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Residential environment and blood pressure in the PRIME Study: is the association mediated by body mass index and waist circumference?

Basile Chaix^{a,b}, Pierre Ducimetière^c, Thierry Lang^d, Bernadette Haas^e, Michèle Montaye^{f,g,h}, Jean-Bernard Ruidavets^d, Dominique Arveiler^e, Philippe Amouyel^{f,g,h}, Jean Ferrières^d, Annie Bingham^c and Pierre Chauvin^{a,i}

Objectives Few studies have examined whether social characteristics of the residential environment are associated with blood pressure after controlling for individual sociodemographic characteristics. Even less is known about the processes by which these associations operate. Therefore, we examined whether distinct dimensions of the residential environment (socioeconomic position and urbanicity) were associated with systolic blood pressure. To better understand the processes involved in the associations between contextual factors and blood pressure, we assessed the extent to which these associations were mediated by body mass index and waist circumference.

Methods We analysed data from the PRIME Study (7850, 50–60-year-old men surveyed in 1991–1993 in three French regions and recently geocoded on a local scale). We used multilevel regression models to estimate associations between contextual factors and blood pressure, and path analysis to investigate possible mediators of these associations.

Results After adjustment for individual socioeconomic variables, systolic blood pressure increased independently with decreasing municipality population density and decreasing neighbourhood educational level. Path analysis indicated that approximately 37% of the association between neighbourhood education and blood pressure was statistically explained by the heavier weight and stronger

central adiposity of people from deprived neighbourhoods. Approximately 19% of the association with population density was mediated by anthropometric factors.

Conclusions These data suggest that the neighbourhood environment may influence blood pressure; only part of the associations between contextual factors and blood pressure may operate through body weight and body shape modification. *J Hypertens* 26:1078–1084 © 2008 Wolters Kluwer Health | Lippincott Williams & Wilkins.

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Keywords: blood pressure, residence characteristics, social environment, socioeconomic factors, urbanization

Abbreviation: SD, standard deviation

^aInserm U707, Research Team on Social Determinants of Health and Healthcare, ^bUniversité Pierre et Marie Curie-Paris6, UMR-S 707, Paris, ^cInserm U780, Villejuif, ^dInserm U558 and Toulouse University School of Medicine, Toulouse, ^eLouis Pasteur University, Faculty of Medicine, EA 1801-Department of Epidemiology and Public Health, Strasbourg, ^fInserm U744, Public Health and Molecular Epidemiology of Aging-Related Diseases, Lille, ^gInstitut Pasteur de Lille, ^hUniversité de Lille 2, UMR-S 744, Lille and ⁱAP-HP, Saint-Antoine Hospital, Public Health Unit, Paris, France

Correspondence to Basile Chaix, Inserm UMR-S 707, Faculté de Médecine Saint-Antoine, 27 rue Chaligny, 75012 Paris, France
Tel: +33 1 44 73 86 64; fax: +33 1 44 73 86 63; e-mail: chaix@u707.jussieu.fr

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Introduction

As living conditions are shaped by the characteristics of the residential environment, an increasing number of studies have started to investigate the impact the neighbourhood environment [1–4] may have on blood pressure, beyond effects of individuals' characteristics. Assessing neighbourhood determinants of high blood pressure is relevant from both an etiological viewpoint and a public health perspective.

Excluding studies based on a questionnaire assessment of hypertension [5,6] and those that did not control for

individual socioeconomic variables [7–16], some studies have investigated associations between characteristics of the residential environment and blood pressure. Environmental characteristics considered in those studies pertain to the neighbourhood socioeconomic context [2,17–23], the urbanicity level of the residential area [24], road and air traffic, air and noise pollution [25–28], and the type of local food stores in the vicinity [29].

In the present study, we followed two complementary strategies to extend our understanding of the processes involved in the context–blood pressure associations.

