Original Article

A typology of neighborhoods and blood pressure in the RECORD Cohort Study

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Background: Studies of associations between neighborhood environments and blood pressure (BP) have relied on imprecise characterizations of neighborhoods. This study examines associations between SBP and DBP and a neighborhood typology based on numerous residential environment characteristics.

Methods: Data from the Residential Environment and Coronary Heart Disease Study involving 7290 participants recruited in 2007–2008, aged 30–79 years, and residing in the Paris metropolitan area were analyzed. Cluster analysis was applied to measures of the physical, services and social interactions aspects of neighborhoods. Six contrasting neighborhood types were identified and examined in relation to SBP and DBP using multivariable linear regression, adjusting for individual/neighborhood socioeconomic status and individual risk factors for hypertension.

Results: The neighborhood typology included suburban to central urban neighborhood types with varying levels of adverse social conditions. SBP was 2–3 mmHg higher among participants residing in suburban neighborhood types and in the urban with low social standing neighborhood type, compared to residents of central urban with intermediate social standing neighborhoods (reference). The association between residing in urban low social standing neighborhoods and SBP remained after adjusting for individual/neighborhood socioeconomic status and individual risk factors for hypertension. Overall, an inverse association between DBP and level of urbanicity of the neighborhood was observed, even after adjustment for individual risk factors for hypertension.

Conclusions: Variations in BP were observed by levels of urbanicity and social conditions of residential neighborhoods, with different patterns for SBP and DBP. Population interventions to reduce hypertension targeted towards specific neighborhood types hold promise.

Keywords: blood pressure, built environment, cluster analysis, cohort study, neighborhood characteristics, pulse pressure, social environment

Abbreviations: BP, blood pressure; b.p.m., beats per minute; RECORD Study, Residential Environment and Coronary Heart Disease Study

INTRODUCTION

Over the past 15 years, a considerable amount of literature has focused on links between neighborhood environments and behavioral and metabolic risk factors for cardiovascular diseases [1]. However, the published literature on effects of neighborhood exposures is much scarcer for cardiovascular disease risk factors such as hypertension, dyslipidemias, and diabetes than for physical inactivity and obesity [2].

Specifically with respect to blood pressure (BP), the majority of studies have focused on the impact of the socioeconomic status of residential neighborhoods [2]. Studies have generally shown that lower neighborhood socioeconomic status is associated with higher BP levels after adjusting for individual socioeconomic status [3–9]. Other dimensions of the neighborhood environment have not been investigated as extensively. For example, with respect to the neighborhood physical environment, studies have focused mainly on the impact of air and noise pollution on BP [10–13], and few studies have examined links between features of the built environment and BP [14,15] despite growing evidence of its associations with excess weight, which is a known risk factor for hypertension [16]. With regards to the availability of services in the neighborhood, past studies have focused on the food environment (i.e. food stores and restaurants) and have reported mixed findings in relation to BP levels [14,15,17]. Lastly, with respect to social interactions in the neighborhood environment, studies have shown that elevated

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crime and perceived insecurity as well as low social cohesion and social capital are associated with elevated BP [14,18].

There are limitations to existing work on neighborhood environments and hypertension. First, each study is restricted to a limited number of neighborhood dimensions; yet Chaix [19] identified at least four distinct domains of neighborhood environmental factors: the physical environment, the services environment, the social interactions environment, and the sociodemographic environment. Second, studies have often failed to properly control for important neighborhood level confounders, such as neighborhood socioeconomic status, which may result in spurious associations [20]. Third, studies have not adequately addressed the fact that many neighborhood characteristics are strongly correlated with one another, thus limiting ability to disentangle effects of one variable over another or to consider the combined effects of exposure to multiple co-occurring neighborhood environment conditions on BP.

Given limitations in existing literature, we examined associations between SBP and DBP and a neighborhood typology based on a combination of several residential neighborhood environment characteristics. We improve on past efforts by using data from a large, well defined population-based cohort; considering a large number of variables related to the physical, services, and social interactions environment; constructing a typology of neighborhoods allowing us to assess the combined effect of neighborhood characteristics that are strongly correlated with one another; controlling for neighborhood socioeconomic status to address neighborhood-level confounding; and assessing whether individual risk factors for hypertension may explain associations between neighborhood characteristics and BP.

METHODS

Participants

The Residential Environment and Coronary Heart Disease (RECORD) Study (www.record-study.org) includes 7290 French residents recruited between March 2007 and February 2008. The study benefited from free medical check-ups, offered every 5 years by the French National Health Insurance System for Salaried Workers to all working and retired employees and their families. A convenience sample of participants was recruited during these 2-h preventive medical check-ups conducted by the Centre d'Investigations Préventives et Cliniques in four of its health centers, located in the Paris metropolitan area. Eligibility criteria were: age 30–79 years; ability to complete study questionnaires; and residence in one of the 10 (out of 20) administrative divisions of Paris or 111 other municipalities selected in the metropolitan area. These territories were selected *a priori* to include suburban and urban areas from contrasted socioeconomic backgrounds. Participants completed questionnaires, provided biological specimens and underwent clinical examinations. A detailed description of the study is available elsewhere [21,22]. The study protocol was approved by the French Data Protection Authority.

Measures

Blood pressure

During the medical check-up, supine brachial BP was measured by trained nurses three times in the right arm after a 10 min rest period, using a manual mercury sphygmomanometer [23]. A standard cuff size was used, but a large cuff was employed if necessary. SBP and DBP were defined as the first and fifth Korotkoff phases, respectively, using the mean of the last two BP measurements [24]. In secondary analyses pulse pressure was defined as the difference between SBP and DBP.

