doi: 10.1111/j.1467-789X.2010.00726.x

Other Review

The influence of geographic life environments on cardiometabolic risk factors: a systematic review, a methodological assessment and a research agenda

C. Leal[1,2,3] and B. Chaix[1,2]

[1]Inserm, U707, Research Unit in Epidemiology, Information Systems, and Modeling, Paris, France; [2]Université Pierre et Marie Curie-Paris6, UMR-S 707, Paris, France; [3]EHESP School of Public Health, Rennes, France

Received 23 September 2009; revised 16 December 2009; accepted 7 January 2010

Address for correspondence: C Leal, UMR-S 707 Inserm – UPMC-Paris6, Faculté de Médecine Saint-Antoine, 27 rue Chaligny, 75012 Paris, France. E-mail: leal@u707.jussieu.fr

Summary

Recent environmental changes play a role in the dramatic increase in the prevalence of cardiometabolic risk factors (CMRFs) such as obesity, hypertension, type 2 diabetes, dyslipidemias and the metabolic syndrome in industrialized countries. Therefore, identifying environmental characteristics that are associated with risk factors is critical to develop more effective public health interventions. We conducted a systematic review of the literature investigating relationships between characteristics of geographic life environments and CMRFs (131 articles). Most studies were published after 2006, relied on cross-sectional designs, and examined whether sociodemographic and physical environmental characteristics, and more recently service environment characteristics, were associated with obesity or, to a lesser extent, hypertension. Only 14 longitudinal studies were retrieved; diabetes, dyslipidemias and the metabolic syndrome were rarely analysed; and aspects of social interactions in the neighbourhood were critically underinvestigated. Environmental characteristics that were consistently associated with either obesity or hypertension include low area socioeconomic position; low urbanization degree; low street intersection, service availability and residential density; high noise pollution; low accessibility to supermarkets and high density of convenience stores; and low social cohesion. Intermediate mechanisms between environmental characteristics and CMRFs have received little attention. We propose a research agenda based on the assessment of underinvestigated areas of research and methodological limitations of current literature.

Keywords: Environment, metabolic diseases, obesity, residence characteristics.

obesity reviews (2010)

Introduction

Obesity prevalence has increased at a dramatic rate over the last three decades in industrialized countries, contributing to the alarming rise in obesity-related disorders such as hypertension, type 2 diabetes and dyslipidemia (1).

This sudden increase in obesity is more likely to be related to environmental changes than to biological changes (2). Broadly defined environmental factors such as changes in agriculture, food processing and marketing, transportation habits, physical demands of work, and levels of sedentary activities create the context for a population-level increase in obesity rates, and through their effects on obesity, in blood pressure, cholesterol and diabetes incidence.

The limited success of education programs targeting attitudes related to physical activity or dietary behaviour may be due to the failure to consider environmental barriers to and environmental opportunities for healthy living. Accordingly, there is a growing recognition that environmental and policy interventions are promising strategies for creating population-wide changes in rates of obesity and related metabolic disorders (3).

We undertook a systematic review of the literature on environmental effects on cardiometabolic risk factors (CMRFs), to promote the development of innovative interventions to change modifiable environmental exposures or mitigate the adverse effects of non-modifiable environmental exposures. Our specific objectives were:

1. To catalogue the environmental correlates of different CMRFs (obesity, hypertension, type 2 diabetes, dyslipidemias and the metabolic syndrome) identified in the literature;
2. To report circumstances that modify the observed associations between contextual variables and CMRFs, allowing the identification of populations at a particular risk from environmental exposures;
3. To identify mediating pathways investigated between environmental exposures and CMRFs, which is useful to develop more efficient interventions targeting the mechanisms;
4. To identify underinvestigated areas of research, evaluate the methodological strengths and shortcomings of previous literature, and propose a research agenda.

