Multilevel and Spatial–Time Trend Analyses of the Prevalence of Hypertension in a Large Urban City in the USA

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ABSTRACT We aimed to test two hypotheses that (1) there were significant variations in the prevalence of hypertension (HBP) across neighborhoods in the city of Philadelphia and (2) these variations were significantly explained by the variations in the neighborhood physical and socioeconomic environment (PSE). We used data from the Southeastern Pennsylvania Household Health Surveys in 2002–2004 (study period 1, $n=8,567$), and in 2008–2010 (period 2, $n=8,747$). An index of neighborhood PSE was constructed using multiple specific measures. The associations of HBP with PSE at the neighborhood level and other risk factors at the individual level were examined using multilevel regression analysis. The results show that age-adjusted prevalence of HBP increased from 30.33 to 33.04 % from study periods 1 to 2 ($p<0.001$). An estimate of 44 and 53 % of the variations in the prevalence of HBP could be explained by the variations in neighborhood PSE in study periods 1 and 2, respectively. In conclusion, prevalence of HBP significantly increased from 2002–2004 to 2008–2010. Individuals living in neighborhoods with disadvantaged PSE have significantly higher risk of the prevalence of HBP.

KEYWORDS Hypertension, Neighborhood environment, Urban health, Multilevel models

INTRODUCTION

In the USA, approximately one in three adults or an estimated 68 million people, have hypertension. Of patients with cardiovascular disease, about 70 % including those having a first heart attack, or having a first stroke, or chronic heart failure, have hypertension.^{1,2} Risk factors for hypertension at the individual level have been extensively studied. Most recently, there is accumulative evidence showing that neighborhoods with disadvantaged physical and socioeconomic environment (PSE) are at higher risk of hypertension, stroke, and coronary heart disease.^{3–6} Philadelphia, which is both a city and a county, has approximately 1.5 million residents (2010 census), is the largest city in the state of Pennsylvania and ranks as

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the top fifth city in the USA. Unfortunately, it also ranked last out of 67 counties in the state of Pennsylvania according to measures of health outcomes including health factors, chronic disease morbidity, and mortality rates.⁷ In 2009, among ten the largest cities in the USA, Philadelphia had the highest prevalence of hypertension (34.5 %) and heart disease (4.5 %), the second highest prevalence of diabetes (10.7 %, after city Dallas 11.7 %) and obesity (29.3 %, after city Houston 29.7 %).⁸ However, evidence of risk factor studies for these chronic conditions is very limited, and no other previously conducted study used data from a large-scale representative sample and analyzed data using hypothesis-driven and multilevel analytical approaches to test risk factors of hypertension at both neighborhood and individual levels. In the present study, we used data from the Southeastern Pennsylvania (SEPA) 2002, 2004, 2008, and 2010 Household Health Survey (HHS), one of the largest population-based surveys in the region to test two specific hypotheses.⁹ First, there were significant variations in the prevalence of hypertension across neighborhoods in the city of Philadelphia. Second, these variations were significantly explained by variations of neighborhood PSE status. We believe that findings from the study may offer new insights into the control and prevention of hypertension in the city of Philadelphia, and any other large urban city that has distinct disparities in neighborhood PSE.

METHODS

Study Design and Population

The HHS is conducted biannually by the Public Health Management Corporation's (PHMC) using a cross-sectional study design and a probability sample of over 10,000 households from five counties in southeastern Pennsylvania: Philadelphia, Bucks, Chester, Delaware, and Montgomery counties.⁹ The surveys target key information on residents' health status, health behaviors, and neighborhood health status. Interviews, using standard survey instruments, are conducted by telephone using a random-digit dial methodology. Adults aged ≥ 18 are selected randomly using the "last birthday" method. In the present analysis, we focused on health status in Philadelphia because it had the highest prevalence of hypertension among the five counties. We defined neighborhoods on the basis of zip codes. Of 47 five-digit zip codes, one zip code was excluded because few residents lived there and few participants ($n < 6$) were in the HHS data. To test the time trend, we combined data from 2002 to 2004 surveys as study period 1 ($n = 8,567$) and 2008 to 2010 surveys as study period 2 ($n = 8,747$) in order to have sample sizes large enough in each of the study neighborhoods ($n = 46$). In the final sample, the median (inter quarter range) sample size of each of the 46 neighborhoods was 180 (123–254) in study period 1 and 211 (115–230) in study period 2.