Individual sociodemographic variables

Age was examined as a continuous variable. Education was divided into four categories: no education (low); primary and lower secondary education (middle-low); higher secondary and lower tertiary education (middle-high); and upper tertiary education (high). Employment status was coded in four categories: employed, unemployed, retired, and other. Binary variables for financial strain and for residence ownership were obtained from self-report questionnaires. We followed the approach proposed by Beckman *et al.* [25] in attributing to each individual the 2004 Human Development Index of his/her self-reported country of birth, as a proxy of the country's social development level. Following the United Nations Development Program [26], a binary variable was derived to distinguish participants born in low development countries (Human Development Index <0.5) from those born in middle or high development countries (Human Development Index ≥ 0.5).

Antihypertensive medication use

Individual use of antihypertensive medication was determined by merging a National Health Insurance Administrative Database for all healthcare reimbursements in 2006–2009 to the RECORD Study. A binary variable was created indicating whether or not individuals had been reimbursed for any antihypertensive medication in the previous year.

Risk factors for hypertension

Family history of hypertension was self-reported. Participants were asked whether or not they engaged in physical activities equivalent to a total of 1 h of walking throughout the day (including at work, for transportation, and during leisure time). Alcohol consumption was coded in four categories: never, former, light, and regular drinkers (> two glasses per day for women and > three glasses per day for men). For smoking status, we distinguished between never, former, and current smokers. Height (using a wall-mounted stadiometer) and weight (using a calibrated scale) were recorded by a nurse. BMI was divided into three categories (normal: $<25\,kg/m^2$, overweight: 25 to $<30\,kg/m^2$, and obese: $\geq 30\,kg/m^2$). Waist circumference was measured using an inelastic measurement tape placed midway between the lower ribs and iliac crests on the midaxillary lines, and was divided into three categories (<94 cm, 94–102 cm, and >102 cm for men; <80 cm, 80–88 cm, and >88 cm for women). Resting heart rate was measured by ECG after a 5–7-min rest period and was subsequently divided into three categories: <60 b.p.m., 60–70 b.p.m., and >70 b.p.m. (70 rather than 80 b.p.m. was used as a cut-off because only 4.8% of participants had a resting heart rate ≥80 b.p.m.).

Neighborhood measures

In order to create a meaningful and multidimensional neighborhood typology, we defined measures pertaining to the physical and services neighborhood environments using multiple methodologies including simple aggregation with classical database management software and geographic information systems. When possible, variables were computed for 500 m radius circular zones centered on the participants' residence (ego-centered areas) [27]. Additional variables related to the physical and social interactions environments were derived through ecometric modeling techniques, wherein individual responses from questionnaire data are aggregated for residents of a given neighborhood [28]. These variables were defined at the level of relatively broad administrative units (census areas) comprising a median of 10 662 inhabitants [interquartile range (IQR) 9164, 12 279]. Details on definitions and measurement approaches for neighborhood measures are described in Table 1.

Regarding the neighborhood physical environment, the following variables were defined for 500 m radius zones (unless indicated otherwise): two indicators of building characteristics (proportion of neighborhood area covered with buildings and mean building height); four indicators describing the local street network (density of three or more-way street intersections, average street block length, link to node ratio, and route directness); presence of a highway within 250 m of the residence; two measures of road traffic-related pollution (concentrations of nitrogen dioxide and particulate matters); exposure to air traffic noise at 1000, 2000, and 3000 m above the participant's residence; presence of a waste treatment facility; surface area covered by parks and green spaces; and presence of lakes or waterways. Two additional ecometric variables were considered: neighborhood active living potential and physical deterioration of the neighborhood.

Indicators of the neighborhood services environment within 500 m radius circular zones include: total number of destinations; presence of historic monuments and other enjoyable sites; number of public transportation lines; presence of a commercial center; number of hypermarkets, supermarkets, and grocery stores; number of fruit and vegetable shops and stands; proportion of fast food restaurants among all restaurants; and number of sport facilities. Lastly, the proportion of incoming and outgoing traffic by public transportation rather than by car was obtained from a road traffic model for larger neighborhood areas.

Indicators of the neighborhood social interactions environment include school violence near the residence; and ecometric variables each obtained from responses on three to four questionnaire items namely, neighborhood social cohesion; stressful social interactions among neighbors; neighborhood mistrust and hostility; and stigmatized neighborhood identity based on participants' claims of a poor neighborhood reputation.

Finally, two neighborhood sociodemographic variables were computed using 2006 census data for 500 m radius zones around the residence: the proportion of residents aged at least 15 years who completed university education used as an indicator of neighborhood socioeconomic status, and population density computed as the number of inhabitants per km^2. A previous analysis of RECORD data demonstrated that neighborhood level of education was a much stronger determinant of BP than other neighborhood socioeconomic variables [8].

Statistical analysis

Definition of a neighborhood typology

A two-step approach was used to define the neighborhood typology. In the first step, we selected a number of variables from the original list of neighborhood characteristics. To do so, factor analysis was performed on the variables listed in Table 1 (with the exception of the neighborhood socioeconomic variable which was considered as a potential confounder in multivariable models, and population density which was used to describe the resulting clusters), using a varimax rotation and principal components extraction. A four-factor solution was selected based on Eigenvalues greater than 1. Internal consistency of factors was also examined. We then retained only variables with factor loadings at least 0.75 for subsequent analyses. This allowed us to select variables that contributed the most to the underlying factors. A total of 13 variables were retained (see Table 2) which were then standardized [mean of 0 and standard deviation (SD) of 1].