First, we examined whether distinct dimensions of the residential environment that differently shape living conditions of individuals (i.e., neighbourhood socioeconomic position and urbanicity) were associated with blood pressure, after controlling for individual sociodemographic characteristics. Second, using path analysis [30], we examined whether associations between contextual factors and blood pressure were statistically explained by general obesity and central adiposity. As the present study is the first to investigate mediators between the environment and blood pressure, we only tested a parsimonious mediation model. Even if other risk factors may intervene (physical inactivity, alcohol consumption, smoking, etc.), only body mass index and waist circumference were investigated as potential mediators, as obesity is linked to neighbourhood characteristics [31] and is known as one of the major determinants of blood pressure [32,33].

Some authors have argued that the association between neighbourhood social deprivation and blood pressure may be due to cardiovascular reactivity to stress accumulated over a large number of stressful events [8,21]. Showing that associations between neighbourhood social characteristics and blood pressure are mediated to a certain extent by general obesity and body fat distribution would suggest an alternative or complementary hypothesis, providing valuable clues on the environmental causes of high blood pressure.

Methods

Data sources

The PRIME Study is a cohort study focused on coronary heart disease. The cohort was recruited between 1991 and 1993 in three centres in France (Lille in the north, Bas-Rhin in the east and Haute-Garonne in the south-west) and one region in Northern Ireland (Belfast) [34,35]. In each centre, the sample was composed of about 2600 men aged 50–59 years recruited to match the occupational structure of the background population [35]. The recruitment frame was based on industry, various employment groups, health screening centres and general practices. Subjects were informed of the aim of the study and agreed to participate in a comprehensive health examination and blood testing [35]. Approval from the appropriate local Ethical Committee was obtained in each centre.

Self-administered questionnaires related to demographic, socioeconomic, and lifestyle factors were completed at home by the participants and checked by the technician with the subject at the clinic. Data on education and occupation were directly collected by the technician. During the examination, anthropometric measurements were taken including height and weight without shoes and hip and waist circumferences. As reported in detail previously [35], blood pressure was

measured in a quiet room in the sitting position with the right arm on a desk at the heart level after a 5-min rest using an automatic sphygmomanometer (Spengler SP9; Springler, Cachan, France). A standard cuff size was used, but a large cuff was employed if necessary.

The Irish sample was not considered in the present analysis to avoid heterogeneity in the neighbourhood exposures (significant differences exist between France and Ireland in population census years, the census variables, their definition, and the sizes and administrative functions of geographical subdivisions). Thus, the present study used the cross-sectional data of the three French population samples. After excluding 12 individuals with missing value for systolic blood pressure, there were 7838 participants in the database.

Measures

Systolic blood pressure, body mass index and waist circumference were considered as continuous variables. Questionnaire data allowed us to define the following individual variables: age, antihypertensive medication (yes or no), French citizenship (yes or no), marital status (married/cohabiting or not), number of school years (0–12, ≥ 13), employment status (employed, unemployed, other), occupation (high white-collar worker, intermediate occupation, low white-collar worker, blue-collar worker, nonsalaried worker), housing tenure (ownership or renting), and a proxy for material wealth of the household. To determine the latter variable, we adjusted the reported number of cars, number of toilets in the dwelling and number of baths for household size by means of three separate Poisson regression models. We extracted the residuals of each model, standardized them, summed them for each individual to form the indicator, and divided the resulting variable into three categories using the tertiles of the distribution.

Previous analyses of the PRIME Study data [35–37] put the emphasis on regional and national differences in the incidence of coronary heart disease and the prevalence of its risk factors. To investigate spatial variability on a more local scale, we recently used the postal addresses of the French participants in 1991–1993 to precisely geocode them. Eighty-eight percent of the participants were geocoded at the street number or street level, or at the block level or block-group level (groupings of blocks with homogeneous forms of habitat). The others, that is, 12% participants living in small municipalities not divided into blocks (municipality population < 5000) and the remaining 0.4% who could not be geocoded at the block-group level, were georeferenced at the municipality level. The median number of inhabitants in the 1387 areas represented in our dataset (block groups or small municipalities), thereafter denominated neighbourhoods, was 1954 (interquartile range: 1033–2583; interdecile range: 433–3465). Participants were also

considered at the municipality level (663 municipalities in our dataset).