Study Outcomes

Hypertension (i.e., high blood pressure) is diagnosed for those who have systolic blood pressure (BP) greater than or equal to 140 mmHg and/or diastolic BP greater than or equal to 90 mmHg on three or more on the occasions, or are being treated with antihypertensive medication. In the study, hypertension was defined for those who answered *yes*, to the question, "Have you EVER been told by a doctor or other health professional that you have high blood pressure or hypertension?"

Risk Factors at Neighborhood Level—the Measures of PSE

To assess the impact of neighborhood environment on health, we constructed a hypothesis-driven index derived from eight neighborhood-focused questions. These questions addressed: access to/usage of recreational facilities, accessibility of fruits and vegetables, quality of accessible groceries, likelihood that neighbors help each other, examples of neighbors working together, sense of belonging, and degree of trust in neighbors and poverty level (see “Appendix” for sample questions). We created a weighted PSE score for each neighborhood through four steps. First, we estimated the relationship between eight PSE measures (X_i) and the prevalence of hypertension (Y) using multivariate logistic regression with adjustment for age. Second, the estimated standard regression coefficients (SB_i) with a positive relationship to the prevalence of hypertension were used to weight individual measures, resulting in the production of $SB_i \times X_i$. Third, weighted PSE measures were summed to create a total PSE score. Lastly, the mean PSE score was calculated for each neighborhood; a higher score indicates a neighborhood with a worse PSE. The principal of constructing a weighted index has been applied and validated by several studies including our own work.^{10–14}

Risk Factors at the Individual Level

To evaluate risk factors at the individual level, several demographic, health status, and lifestyle factors were included in the study. Demographic factors included: age, sex, race/ethnicity (White, Black, and others) and education attendance (<high school, high school and >high school). Body weight and height and resulting body mass index (BMI), calculated using weight (in kilogram) divided by square of height (in meter) were also included. BMI was grouped using the World Health Organization criteria of BMI <18.5, 18.5–24.9, 25–29.9, and ≥ 30 kg/m², for those who are with underweight, normal, overweight, and obese, respectively. Lifestyle factors included: smoking, physical activity, and consumption of fruit/vegetables. Smoking status was queried by “do you now smoke”; or “have you smoked at least 100 cigarettes in your entire life”. Classifications included current, former smoker, or never smoked. Physical activity status was assessed by positive responses to the survey question “thinking about the past month, how many times per week did you participate in any physical activities for exercise that lasted for at least one half hour, such as walking, basketball, dance, rollerblading or gardening?” Fruit and/or vegetable consumption was queried by responses to “how many servings of fruits and vegetables do you eat on a typical day? (A serving of a fruit or vegetable is equal to a medium apple, half a cup of peas, or half a large banana).” Classifications included <3, 3–4, and ≥ 5 servings per day.

Statistical Analysis

A serial analysis was conducted. First, we described participant characteristics by study periods 1 (2002–2004) and 2 (2008–2010). Differences in categorical variables were tested using Chi-square test, and continuous variables using t-tests and ANOVA. Second, we mapped age-adjusted prevalence of hypertension across 46 neighborhoods using Geographic Information System (ArcGIS version 10). Age-adjusted prevalence of hypertension was estimated using direct standardization method for the US 2000 population. Geographic (spatial)–time analyses of the prevalence of hypertension between the study periods 1 and 2, and across neighborhoods were conducted using correlation analysis and linear regression models. Third, we used multilevel analysis technique (generalized linear mixed model, GLMM) to estimate odds ratios of individual-level risk factors (age, sex, race/ethnicity, education level, smoking status, body weight, physical activity, and vegetable and/or fruit intake) and neighborhood PSE score (quarters 2–4 vs. Q1) for the odds of the prevalence of hypertension.¹⁵ In the analysis, we combined data

from study periods 1 and 2 in order to test independent effects of PSE scores, study period, and individual level risk factors on the prevalence of hypertension. Interaction effects of PSE with study periods, BMI, and race/ethnicity on the study outcome were tested.