In the second step, cluster analytic methods were applied to the standardized variables selected in step 1, in order to identify unique neighborhood types for subsequent examination in relation to BP [29]. Hierarchical cluster analysis using Ward's method starts with each multidimensional observation (neighborhood) as a single cluster and then repeatedly merges the next two closest clusters in terms of Euclidian distances between observations until a single, all-encompassing cluster remains [30]. Application of this method results in a neighborhood typology wherein neighborhoods that are substantively comparable on selected characteristics are grouped together even though they are not necessarily geographically adjacent [31–35]. Following assessment of corresponding dendograms, we examined results for $n = 4$ to $n = 7$ clusters, attempting to identify substantively distinct neighborhood types appearing at each separation point. The results presented here with $n = 6$ clusters were those representing the most contrasted neighborhood types with over half of the variation in selected neighborhood variables being accounted for ($R^2 = 0.55$).

Neighborhood typology and blood pressure

Multivariable linear regression was used to examine associations between neighborhood type and SBP and DBP. We used the most dense neighborhood type (highest population density) as the reference category to which we compared the remaining neighborhood types using five indicator variables. Models were adjusted for individual

TABLE 1. Characteristics of the physical, services, and social interactions neighborhood environments considered for the creation of a neighborhood typology

Neighborhood characteristic	Data source	Measurement approach
Domain: Neighborhood physical environment		
Proportion of neighborhood area covered with buildings	Three-dimensional data from IGN on buildings' ground shapes and height in 2008	GIS processing: surface within 500 m radius circular areas
Mean height of buildings in the neighborhood	Three-dimensional data from IGN on buildings' ground shapes and height in 2008	GIS processing: mean building height weighted by each building's ground surface within 500 m radius circular areas
Density of three or more-way street intersections	Data from IGN on street and road network in 2008	GIS processing: count of intersections with at least three ways within 500 m radius circular areas, per area unit (squared km)
Average street block length	Data from IGN on street and road network in 2008	GIS processing: average length of street network segments in m falling within 500 m radius circular areas
Link : node ratio	Data from IGN on street and road network in 2008	GIS processing: number of links (street segments) divided by the number of nodes (intersections) within 500 m radius circular areas
Route directness	Data from IGN on street and road network in 2008	GIS processing: ratio of total length of street network segments falling within 500 m radius circular areas to total straight length of these segments
Highway nearby the residence	Data from IGN on street and road network in 2008	GIS processing: presence of a highway within 250 m of the residence (yes/no)
Road traffic-related pollution (concentration of nitrogen dioxide, $\mu g/m^3$)	Modeled data from AIRPARIF on annual concentrations of nitrogen dioxide in 2007–2008	GIS processing: average concentration within 500 m radius circular areas
Road traffic-related pollution (concentration of particulate matter, mg/m^3)	Modeled data from AIRPARIF on annual concentrations of particulate matter in 2007–2008	GIS processing: average concentration within 500 m radius circular areas
Air traffic exposure	Data on air traffic from ACNUSA in 2005	GIS processing: four category variable based on whether or not airplane traffic passes within 1000, 2000, or 3000 m in altitude above the residence.
Waste treatment facilities	Geocoded waste treatment facilities in 2008, data obtained from IAU-IdF	GIS processing: count of waste treatment facilities within 500 m radius circular area (including incinerators, urban composts, water treatment plants, etc.)
Surface of green spaces	Linear and polygonal data from IAU-IdF on public parks and green spaces in 2008	GIS processing: surface per squared km within 500 m radius circular areas
Presence of lakes or waterways	Polygonal data from IAU-IdF on land use in 2003	GIS processing: binary variable indicating the presence of lakes, rivers, or waterways in 500 m radius circular areas
Neighborhood active living potential	Three items from the RECORD questionnaire	Three-level multilevel ordinal ecometric model (high score = low active living potential)
Deterioration of the physical environment	Four items from the RECORD questionnaire	Three-level multilevel ordinal ecometric model (low scores = low deterioration)
Domain: Neighborhood services environment		
Number of destinations	Geocoded destinations from the 2008 Permanent Database of Facilities of Insee	GIS processing: count of destinations (administrations, public/private shops, entertainment facilities, etc.) within 500 m radius circular areas
Presence of monuments	Geocoded monuments in 2005 from IAU-IdF	GIS processing: count of monuments and other enjoyable sites within 500 m radius circular areas
Number of transportation lines	Geocoded bus stops, subways, and train stations in 2008 from STIF	GIS processing: count of different transportation lines within 500 m radius circular areas
Proportion of incoming and outgoing traffic by public transportation rather than by car	Raw data from a road traffic model obtained from DRE-IdF	GIS processing: proportion of traffic by public transportation in the area
Presence of a commercial center	Geocoded commercial centers in 2008 from IAU-IdF	GIS processing: count of commercial centers within 500 m radius circular areas
Number of hypermarkets	Geocoded hypermarkets in 2008 from the Permanent Database of Facilities of Insee	GIS processing: count of hypermarkets within 500 m radius circular areas
Number of supermarkets	Geocoded supermarkets in 2008 from the Permanent Database of Facilities of Insee	GIS processing: count of supermarkets within 500 m radius circular areas
Number of grocery stores	Geocoded grocery stores in 2008 from the Permanent Database of Facilities of Insee	GIS processing: count of minimarkets and grocery stores within 500 m radius circular areas
Number of shops and stands selling fruits/vegetables (including street markets)	Geocoded fruit and vegetable shops in 2007 from the SIRENE database from Insee	GIS processing: count of fruit and vegetable shops within 500 m radius circular areas
Proportion of fast food restaurants (compared to the total number of restaurants)	Geocoded restaurants in 2007 from the SIRENE database from Insee	GIS processing: ratio between count of fast food restaurants and total count of restaurants within 500 m radius circular areas
Number of sports facilities	Data from the Census of Sport Facilities in 2008 from DRJSCS	GIS processing: count of facilities within 500 m radius circular areas

