	0.1604***	0.0513	-0.0003	-0.0126
Socioeconomic Composition	0.6766***	0.4677***	0.3630***	0.2065***
Neighborhood Crimes	0.1271**	0.1354**	0.0912*	0.0140
Residential Stability	0.4674***	0.1352***	0.0164	-0.0097
DVMT	0.1845**	0.0319	-0.0199	0.0032

Table 2. The impacts of social locations on stress in the Philadelphia County

Variables	VIF	Null Model	Model I	Model II	Model III	Model IV
Intercept	N.A.	5.2761***	6.6995***	6.6327***	6.5665***	6.1476***
Individual Level (N=4095)						
Age Group	1.0307		-0.5200***	-0.5168***	-0.5105***	-0.4693***
Gender (Male =1)	1.0394		-0.1294	-0.1093	-0.1005	-0.1017
Race (Black = 1, else 0)	1.0509		-0.0847	-0.0842	-0.1113	-0.1070
Marital Status						
Married	1.4270		-0.0330	-0.0117	0.0181	0.0818
Previously Married	1.4704		0.0098	0.0069	0.0498	0.0294
Employed	1.3441			-0.0378	-0.0237	0.0413
Education (Over high school =1, else 0)	1.1390			0.0687	0.0894	0.1674
Poverty (Poor = 1, else 0)	1.1357			0.2112*	0.1678	0.0345
Religiosity (weekly =1, else 0)	1.0449				0.0522	0.0753
Neighborhood Trust	1.0620				-0.1565***	-0.1210**
Food Insecurity	1.0294					0.1626***
Health	1.3187					-0.1127[+]
Variance Component u_0	N.A.	0.0689**	0.0486**	0.0360*	0.0328*	0.0382*

+ p<.1; * p<.05; ** p<.01; *** p<.001

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Table 3. The impacts of both social and residential locations on stress in the Philadelphia County

Variables	VIF	Model V	Model VI	Model VII	Model VIII
Intercept	N.A.	6.1469***	6.1493***	6.1015***	6.0592***
Individual Level (N=4095)					
Age Group	1.0406	-0.4693***	-0.4672***	-0.4648***	-0.4646***
Gender (Male =1)	1.0424	-0.1015	-0.0999	-0.0966	-0.0953
Race (Black = 1, else 0)	1.1380	-0.1051	-0.1264	-0.0927	-0.0436
Marital Status					
Married	1.4318	0.0812	0.0835	0.0817	0.0798
Previously Married	1.4763	0.0288	0.0279	0.0250	0.0301
Employed	1.3482	0.0408	0.0417	0.0403	0.0415
Education (Over high school =1, else 0)	1.1735	0.1659	0.1551	0.1613	0.1634
Poverty (Poor = 1, else 0)	1.1494	0.0355	0.0316	0.0302	0.0262
Religiosity (weekly =1, else 0)	1.0469	0.0759	0.0778	0.0809	0.0796
Neighborhood Trust	1.0751	-0.1216**	-0.1234**	-0.1244**	-0.1183**
Food Insecurity	1.0415	01627***	0.1633***	0.1630***	0.1627***
Health	1.3224	-0.1128$^+$	-0.1110$^+$	-0.1110*	-0.1102$^+$
Neighborhood Level (N=158)					
Socioeconomic Composition	1.2556	-0.0052	-0.0097	-0.0358	0.0013
Neighborhood Crimes	1.1712		-0.0064	-0.0051	-0.0199
Residential Stability	1.0667		-0.0758$^+$	-0.0812	-0.0408
TRI	1.2402			0.0677*	0.0494*
RWO	1.0931			-0.1312	-0.0651
DVMT	1.1861				0.0976**
Variance Component u_0	N.A.	0.0464*	0.0444*	0.0618	0.0657

+ p<.1; * p<.05; ** p<.01; *** p<.001