GIS version 10 software (ArcGIS, Redlands, CA) was used to map the prevalence of hypertension by neighborhoods and study periods. All other statistical analyses were conducted using SAS software version 9.2 (SAS Institute, Cary, NC).¹⁶ A weighting approach was applied to take into account for the probability sampling design of the HHS. Multilevel analysis was conducted using SAS Procedure GLIMMIX.¹⁵ A two-sided p value ≤ 0.05 was considered as having statistical significance.

RESULTS

1. Characteristics of participants by study periods.

Of the 17,314 participants ($n=8,567$ and $n=8,747$ in periods 1 and 2, respectively), age-adjusted prevalence rate (95% CI) of hypertension was 30.33 % (29.20–31.46 %) in period 1, and 33.04 % (31.95–34.13 %) in period 2 ($p<0.01$). Table 1 shows significant differences in the proportions of participants by age, race/ethnicity, education level, cigarette smoking, physical activity, and BMI between periods 1 and 2.

2. Mapping the prevalence of hypertension by neighborhoods and study periods.

Panels a and b of Fig. 1 show significant variations in age-adjusted prevalence of hypertension across 46 neighborhoods. In period 1, there were 12 neighborhoods where the prevalence of hypertension was ≥ 35 % (i.e., $\geq$ the highest quarter). These neighborhoods with higher prevalence of hypertension were predominately located in the north, west, and southwest districts (Fig. 1a). In period 2, the number of neighborhoods with hypertension prevalence ≥ 35 % increased to 19, a 58 % increase as compared to period 1 in the city of Philadelphia (Fig. 1b).

3. Multilevel modeling and correlation between PSE score and the prevalence of hypertension.

Of the eight individual PSE measures, six were positively associated with hypertension prevalence. These were: access to/usage of recreational facilities, accessibility if fruits and vegetables, quality of accessible groceries, likelihood that neighbors help each other, degree of trust in neighbors, and poverty level. The weighted mean PSE score of total 46 neighborhoods was 0.59 (range 0.44 to 0.70). The quarter distribution of the PSE score are shown in Table 2.

Multilevel regression analysis shows that aging, being Black or belonging to other racial/ethnic groups, lower education levels, current smoking status, and increased body weight significantly predicted the odds of the prevalence of hypertension (Table 2). Subjects in study period 2 had 1.12 times higher odds of having hypertension (OR=1.12; 95% CI, 1.08–1.17) than those in study period 1. Subjects who lived in neighborhoods with PSE score ≥ 0.64 (quarter 4) had 1.32 times higher odds of having hypertension than those who lived in neighborhoods with PSE score <0.54 (quarter 1). Interaction effects of PSE with study periods, BMI, and race/ethnicity on the odds of hypertension prevalence were not statistically significant. The corresponding statistics p values were 0.57, 0.79, and 0.28, respectively.

Figure 2a depicts that the prevalence of hypertension in study period 1 significantly and positively predicted the prevalence of hypertension in study period 2 across neighborhoods ($R^2=0.52$, $p<0.001$). Figure 2b depicts that subjects living in neighborhoods with higher PSE scores had higher prevalence of hypertension in study periods 1 and 2. The