TABLE 1 (*Continued*)

Neighborhood characteristic	Data source	Measurement approach
Domain: Neighborhood social interactions		
School violence near the residence	School violence in 2005–2006 from the Ministry of Education	Multilevel modeling and GIS processing of violent behaviors occurring in schools located near the residence
Neighborhood social cohesion	Four items from the RECORD questionnaire	Three-level multilevel ordinal ecometric model (low scores = high cohesion)
Neighborhood stressful social interactions	Five items from the RECORD questionnaire	Three-level multilevel ordinal ecometric model (low scores = low stress)
Neighborhood mistrust and hostility	Five items from the RECORD questionnaire	Three-level multilevel ordinal ecometric model (low scores = low mistrust and hostility)
Stigmatized neighborhood identity	Three items from the RECORD questionnaire	Three-level multilevel ordinal ecometric model (low scores = low stigma)
Domain: Neighborhood sociodemographic environment		
Indicator of neighborhood socioeconomic status based on the level of education	Population Census of 2006 geocoded at the residential address by Insee	Aggregation of individual data within 500 m radius circular areas: proportion of residents aged ≥15 years with university education
Neighborhood population density	Population Census of 2006 geocoded at the residential address by Insee	Aggregation of population data within circular areas: number of inhabitants per km^2

ACNUSA, Regulatory Body for Airport Nuisance; AIRPARIF, Air Quality in Paris Ile-de-France Region; DGI, General Directorate of Taxation; DRE-IdF, Regional Directorate of Equipment in Ile-de-France Region; DRJSCS, Regional Directorate for Youth, Sports and Social Cohesion; GIS, Geographic Information System; IAU-IdF, Institute of Urban Planning in Ile-de-France Region; IGN, National Geographic Institute; Insee, National Institute of Statistics and Economic Studies; SIRENE: Information System for the Directory of Businesses and Enterprises; STIF, Transport Union in Ile-de-France Region.

sociodemographic variables, use of antihypertensive medication, and family history of hypertension (model 1), and subsequently for neighborhood level of education (model 2). Lastly, models were adjusted for risk factors for hypertension that are potentially in the causal pathway (mediators) between neighborhood conditions and BP (model 3). In secondary analyses associations between neighborhood type and pulse pressure were examined to support the interpretation of findings for SBP and DBP. Beta coefficients refer to the increase/decrease in mmHg of BP and pulse pressure associated with residing in specific types of neighborhoods in comparison to the most dense neighborhood type. All analyses were conducted with SAS, version 9.2 [36].

RESULTS

Descriptive statistics for the six neighborhood types are presented in Table 2. These neighborhood types correspond to the following: type 1, suburban, low social standing; type 2, suburban, high social standing; type 3, urban, low social standing; type 4, urban, high social standing; type 5, central urban, high social standing; and type 6, central urban, intermediate social standing (reference category). They encompass suburban to central urban neighborhood types based on varying values of population density, land use, road traffic pollution, and available services. They also encompass neighborhoods with lower to higher social standing based on different values on measures of neighborhood social interactions. Appendix Fig. S1, http://links.lww.com/HJH/A175 shows the geographical distribution of participants by neighborhood type.

Characteristics of study participants by neighborhood type are presented in Table 3. Individual level of education was lowest in neighborhood types 1 and 3, and highest in neighborhood types 4–6. Individual unemployment, financial strain, and birth in a low Human Development Index country were more common in type 1 neighborhoods. Individual risk factors for hypertension differed by neighborhood type: residents from type 6 neighborhoods (central urban, intermediate social standing) were more likely to be regular drinkers and smokers, whereas residents from type 1 neighborhoods (suburban, low social standing) were more likely to be obese and have a high resting heart rate. On average, SBP and DBP were higher in the suburban (types 1 and 2) and urban with low social standing (type 3) neighborhoods.

Results from multivariable linear regressions are presented in Tables 4 and 5 for SBP and DBP, respectively. After adjustment for individual sociodemographic variables, SBP was found to be 2 mmHg higher in participants residing in the two suburban neighborhood types [type 1: 1.87, 95% confidence interval (CI) 0.18; 3.56; and type 2: 1.87, 95% CI 0.65; 3.09] and still more elevated in the urban with low social standing neighborhood type (type 3: 3.05, 95% CI 1.72; 4.38), in comparison to the reference category. After adjustment for neighborhood socioeconomic status, these coefficients were generally attenuated but associations remained for type 2 (suburban, high social standing) and type 3 (urban, low social standing) neighborhoods. Moreover, in this model, an association appeared between residing in central urban with high social standing neighborhoods and SBP (type 5: 1.60, 95% CI 0.16; 3.03). After further adjusting for individual risk factors for hypertension, only residence in urban low social standing neighborhoods remained associated with SBP (type 3: 2.11, 95% CI 0.70; 3.52). For DBP, results from models 1 and 2 showed a slightly different pattern of association (Table 5), with evidence of a regular increase in BP with decreasing urbanicity degree of neighborhood types. This pattern remained apparent (even if reduced in magnitude) after adjustment for individual risk factors for hypertension.