We used the 1990 French population census to define area characteristics. Socioeconomic position and urbanicity were the two clearly distinct contextual dimensions that were considered. Area socioeconomic position was expressed as the proportion of inhabitants with a university degree or equivalent. Following consensus that socioeconomic environment should be considered on a very local scale [1–4], area socioeconomic position was defined at the neighbourhood level. Urbanicity was expressed as population density (number of inhabitants per square kilometre). As differentiation between the urban and the perurban environments takes place on a broader scale than that of the neighbourhood, population density was measured at the municipality level. Contextual variables were divided into four categories containing an equal number of participants.

Statistical analysis

The small number of participants per neighbourhood (median = 4; interquartile range: 2–8) did not allow us to reliably assess intra-neighbourhood correlation in systolic blood pressure [38,39]. Nevertheless, we used a multilevel linear regression model with systolic blood pressure as the outcome, including a random effect defined at the neighbourhood level for a more accurate estimation of the parameter variances. The model was systematically adjusted for the recruiting centre and antihypertensive medication use or not, and in a final step for individual sociodemographic covariates. We estimated associations between the two contextual variables each divided into four categories and blood pressure, first by including three dummy variables into the model and then by entering a variable coded from 1 to 4 as a test of linear trend.

Finally, using Mplus 4.2. [40], we estimated a path analysis model [30] to assess whether body mass index and waist circumference mediated any part of the associations between contextual factors and blood pressure. This model, adjusted for individual sociodemographic variables, considered contextual factors as ordinal variables coded from 1 to 4. We specified both a direct effect of contextual variables on blood pressure and an indirect effect of contextual variables on blood pressure mediated by body mass index and waist circumference. It allowed us to approximately assess the proportion of the associations between contextual factors and blood pressure that was statistically explained by obesity [30]; this proportion was cautiously interpreted as it would be biased in case of major confounding of the obesity–blood pressure association [41].

Results

As shown in Table 1, the mean systolic blood pressure was 134 mmHg (interquartile range: 120–144). Thirty-

Table 1 Descriptive data for the main variables, PRIME Study, 1991–1993, *n* = 7838

Age [mean (SD)]	54.9 [2.9]
Systolic blood pressure in mmHg [mean (SD)]	134 [18]
Diastolic blood pressure in mmHg [mean (SD)]	84 [12]
Antihypertensive medication (%)	14.3
Body mass index [mean (SD)]	26.7 [3.5]
Obese individuals (%)	15.6%
Waist circumference in cm [mean (SD)]	95.9 [10.0]
Non-French citizens (%)	4.7
Living alone (%)	12.3
Number of school years [mean (SD)]	11.4 [3.8]
High white-collar workers (%)	24.9
Blue-collar workers (%)	27.6
Unemployed (% in active population)	7.9
Municipality population density [mean number of inhabitants/km ² (SD)]	2119 [1936]
Proportion with a university degree in the neighbourhood [% , mean (SD)]	6.4 [5.3]

SD, standard deviation.

four percent of the participants had a systolic blood pressure equal to or greater than 140 mmHg. Overall, 14% received antihypertensive medication. About 16% of the participants were obese (body mass index >30 kg/m²).

As shown in Table 2, we first estimated a multilevel model for each of the two contextual variables. These models were adjusted for study centre and antihypertensive medication use (but not for the other individual variables). We found that systolic blood pressure monotonously increased with decreasing population density of the municipality. We also noted a strong and monotonous increase in blood pressure with decreasing educational level of the neighbourhood.