TABLE 1 Characteristics of participants by study periods 1 and 2

	2002–2004		2008–2010		<i>p</i> value
	(<i>n</i> = 8,567)		(<i>n</i> = 8,747)		
	%	(SEP)	%	(SEP)	
Age, (year)					
18–44.9	51.32	(0.62)	45.13	(0.67)	<0.001
45–64.9	30.29	(0.57)	37.10	(0.60)	
≥65	18.39	(0.47)	17.78	(0.44)	
Male, (%)	44.76	(0.63)	44.78	(0.67)	0.981
Race/ethnicity, (%)					
White	45.74	(0.63)	42.97	(0.65)	0.001
Black	40.40	(0.61)	41.25	(0.65)	
Others	13.87	(0.39)	15.78	(0.53)	
Education level					
< High school	14.70	(0.45)	12.65	(0.46)	0.006
High school	37.39	(0.61)	38.31	(0.64)	
≥High school	47.91	(0.62)	49.04	(0.66)	
Body weight ^a					<0.001
Underweight	2.08	(0.17)	1.77	(0.17)	
Normal	36.57	(0.60)	32.91	(0.64)	
Overweight	34.25	(0.60)	34.74	(0.63)	
Obesity	27.09	(0.56)	30.58	(0.60)	
Smoking status, (%)					<0.001
Never	63.34	(0.60)	51.46	(0.66)	
Former	14.50	(0.44)	29.27	(0.58)	
Current	22.16	(0.53)	19.27	(0.54)	
Physical activity, (%)					<0.001
No	18.07	(0.48)	14.26	(0.46)	
<1 day/week	12.70	(0.42)	9.17	(0.37)	
1–3 days/week	36.40	(0.60)	36.43	(0.63)	
≥4 days/week	32.82	(0.59)	40.15	(0.65)	
Vegetable/fruit intake					0.825
<3 servings/day	60.53	(0.60)	60.42	(0.64)	
3–4 servings/day	28.93	(0.56)	29.30	(0.59)	
≥5 servings/day	10.54	(0.38)	10.27	(0.38)	

SEP standard error of proportion.

^aUnderweight, normal, overweight, and obesity are defined using the WHO criteria of body mass index [BMI: weight(kg)/height×height(m)] <18.5, 18.5–24.9, 25–29.9, and ≥30 kg/m², respectively

neighborhood variations in PSE status could explain 44 and 53 % of the variations in the prevalence of hypertension in study periods 1 ($R^2=0.44$) and 2 ($R^2=0.53$).

DISCUSSION

The present study, which used data from a large regional health survey, is the first to examine multilevel risk factors of hypertension using advanced biostatistical analysis approach and geographic information system. Results from the study have shown that the prevalence of hypertension significantly increased from 2002–2004 to 2008–2010 in the city of Philadelphia. Residents who lived in neighborhoods with disadvantaged PSE

FIG. 1 Age-adjusted prevalence (in percent) of hypertension by neighborhoods in study periods 1 (a) and 2 (b)

had significantly higher prevalence of hypertension than those who lived in neighborhoods with a better PSE status.

Hypertension in Philadelphia

Hypertension is a modifiable risk factor for CVD.^{1,17–21} Data from the Behavior Risk Factor Surveillance System, a nationally representative survey, suggests that nationwide, the prevalence of hypertension rose almost three percentage points from 24.8 % in 2003 to 27.5 % in 2007. An increasing trend was also observed in several other large cities, such as New York City where the prevalence of hypertension increased from 25.3 % in 2003 to 27.2 % in 2007.^{22,23} Our present study adds new evidence to the literature and shows that the prevalence of hypertension significantly increased in the city of Philadelphia.

Neighborhood PSE and Hypertension

Most previous studies used census data as a proxy to assess neighborhood PSE, such as neighborhood poverty rate and the number of fresh food supermarkets.^{3,4,10,24,25} However, a potential limitation of this approach is that census data may not reflect an individual’s actual neighborhood environment because data from census are overall

TABLE 2 Multilevel analysis of adjusted odds ratios (95 % CI) of risk predictors for the prevalence of hypertension