TABLE 2. Description of neighborhood types in the RECORD Cohort Study

	Type 1: suburban, low social standing ($n=501$)		Type 2: suburban, high social standing ($n=1616$)		Type 3: urban, low social standing ($n=1098$)		Type 4: urban, high social standing ($n=1978$)		Type 5: central urban, high social standing ($n=844$)		Type 6: central urban, intermediate social standing ($n=1073$)		Fisher's F-test *P* value
	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	
Population density per km^{2}[a]	8 075	2	6 057	1	13 442	3	16 270	4	34 258	5	36 543	6	<0.001
Proportion of neighborhood area covered with buildings (%)	15.3	1	16.1	2	25.6	3	27.5	4	42.1	5	46.8	6	<0.001
Density of intersections per km^2	166.5	4	117.7	1	139.5	2	167.9	5	150.9	3	184.0	6	<0.001
Average street block length (m)	67.9	3	79.0	6	73.6	5	67.9	2	73.1	4	65.5	1	<0.001
Road traffic-related pollution (nitrogen dioxide, $\mu g/m^3$)	25.1	1	28.2	2	40.3	3	41.5	4	46.1	5	51.2	6	<0.001
Road traffic-related pollution (particulate matter, mg/m^3)	25.9	1	27.6	2	30.0	3	30.1	4	30.9	5	31.9	6	<0.001
Deterioration of the physical environment	0.43	4	−1.19	1	0.63	5	−0.73	2	0.17	3	0.99	6	<0.001
Incoming and outgoing traffic by public transportation (%)	34.2	1	42.4	2	48.2	3	54.3	4	69.8	6	68.3	5	<0.001
Number of destinations	62.8	2	50.3	1	115.3	3	227.9	4	589.0	5	774.2	6	<0.001
Number of supermarkets	0.47	2	0.46	1	1.16	3	1.51	4	5.15	5	5.24	6	<0.001
Number of grocery stores	2.8	2	1.7	1	6.2	3	7.1	4	20.8	5	35.7	6	<0.001
Proportion of residents with university education (%)[a]	21.9	1	39.4	3	25.7	2	47.2	5	55.1	6	46.9	4	<0.001
Neighborhood stressful social interactions	0.35	4	−0.74	1	0.54	5	−0.54	2	−0.12	3	0.63	6	<0.001
Neighborhood mistrust and hostility	0.39	6	−0.22	3	0.38	5	−0.30	1	−0.25	2	0.08	4	<0.001
Stigmatized neighborhood identity	0.73	6	−0.49	2	0.68	5	−0.54	1	−0.44	3	0.16	4	<0.001

[a]Variables not used in cluster analysis to define neighborhood types.

TABLE 3. Characteristics of study participants by neighborhood types in the RECORD Cohort Study

	Type 1: suburban, low social standing (*n* = 501)	Type 2: suburban, high social standing (*n* = 1616)	Type 3: urban, low social standing (*n* = 1098)	Type 4: urban, high social standing (*n* = 1978)	Type 5: central urban, high social standing (*n* = 844)	Type 6: central urban, intermediate social standing (*n* = 1073)	Chi^2 *P* value
Age, years, mean (SD)	47.7 (11.3)	51.5 (11.1)	48.7 (11.3)	50.9 (11.7)	52.0 (12.4)	48.6 (11.8)	<0.001*
Sex (men), % (*n*)	60.3 (302)	67.1 (1085)	65.9 (724)	66.2 (1310)	63.9 (539)	65.8 (706)	0.09
Individual education, % (*n*)							
Low	17.1 (84)	6.7 (107)	13.7 (149)	5.2 (102)	3.9 (33)	6.9 (73)	<0.001
Middle-low	37.6 (185)	25.5 (408)	33.6 (366)	20.8 (409)	16.0 (134)	20.2 (215)	
Middle-high	26.8 (132)	32.4 (518)	30.8 (335)	29.2 (575)	25.2 (212)	29.3 (311)	
High	18.5 (91)	35.5 (568)	21.9 (238)	44.8 (882)	54.9 (461)	43.7 (464)	
Employment status, % (*n*)							
Employed	50.5 (253)	57.7 (933)	63.9 (702)	65.3 (1291)	64.5 (544)	62.3 (668)	
Unemployed	25.4 (127)	14.5 (235)	15.6 (171)	11.3 (224)	10.0 (84)	20.7 (222)	<0.001
Retired	12.2 (61)	19.5 (315)	16.3 (179)	18.6 (368)	21.7 (183)	14.4 (154)	
Financial strain, % (*n*)	30.7 (154)	14.8 (239)	24.8 (272)	12.2 (240)	9.4 (79)	17.5 (187)	<0.001
Owner of residence, % (*n*)	37.8 (189)	67.2 (1086)	40.7 (446)	59.2 (1171)	52.9 (446)	49.2 (526)	<0.001
Low Human Development Index of country of birth, % (*n*)	14.2 (71)	4.0 (65)	8.6 (94)	3.3 (65)	1.3 (11)	2.9 (31)	<0.001
SBP (mmHg) mean (SD)	128.5 (17.6)	129.0 (17.1)	129.7 (18.7)	127.7 (17.6)	128.2 (17.1)	125.1 (16.4)	<0.001*
DBP (mmHg) mean (SD)	78.4 (10.9)	77.8 (10.6)	77.4 (10.8)	76.6 (10.7)	76.3 (10.1)	74.9 (10.4)	<0.001*
Antihypertensive medication use, % (*n*)	16.2 (81)	14.1 (227)	10.8 (118)	12.9 (256)	13.4 (113)	9.0 (97)	<0.001
Family history of hypertension, % (*n*)	36.1 (181)	35.7 (577)	33.8 (371)	35.0 (693)	32.5 (274)	32.4 (348)	0.34
Physically active, % (*n*)	45.5 (228)	43.0 (695)	46.5 (510)	41.3 (817)	42.5 (359)	48.9 (525)	<0.001
Alcohol consumption							
Never drinker	26.3 (131)	11.0 (177)	19.0 (208)	10.9 (215)	7.5 (63)	10.8 (115)	<0.001
Former drinker	9.8 (49)	5.2 (84)	7.5 (82)	3.7 (73)	4.5 (38)	5.5 (59)	
Light drinker	57.0 (284)	76.7 (1233)	66.2 (724)	77.5 (1529)	78.8 (662)	73.6 (787)	
Regular drinker	6.8 (34)	7.1 (114)	7.3 (80)	7.9 (156)	9.2 (77)	10.1 (108)	
Smoking status							
Never smoker	59.7 (299)	53.8 (869)	53.5 (587)	49.9 (986)	46.5 (392)	42.9 (460)	<0.001
Former smoker	21.2 (106)	29.2 (471)	22.7 (249)	29.0 (573)	32.7 (276)	28.2 (302)	
Smoker	19.2 (96)	17.1 (276)	23.9 (262)	21.2 (419)	20.9 (176)	29.0 (311)	
BMI							
Normal weight	41.9 (210)	48.2 (779)	44.2 (485)	52.2 (1031)	53.1 (448)	56.2 (602)	<0.001
Overweight	36.3 (182)	39.6 (640)	39.7 (436)	37.1 (733)	37.0 (312)	34.2 (367)	
Obese	21.8 (109)	12.1 (196)	16.1 (177)	10.8 (213)	9.9 (83)	9.6 (103)	
Waist circumference							
Ideal	55.8 (276)	64.4 (1020)	64.8 (700)	69.4 (1342)	68.4 (555)	71.3 (748)	<0.001
High	21.6 (107)	22.1 (350)	21.7 (234)	20.3 (392)	21.3 (173)	19.0 (199)	
Very high	22.6 (112)	13.6 (215)	13.6 (147)	10.4 (201)	10.3 (84)	9.7 (102)	
Resting heart rate							
Low	28.4 (139)	39.4 (630)	35.7 (385)	41.4 (810)	43.6 (366)	42.3 (451)	<0.001
Medium	38.6 (189)	37.3 (597)	40.0 (432)	38.8 (758)	36.0 (302)	39.6 (422)	
High	33.1 (162)	23.3 (372)	24.3 (262)	19.8 (388)	20.4 (171)	18.1 (193)	