The correlation between neighbourhood education and municipality population density considered at the individual level was equal to 0.22 (95% confidence interval: 0.20–0.24), and judged not to be too high to disentangle their predictive role. The two contextual factors were then introduced simultaneously in a model also adjusted

Table 2 Associations between contextual factors and systolic blood pressure, adjusted for study centre and antihypertensive medication use, PRIME Study, 1991–1993, *n* = 7838

	Coefficient	95% CI
Model 1		
Municipality population density (vs. high)		
Mid-high	+0.7	–0.5, +1.9
Mid-low	+1.5	+0.4, +2.6
Low	+2.5	+1.3, +3.6
Trend test		<i>P</i> < 0.001
Model 2		
Neighbourhood educational level (vs. high)		
Mid-high	+1.1	+0.1, +2.2
Mid-low	+1.4	+0.4, +2.5
Low	+3.3	+2.2, +4.4
Trend test		<i>P</i> < 0.001

The coefficients represent adjusted differences in mean blood pressure in mmHg, relative to the reference category. CI, confidence intervals. The two contextual factors were included separately in models 1 and 2. Cutoffs to categorize the contextual variables were 350, 1600, and 3200 inhabitants per km² for population density and 3, 5, and 9% for the neighbourhood percentage with a university degree.

Table 3 Associations between individual and contextual factors and blood pressure, from a multilevel model including individual and contextual variables simultaneously, PRIME Study, 1991–1993, *n* = 7838

	Coefficient	95% CI
Study centre (vs. Toulouse)		
Lille	+12.0	+10.9, +13.2
Strasbourg	+8.4	+7.4, +9.5
Individual factors		
Age (5-year increase)	+2.7	+2.0, +3.4
Antihypertensive medication	+15.1	+14.0, +16.1
Non-French vs. French citizenship	−1.7	−3.4, +0.1
Alone vs. married/cohabiting	+0.2	−1.0, +1.4
Low number of school years	+1.6	+0.6, +2.5
Occupation (vs. high white-collar worker)		
Nonsalaried worker	+0.3	−1.4, +2.1
Intermediate occupation	+1.2	+0.1, +2.3
Low white-collar worker	+1.4	−0.1, +2.8
Blue-collar worker	+2.4	+1.2, +3.7
Unemployed vs. employed	+0.8	−0.6, +2.2
Material wealth (vs. high level)		
Medium level	+0.8	−0.2, +1.7
Low level	+1.4	+0.4, +2.4
Trend test		<i>P</i> = 0.007
Renting dwelling vs. ownership	−0.8	−1.8, −0.3
Contextual factors		
Municipality population density (vs. high)		
Mid-high	+0.5	−0.9, +1.3
Mid-low	+1.3	+0.1, +2.5
Low	+1.9	+0.6, +3.2
Trend test		<i>P</i> = 0.002
Neighbourhood educational level (vs. high)		
Mid-high	+0.2	−0.9, +1.3
Mid-low	+0.1	−1.0, +1.2
Low	+1.5	+0.3, +2.7
Trend test		<i>P</i> = 0.025

The coefficients represent adjusted differences in mean blood pressure in mmHg, relative to the reference category. CI, confidence interval.

for all individual sociodemographic variables. As shown in Table 3, a higher blood pressure was observed among older and low-educated persons. After adjustment for other individual variables, dose–response associations indicated a monotonous increase of blood pressure with decreasing occupational status and decreasing level of material wealth.

The associations between municipality population density and neighbourhood education on one hand and blood pressure on the other were reduced after mutual adjustment and adjustment for individual sociodemographic characteristics. Despite that, residing in a low-population-density municipality and in a low-education neighbourhood remained a significant predictor of a higher systolic blood pressure. Tests for linear trends confirmed that blood pressure increased with decreasing municipality population density and decreasing neighbourhood education.