Methods

We performed a qualitative systematic review of the literature on geographic life environments and CMRFs. We rejected quantitative systematic review design because of the small number of studies dealing with each particular environmental factor and because of the considerable variability in their design.

Search strategy

Our search only included articles dealing with human samples, conducted in developed countries according to the World Bank list of economies, and published in English between January 1985 and November 2009. We retrieved relevant studies through: (i) a PubMed search based on MeSH keywords (e.g. 'Environment Design', 'Residence Characteristics' or 'Small-Area Analysis', combined with 'Obesity', 'Overweight', 'Blood pressure', 'Diabetes Mellitus', 'Dyslipidemias' or 'Metabolic Diseases') and specific word titles (e.g. 'Community', 'Neighborhood*', 'Neighbourhood*' or 'Place*', combined with 'Adiposity', 'Insulin resistance', 'Hypertension' or 'Metabolic syndrome'), and (ii) hand-screening of the reference lists and citations (ISI Web of Knowledge) of the selected articles. Details of the PubMed search methodology (including exhaustive lists of keywords used in the searches) are provided in Online Appendix S1.

Study selection

The two authors were implied in all steps of the study selection process. All abstracts identified from PubMed were screened by the first author (C. L.) to identify potentially eligible articles. C.L. reviewed the full texts and the second author (B.C.) verified, during daily meetings, which studies met the pre-defined inclusion/exclusion criteria.

Inclusion criteria were: (i) investigating at least one measured or self-reported outcome related to body weight/shape, blood pressure/hypertension, cholesterol or triglyceride levels, insulin resistance, impaired fasting glucose or type 2 diabetes or the metabolic syndrome; (ii) estimating associations between environmental variables assessed on a collective geographic scale related to *geographic* life environments and measured on an infra-national scale and CMRFs; and (iii) adjusting models for at least one individual socioeconomic characteristic to avoid excessive confounding.

Exclusion criteria were specified to restrict the scope of the review to studies examining associations between real-world environmental characteristics and CMRFs. We excluded studies: (i) only assessing geographic variations in CMRFs without incorporating any characteristics of geographic areas; (ii) only considering environmental variables related to *non-geographic* life environments (e.g. household functioning, workplace characteristics, etc.); and (iii) experimental studies simulating environmental factors (e.g. noise) in the laboratory.

Data extraction and assessment of studies

Detailed information on selected studies was extracted and tabulated by C. L. (outcome variables, study design, environmental exposures, statistical analysis, adjustment strategies, modification and mediation analyses, and main findings). The daily meetings scheduled between the co-authors permitted to reach a full agreement between them in the content of the extracted data. To strengthen the literature assessment, we created a specific score allowing us to evaluate the quality of studies dealing with associations between environmental exposures and CMRFs (see Online Appendix S2).

Results

Overview of the review process

The PubMed search retrieved 5357 abstracts. Thirty-six studies were included during the screening of the abstracts, and 336 were selected for a full text examination. From these 336, 57 other articles were included in the review. We then performed a hand-screening search in the 5774 refer-