*P value for Fisher's F-test.

Finally, as shown in Appendix Table S1, http://links.lww.com/HJH/A175, analyses for pulse pressure were coherent with patterns observed for SBP and DBP. Even after adjustment for individual/neighborhood socioeconomic status and individual risk factors for hypertension, we found that pulse pressure was higher in urban low social standing neighborhoods (where SBP was found to be higher), whereas pulse pressure was lower in suburban neighborhoods (where DBP was found to be higher).

DISCUSSION

The present study suggests that combined exposure to a number of conditions related to the physical features, available services, and social interactions of residential neighborhood environments is associated with SBP and DBP, after adjustment for individual and neighborhood socioeconomic conditions, and individual risk factors for hypertension. Specifically, residence in urban areas with low social standing remained associated with higher SBP, whereas residence in suburban and urban (vs. central urban) areas was associated with higher DBP, regardless of social standing.

To our knowledge, this is the first study that used neighborhood clustering techniques to study associations between features of the neighborhood environment and BP. Cluster analysis allowed us to construct a typology and examine the combined exposure to multiple environmental characteristics that are highly correlated and whose effects could not be separated through multivariable regression analysis [29,37]. By regrouping similar neighborhoods based on a multidimensional profile it is possible to

TABLE 4. Beta coefficients and 95% confidence intervals for SBP in the RECORD Cohort Study from multivariable linear regression models (variables in the same column are simultaneously introduced into the model)