Our final objective was to assess whether these associations between area factors and blood pressure were mediated by body mass index and waist circumference. The path analysis model estimated is depicted in Fig. 1 (model adjusted for individual variables). In this model,

both a high neighbourhood educational level and a high municipality population density were associated with a lower body mass index and a smaller waist circumference. Therefore, the associations between the two contextual factors and body mass index and waist circumference were in the same direction as the associations between the contextual variables and blood pressure. As such, the two anthropometric variables, as strong predictors of blood pressure, constitute potential mediators of associations between contextual factors and blood pressure. As shown in Fig. 1, the indirect effects of both municipality population density and neighbourhood education (through body mass index and waist circumference) were statistically significant. After taking those indirect effects into account, the direct (residual) effect of municipality population density on blood pressure remained statistically significant, but that of neighbourhood education did not. We found that approximately 37% of the association between neighbourhood education and blood pressure was statistically explained by body mass index and waist circumference as opposed to only approximately 19% of the association between municipality population density and blood pressure.

Discussion

The present study suggests that characteristics of the residential environment were associated with blood pressure, besides effects of individual socioeconomic variables. The strength of the present study includes the attempt to disentangle the predictive role of two clearly distinct dimensions of the residential environment and our quantification of the extent to which anthropometric parameters mediated associations between contextual factors and blood pressure. Limitations of the present work include the cross-sectional design of our observational study, the absence of repeated measurements of blood pressure over time, and the fact that we could only assess general characteristics of the environment rather than specific features that may be relevant to blood pressure (sport amenities [42], food environment [43], healthcare resources, etc.). Also, our findings should not be generalized to other populations.

Coherently with a previous study from the WHO MONICA Project [44], large differences in blood pressure were observed between study centres. Disparities were also found for body mass index and waist circumference: +0.9 kg/m² (95% confidence interval: 0.7–1.1) and +3.7 cm of waist circumference (95% confidence interval: 3.1–4.2) in Strasbourg than in Toulouse after adjustment for individual sociodemographic characteristics. It is not clear whether between-centre disparities in blood pressure are attributable to true differences between regions, a different recruitment frame in the three centres and/or residual differences in the measurement process (relationship with survey technicians,

Fig. 1

Graphical display of the path analysis model. The three regression equations with body mass index, waist circumference and blood pressure as the outcomes are adjusted for all the individual sociodemographic covariates (not reported in the figure). The equation for blood pressure is also adjusted for body mass index and waist circumference. Note: coefficients of associations with body mass index are in kg/m^2 , with waist circumference in cm, and with systolic blood pressure in mmHg. As shown at the bottom of the figure, the product of the coefficients along a compound path reflects the weight of that path. 95% CI indicates 95% confidence interval.

quietness of the room, etc.). Accordingly, analyses were systematically adjusted for study centre.

Another reason to control for study centre was our aim to extend previous PRIME studies [35–37] that focused on regional differences in risk factors by investigating spatial variability in blood pressure on the more local scale of the neighbourhoods. There are differences between study centres in municipality population density and neighbourhood educational level (Lille has a higher population density, and Toulouse a higher neighbourhood educational level, $P < 0.001$, Kruskal–Wallis test); despite that, there is a substantial overlap in the distributions of contextual factors between the three centres. Adjusting for study centre allowed us to remove the large blood pressure differences observed on the broad regional scale and assess whether local differences in neighbourhood characteristics within each centre had an additional impact on blood pressure.

As in previous studies [2,19], an independent association was found between neighbourhood socioeconomic position and systolic blood pressure. Our strategy to better understand this association was to assess the mediating role of general obesity and central adiposity, as they may be in the pathway between residential environment and blood pressure.

A path analysis model indicated that the association between neighbourhood education and blood pressure was partly mediated by anthropometric variables, that is, by the more important body mass index and central adiposity of people from deprived neighbourhoods. This finding is in accordance with the fact that the obesity risk increases with deprivation level of the neighbourhood (beyond effects of individual socioeconomic variables) [45] and with the major effect of obesity on blood pressure [33]. It provides relevant clues for future etiological research, suggesting that environmental factors relevant to obesity (food environment [43], pedestrian environment and sport facilities [42], neighbourhood social interactions [46], etc.) may play a role in the genesis of blood pressure differences between affluent and deprived neighbourhoods. However, our study does not exclude that other factors (behaviour such as smoking or alcohol consumption, stressful life events [8,21], etc.) also contribute to the association between neighbourhood socioeconomic position and blood pressure.