	OR for hypertension		
Risk predictors ^a	OR	(95% CI)	<i>p</i> value
Individual level			
Age, per 10 years	1.79	(1.75–1.84)	<0.001
Male vs. female	1.08	(1.00–1.17)	0.059
Race/ethnicity			
White	1		
Black	1.67	(1.51–1.84)	<0.001
Others	1.13	(0.99–1.30)	0.078
Education level			
≥College	1		
High school	1.12	(1.03–1.22)	<0.001
<High school	1.35	(1.19–1.52)	0.01
Smoking status			
Never smokers	1		
Former smokers	1.21	(1.08–1.34)	0.001
Current smokers	1.25	(1.13–1.39)	<0.001
Body weight			
Normal weight	1		
Underweight	0.91	(0.65–1.28)	0.605
Overweight	1.77	(1.61–1.96)	<0.001
Obesity	3.45	(3.12–3.81)	<0.001
Physical activity, (%)			
No	1		
<1 day/week	1.03	(0.92–1.15)	0.651
1–3 days/week	0.99	(0.87–1.13)	0.903
≥4 days/week	0.98	(0.89–1.07)	0.591
Vegetable/fruit intake			
≥5 servings/day	1		
3–4 servings/day	1.03	(0.90–1.18)	0.630
<3 servings/day	1.09	(0.94–1.25)	0.261
Study periods ^b			
Period 2 vs. period 1	1.12	(1.08–1.17)	<0.001
Neighborhood PSE index ^c			
Q1 (0.44 to <0.54)	1		
Q2 (0.54 to <0.59)	1.11	(0.97–1.26)	0.123
Q3 (0.59 to <0.64)	1.28	(1.11–1.47)	0.001
Q4 (0.64 to 0.70)	1.32	(1.15–1.52)	<0.001

PSE index: Weighted for standard regression coefficients
^aAll predictors were adjusted with each other in multilevel modeling
^bPeriod 1: 2002–2004; period 2: 2008–2010
^cPSE: Physical- and social environmental index (towards disadvantaged)

indicators. Several measures of PSE-related factors, such as the quality of groceries, individual trust and help with each other status, etc. are not commonly available from census survey, although it is known that a better measure of neighborhood PSE should be integrated with the perceptions of individual residents who actually live in the neighborhood.^{10,24} In the present study, we constructed a novel index of neighborhood PSE using multiple neighborhood measures, driven by individuals who lived in the

FIG. 2 Associations in age-adjusted prevalence of hypertension between study periods 1 and 2 (a), and between neighborhood PSE score (towards disadvantaged) and the prevalence of hypertension in study periods 1 and 2 (b)

neighborhood. Findings of the study suggested that the variations in PSE status could explain almost 45 % variations in the prevalence of hypertension in period 1 ($R^2 = 44\%$) and more than 50 % in period 2 ($R^2 = 52\%$) across 46 neighborhoods in the city of Philadelphia. This finding supports an important public health hypothesis that improving neighborhood PSE may play a crucial role in the control of hypertension.

Risk Factors at the Individual Level and Hypertension

In consistency with several previous studies,^{3,4,10,24,26} our study also observed that several risk factors at the individual level were significantly associated with the prevalence of hypertension, including age, race/ethnicity, educational level, smoking, and being overweight or obese. Furthermore, there were tendencies of increases in physical activity and vegetable/fruit intake related to decreased odds of hypertension although these associations were not statistically significant in the present study. However, this non-significant finding does not necessarily indicate that these factors are not important. A known effect of multivariate modeling is that factors with a very strong relation to the study outcome when combined in the same model with those that have a less strong relation will result in the latter being not statistically significant. The present results also show a wide range of 95 % CI for the associations of physical activity and vegetable/fruit intake with the study outcome, which suggests that further studies with a larger statistical power are needed to test these associations. Furthermore, potential reverse causation bias may occur in a study with a cross-sectional design, like our present study. For example, subjects who were diagnosed with hypertension may have changed their unhealthy behaviors. If so, this change may lead to an underestimate of the association between exposures and outcomes.