	Model 1: adjusted $R^2 = 0.20$		Model 2: adjusted $R^2 = 0.21$		Model 3: adjusted $R^2 = 0.28$	
	Beta	95% CI	Beta	95% CI	Beta	95% CI
Neighborhood type (vs. type 6: central urban, intermediate social standing)						
Type 1: suburban, low social standing	1.87	(0.18; 3.56)	1.00	(−0.85; 2.85)	0.03	(−1.74; 1.79)
Type 2: suburban, high social standing	1.87	(0.65; 3.09)	1.57	(0.33; 2.82)	1.17	(−0.02; 2.36)
Type 3: urban, low social standing	3.05	(1.72; 4.38)	2.30	(0.81; 3.78)	2.11	(0.70; 3.52)
Type 4: urban, high social standing	1.07	(−0.09; 2.24)	1.06	(−0.10; 2.23)	0.90	(−0.21; 2.00)
Type 5: central urban, high social standing	1.32	(−0.09; 2.74)	1.60	(0.16; 3.03)	1.25	(−0.11; 2.62)
Age (1-year increase)	0.48	(0.44; 0.52)	0.49	(0.44; 0.53)	0.41	(0.37; 0.45)
Male (vs. female)	5.35	(4.56; 6.15)	5.35	(4.55; 6.14)	5.21	(4.41; 6.00)
Individual education (vs. high)						
Low	3.59	(2.08; 5.11)	3.26	(1.71; 4.80)	2.37	(0.88; 3.86)
Middle-low	3.11	(2.11; 4.11)	2.82	(1.78; 3.89)	2.07	(1.08; 3.06)
Middle-high	1.19	(0.27; 2.10)	1.04	(0.11; 1.96)	0.79	(−0.09; 1.67)
Low Human Development Index of country of birth (vs. medium or high)	4.84	(3.08; 6.60)	4.70	(2.94; 6.46)	4.04	(2.35; 5.72)
Employment status (vs. employed)						
Unemployed	−2.12	(−3.18; −1.06)	−2.14	(−3.20; −1.08)	−1.95	(−2.97; −0.93)
Retired	0.41	(−0.90; 1.72)	0.41	(−0.91; 1.72)	0.51	(−0.75; 1.77)
Nonownership of residence (vs. owner)	2.13	(1.31; 2.95)	2.07	(1.25; 2.89)	1.37	(0.58; 2.16)
Antihypertensive medication use	8.58	(7.40; 9.77)	8.54	(7.35; 9.72)	6.48	(5.34; 7.63)
Family history of hypertension	3.08	(2.30; 3.87)	3.06	(2.27; 3.84)	2.80	(2.05; 3.54)
Percentage residents with university education			−3.94	(−7.39; −0.49)	−0.89	(−4.19; 2.41)
Physically active					0.70	(−0.01; 1.40)
Smoking (vs. never smoker)						
Former smoker					−1.57	(−2.42; −0.72)
Smoker					−1.85	(−2.79; −0.91)
Alcohol consumption (vs. never drinker)						
Former drinker					1.50	(−0.30; 3.29)
Light drinker					2.98	(1.86; 4.10)
Regular drinker					7.47	(5.82; 9.13)
Waist circumference (vs. ideal)						
High					1.18	(0.17; 2.19)
Very high					2.30	(0.72; 3.87)
BMI (vs. normal)						
Overweight					3.59	(2.73; 4.46)
Obese					8.06	(6.46; 9.67)
Resting heart rate (vs. low)						
Medium					3.79	(2.99; 4.58)
High					8.34	(7.40; 9.29)

examine the impact of a constellation of neighborhood environment features that may jointly rather than individually influence health and health behaviors [38].

Additional strengths of this study include the large sample size and study territory allowing comparison of diverse neighborhoods, as well as the range of variables available to precisely characterize neighborhoods. Limitations include the cross-sectional nature of the study design making it impossible to determine the directionality of associations. Additionally, it was demonstrated that the absence of *a priori* sampling in the recruitment of participants led to selective participation of individuals with certain neighborhood profiles, and a similar health-related selection cannot be discounted [22]. Thus, if participation is related to both neighborhood exposures and BP levels (or related health conditions) selection bias may result in under or overestimation of associations. Lastly, whereas BP measured in the supine position may influence interpretation of mean BP levels, it does not interfere with interpretation of measures of associations since a standardized protocol was followed for BP measurement in all study participants.

Previous studies have reported that residents from more walkable neighborhoods, characterized by high land use mix, street connectivity and the presence of destinations to walk have lower BP levels [14,15]. Similarly, lower neighborhood population density has been associated with higher BP [39]. These findings are in line with our results showing that residents of suburban and urban neighborhoods had higher BP (especially higher DBP) compared to residents of central urban neighborhoods. The latter are characterized by a large number of destinations, a higher density of street intersections, and shorter street block lengths, and may be related to lower BP levels through their positive effect on regular walking [40]. Interestingly, the distribution of risk factors for hypertension differed according to neighborhood type, with a concentration of regular alcohol consumption and smoking in denser neighborhoods, and a concentration of obesity in more sparsely populated neighborhoods.

TABLE 5. Beta coefficients and 95% confidence intervals for DBP in the RECORD Cohort Study from multivariable linear regression models (all variables in the same column are simultaneously introduced into the model)

	Model 1 (adjusted $R^2=0.13$)		Model 2 (adjusted $R^2=0.13$)		Model 3 (adjusted $R^2=0.26$)	
	Beta	95% CI	Beta	95% CI	Beta	95% CI
Neighborhood type (vs. type 6: central urban, intermediate social standing)						
Type 1: suburban, low social standing	2.61	(1.54; 3.68)	2.04	(0.87; 3.22)	1.27	(0.18; 2.36)
Type 2: suburban, high social standing	1.93	(1.16; 2.71)	1.74	(0.95; 2.53)	1.41	(0.67; 2.15)
Type 3: urban, low social standing	1.72	(0.88; 2.57)	1.23	(0.29; 2.17)	1.06	(0.19; 1.94)
Type 4: urban, high social standing	1.03	(0.29; 1.77)	1.03	(0.29; 1.77)	0.86	(0.17; 1.54)
Type 5: central urban, high social standing	0.75	(−0.15; 1.65)	0.93	(0.02; 1.84)	0.66	(−0.19; 1.50)
Age (1-year increase)	0.26	(0.23; 0.29)	0.26	(0.24; 0.29)	0.22	(0.19; 0.25)
Male (vs. female)	4.34	(3.84; 4.85)	4.34	(3.83; 4.84)	4.14	(3.65; 4.63)
Individual education (vs. high)						
Low	1.81	(0.84; 2.78)	1.60	(0.61; 2.58)	0.97	(0.05; 1.89)
Middle-low	1.58	(0.93; 2.22)	1.39	(0.73; 2.05)	0.91	(0.29; 1.53)
Middle-high	0.72	(0.14; 1.30)	0.63	(0.04; 1.21)	0.37	(−0.18; 0.91)
Low Human Development Index of country of birth (vs. medium or high)	3.43	(2.30; 4.55)	3.34	(2.22; 4.47)	3.11	(2.07; 4.16)
Employment status (vs. employed)						
Unemployed	−0.92	(−1.60; −0.24)	−0.93	(−1.61; −0.24)	−0.83	(−1.46; −0.19)
Retired	−3.23	(−4.07; −2.40)	−3.24	(−4.07; −2.40)	−2.94	(−3.71; −2.16)
Nonownership of residence (vs. owner)	0.82	(0.29; 1.35)	0.79	(0.26; 1.32)	0.30	(−0.20; 0.79)
Financial strain	0.80	(0.11; 1.48)	0.76	(0.07; 1.44)	0.30	(−0.34; 0.94)
Antihypertensive medication use	4.02	(3.27; 4.77)	3.99	(3.24; 4.74)	2.72	(2.01; 3.42)
Family history of hypertension	1.74	(1.24; 2.24)	1.73	(1.23; 2.23)	1.50	(1.04; 1.96)
Percentage residents with university education			−2.59	(−4.78; −0.39)	−0.40	(−2.44; 1.65)
Physically active					0.16	(−0.27; 0.60)
Smoking (vs. never smoker)						
Former smoker					−0.19	(−0.72; 0.34)
Smoker					−0.71	(−1.29; −0.13)
Alcohol consumption (vs. never drinker)						
Former drinker					0.76	(−0.35; 1.86)
Light drinker					1.62	(0.93; 2.31)
Regular drinker					4.83	(3.81; 5.85)
Waist circumference (vs. ideal)						
High					0.46	(−0.16; 1.09)
Very high					0.95	(−0.03; 1.92)
BMI (vs. normal)						
Overweight					2.65	(2.12; 3.18)
Obese					4.99	(3.99; 5.98)
Resting heart rate (vs. low)						
Medium					3.80	(3.31; 4.29)
High					7.80	(7.22; 8.39)