Regarding urban–rural differences, most studies (all of them conducted in nonindustrialized countries [12–15, 24]) have reported a higher blood pressure in urban areas; however, two studies did not note any urban–rural difference [47,48] and three [10,11,16] found a higher blood pressure in low population density territories. Population

density must be understood as antecedent to a set of more proximate risk factors, and its relation to blood pressure may vary from positive to negative in different settings depending on the specific distribution of risk factors across the population density gradient [49]. The urban–rural difference in blood pressure in non-industrialized countries is not comparable with the urban–periurban contrast considered in our study. The former has been extensively investigated, but the latter has received almost no attention.

The association between population density and blood pressure persisted after adjustment for the anthropometric variables (obesity explained a weaker share of the association with population density than of the association with neighbourhood education). Among other factors, differences in access to care may contribute to this association.

As no previous study explored the mediators between the environment and blood pressure, we found it necessary to start with a parsimonious mediation model, selecting obesity as a candidate mediator because of its major influence on blood pressure [32,33] and demonstrated association with residential environment factors [31]. An extension of our model may be to take into account, in addition to obesity, health behaviour such as physical activity, alcohol consumption or smoking. However, longitudinal data on health behaviour and clinical risk factors and a more complex sequential path analysis model (e.g., environment → physical activity → obesity → hypertension) would be needed to test these relationships.

In summary, our finding that associations between area factors and blood pressure were only partially mediated by obesity does not allow us to draw conclusions on the processes involved in these associations; however, it gives preliminary clues for future research on the environmental causes of blood pressure. Public health strategies to reduce blood pressure disparities between neighbourhoods may need to include transformations of the food landscape, environment for physical activity, and social milieu, and additional individual-based assistance for people for whom the residential environment constitutes an obstacle to behaviour change.

The PRIME Study Group

The PRIME Study is organized under an agreement between Inserm and the Merck, Sharpe and Dohme-Chibret Laboratory, with the following participating laboratories:

- The Strasbourg MONICA Project, Department of Epidemiology and Public Health – EA1801, Université Louis Pasteur, Faculté de Médecine, Strasbourg, France (D. Arveiler, B. Haas).
- The Toulouse MONICA Project, Inserm, U558; Department of Epidemiology, Université Paul Sabatier – Toulouse Purpan, Toulouse, France (J. Ferrières, J.-B. Ruidavets).
- The Lille MONICA Project, Inserm, U744, Lille; Institut Pasteur de Lille, Lille; Université de Lille 2, Lille, France (P. Amouyel, M. Montaye).
- The Department of Epidemiology and Public Health, Queen's University, Belfast, Northern Ireland (A. Evans, J. Yarnell, F. Kee).
- The Department of Atherosclerosis, Inserm, U545, Lille; Institut Pasteur de Lille, Lille; Université de Lille 2, Lille, France (G. Luc, J.-M. Bard).
- The Laboratory of Haematology, Inserm, U626, Marseille, Hôpital La Timone, Marseille, France (I. Juhan-Vague, P. Morange).
- The Laboratory of Endocrinology, Inserm U563, Toulouse, France (B. Perret).
- The Vitamin Research Unit, The University of Bern, Bern, Switzerland (F. Gey).
- The Nutrition and Metabolism Group, Centre for Clinical and Population Sciences, Queen's University Belfast, Northern Ireland (J. Woodside, I. Young).
- The DNA Bank, Inserm U525, Paris, France (F. Cambien).
- The Coordinating Centre, Inserm, U780, Villejuif, France (P. Ducimetière, A. Bingham).

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