The mechanisms by which disadvantaged PSE increases the risk of the prevalence of hypertension remain to be explored. Potential hypertension-inducing characteristics of neighborhoods include limited accessibility to healthcare resources, healthy food markets, safety environments, etc. These factors may partly explain the association between neighborhood PSE and risk of hypertension. Further studies with a longitudinal study design are requested to test these potential mechanisms.^{3,10}

The present study has several advantages. First, the results provide timely evidence of an increased burden of hypertension and its association with neighborhood PSE. Second, the study contributes to the emerging literature of the application of multilevel and geographic (spatial) analysis techniques to evaluate risk factors and outcomes.^{3,4,27} This approach is of particular importance to the study of health disparities in urban cities that

have a diverse PSE. Several limitations should be also kept in mind when interpreting the present results. First, the findings are based on surveys with a cross-sectional study design. Therefore, any casual relationship between exposure and outcomes cannot be interpreted directly. Second, the reliance on self-report of hypertension may lead to an either under- or over-estimate of the prevalence of hypertension because individuals with unknown hypertension might have been grouped as “no hypertension”, or those who mistakenly reported having hypertension when the doctor had said pre-hypertension. We are unable to examine this bias due to lack of actual measures of systolic and diastolic blood pressure. However, this approach using self-reported physician diagnosis of chronic conditions has been demonstrated as an acceptable and valid method in population-based surveys in the USA.^{28,29} Furthermore, our report of the prevalence of hypertension (33.04 % in 2008–2010) was similar to the estimated rate for Philadelphia (34.5 %) using data from the CDC coordinated 2009 Behavior Risk Factor Surveillance Systems.⁸ Third, the classifications of neighborhoods are on the basis of zip codes that may cause misclassification because few small areas within a single zip code may have significant differences in PSE. If so, this will lead to an underestimate of the association between neighborhood PSE and outcomes because the mean value of neighborhood PSE may not well represent the zip code’s PSE.

In spite of the aforementioned limitations, we conclude that the present study contributes to the literature on links between neighborhood PSE and the prevalence of hypertension using data from a large and representative population sample. The findings suggest that the prevalence of hypertension significantly increased from 2002–2004 to 2008–2010. Neighborhood PSE significantly predicts odds of the prevalence of hypertension.

ACKNOWLEDGMENTS

L Liu and AE Núñez are partly supported by the US DHHS Office of Women’s Health and Office of Public Health and Service-funded Philadelphia Ujima Study (Mind Spirit Body Health Collaborative, PI: AE Núñez). Grant number 5 CCEWH111020-02-00. The study used data from the Public Health Management Corporation (PHMC) Philadelphia. The responsibility for the analysis and interpretation of these data is solely that of the authors. The opinions expressed in this paper are those of the authors and do not represent the views of PHMC. Our thanks also go to Miss Michelle Klawans and Ms. Deirdre Potter for their careful proofreading of the report.

APPENDIX

PSE-related questions

1. In the past year, how often did you use public recreation facilities in your neighborhood, such as public swimming pools, parks, schools, walking trails, bike paths, or recreation centers? (1 = more than once a week, 2 = once a week, 3 = a few times a month, 4 = once a month, 5 = less than once a month, 6 = never, 7 = there are no public recreation facilities in my neighborhood).
2. How easy or difficult is it for you to find fruits and vegetables in your neighborhood? Would you say that is very easy, easy, difficult, or very difficult (score 1–4)?

3. How would you rate the overall quality of groceries available in the stores in your neighborhood? Would you say it is excellent, good, fair, or poor (score 1–4)?
4. Using the following scale, please rate how likely people in your neighborhood are willing to help their neighbors with routine activities such as picking up their trash cans, or helping to shovel snow. Would you say that most people in your neighborhood are always, often, sometimes, rarely, or never willing to help their neighbors (score 1–5)?
5. Have people in your neighborhood ever worked together to improve the neighborhood (for example, through a neighborhood watch, creating a community garden, building a community playground, or participating in a block party, 1 = yes, 2 = no)?
6. Please tell me if you strongly agree, agree, disagree, or strongly disagree with the following statement: I feel that I belong and am a part of my neighborhood (score 1–4).
7. Please tell me if you strongly agree, agree, disagree, or strongly disagree with the following statement: Most people in my neighborhood can be trusted (score 1 – 4).
8. Household poverty level: 0 = not poor, at or above 150 % of federal poverty level, 1 = poor, below 150 % of federal poverty level.

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