Past studies also identified relationships between neighborhood socioeconomic conditions and BP, independently of individual socioeconomic status [3–9]. Previous work based on the RECORD Study comparing neighborhoods on the basis of three socioeconomic indicators showed that neighborhood education was more particularly associated with SBP [8]. However, other dimensions of neighborhood environments had not been examined. Interestingly, in the current study the combined exposure to areas characterized both as urban (with a lower density of services than in central urban areas) and as having deteriorated social interactions was found to be related to the greatest increase in SBP, even after adjustment for individual and neighborhood confounders. This suggests that SBP was particularly elevated in neighborhoods with adverse social interaction patterns, independently of neighborhood socioeconomic status.

One hypothesis from the literature is that stressors experienced within the neighborhood environment in relation to social relationships relate to hypertension [41]. Our findings of a relationship between poor urban neighborhoods with stressful social interactions and SBP supports this hypothesis to some extent, even if our data do not demonstrate direct effects of neighborhood social interaction stressors with BP.

Interestingly, patterns of associations were rather different for DBP, for which higher values were linked with decreasing urbanicity degree (captured by the neighborhood typology). Lower neighborhood socioeconomic status was related to higher DBP but (contrary to SBP) the association disappeared after controlling for individual risk factors for hypertension, whereas the association with urbanicity persisted.

As ‘distal’ exposures, features of the neighborhood environments are likely to have effects on BP that are mediated by more proximal behavioral risk factors such as physical activity and diet or related clinical risk factors such as obesity [8,39,42]. In our study, after adjustment for a number of individual risk factors for hypertension, associations between neighborhood type and SBP and DBP were attenuated but did not disappear entirely. However, this reduction in effect size does not imply that neighborhoods have little effect on BP, but that their effects partly operate through individual-level risk factors. Obesity explained most of the association between neighborhood factors and BP given that half the variance in SBP explained by individual-level risk factors was accounted for by BMI and waist circumference alone. The study therefore suggests that interventions targeting neighborhood environments to increase the potential for healthy lifestyles may have substantial health benefits, including improvement in BP levels. Specifically, such interventions may have important impacts at the population level, even though individual-level effects appear relatively small [43].

In this study, using cluster analysis in combination with regression analysis, we were able to examine associations between BP and a constellation of characteristics pertaining to the physical, services, and social interactions neighborhood environments while adequately controlling for potential confounders and examining the role of potential mediators. Although it is premature to formulate definite public health implications from our results, two recommendations can be made: efforts to reduce hypertension in the population should incorporate policies to transform the physical, services, and social interactions neighborhood environments; and strategies should be crafted so as to account for the complexity of neighborhood environments which are composed of a variety of factors that interact in complex ways to influence cardiovascular disease risk factors. Specifically, this study allowed us to identify neighborhood types that are associated with higher or lower BP. Based on this neighborhood profiling of risk, population-level interventions to reduce hypertension that are targeted towards or tailored according to specific neighborhood types show promise.

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Conflicts of interest

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Reviewers' Summary Evaluations

Reviewer 1

The aim of the study was to examine the influence of neighborhood environments and blood pressure values. The Authors' conclusion is that an inverse association between diastolic blood pressure values and level of urbanicity of the neighborhood is present even after adjustment for individual risk factors for hypertension. The result, although expected, is interesting. The strengths of the present study are the precise characterization of neighborhoods and the large number of subjects evaluated (7290). A possible weakness is related to the complexity of the presentation, including detailed tables, making the manuscript a bit demanding for the average reader.

Reviewer 2

The study provides insight in the impact of physical environment, services, social interactions and demographic data in one of the most important CV risk factors, high BP. The lower the urbanicity the higher the DBP. The study has considered the potential impact of some confounders, such as country of origin, race and socio-economic status. Although a causal relationship cannot be inferred from this study, it calls for attention from public authorities about the health consequences of daily living conditions.