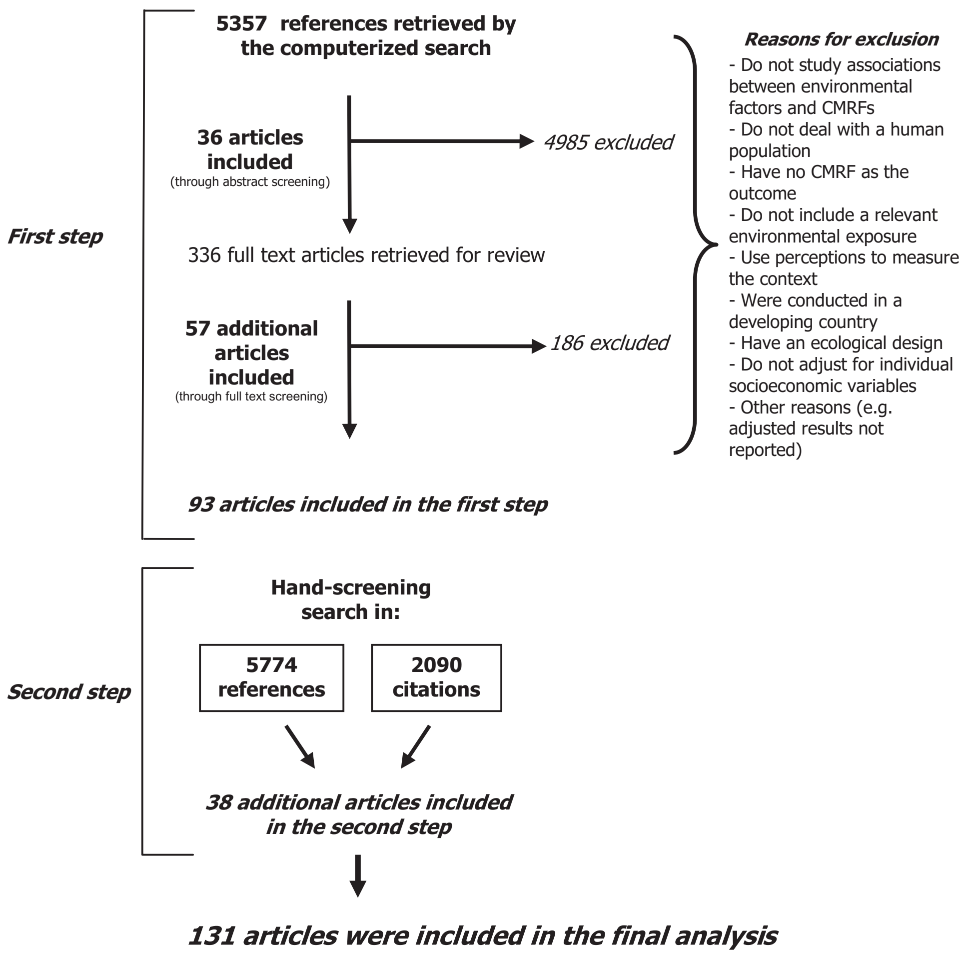

Figure 1 Computerized and hand-screening searches (see Online Appendix S1 for details on the search protocol). We distinguish between studies that were included in the review through the screening of abstracts, through the screening of full texts, and through the screening of citations and references. CMRF, cardiometabolic risk factor.

ences and 2090 citations of these articles. Thirty-eight other articles were retrieved, leading to a total of 131 articles (see details in Fig. 1).

Additional resources provided to the readers as Online Appendices include: a detailed table (Online Appendix S3) and a summary table (Online Appendix S4) reporting all information extracted from the 131 articles, and exhaustive lists of studies presenting each specific characteristic in Online Appendix S5 (only examples are provided below). We also refer the readers to Fig. 2 that provides an overview of the development of the literature over the past 24 years and illustrate the progression of the quality of these studies over time (based on the quality score described in Online Appendix S2).

Main characteristics of the samples

Seventy-nine studies out of 131 were published over the past 4 years (2006–2009), indicating a recent increase in the interest for these issues. 66% of the selected studies were conducted in the USA, 7% in Sweden, 6% in Canada and 5% in the UK.

Of the studies, 66% considered adult samples (>18 years), 17% focused on children or adolescent and 16% included both children/adolescents and adults. 91% of the studies with children/adolescents were devoted to weight-related outcomes.

Of the studies, 53% included between 1000 and 10 000 participants and 31% of them between 10 000 and 100 000 participants. The minimum and maximum sample sizes were 67 (4) and 1 611 961 (5).

Outcomes

Definition

Each study investigated from one to five CMRFs. 81% of the studies dealt with weight-related outcomes, and 73% *only* considered weight outcomes. 21% of the studies investigated blood pressure, 7% diabetes or insulin resistance,

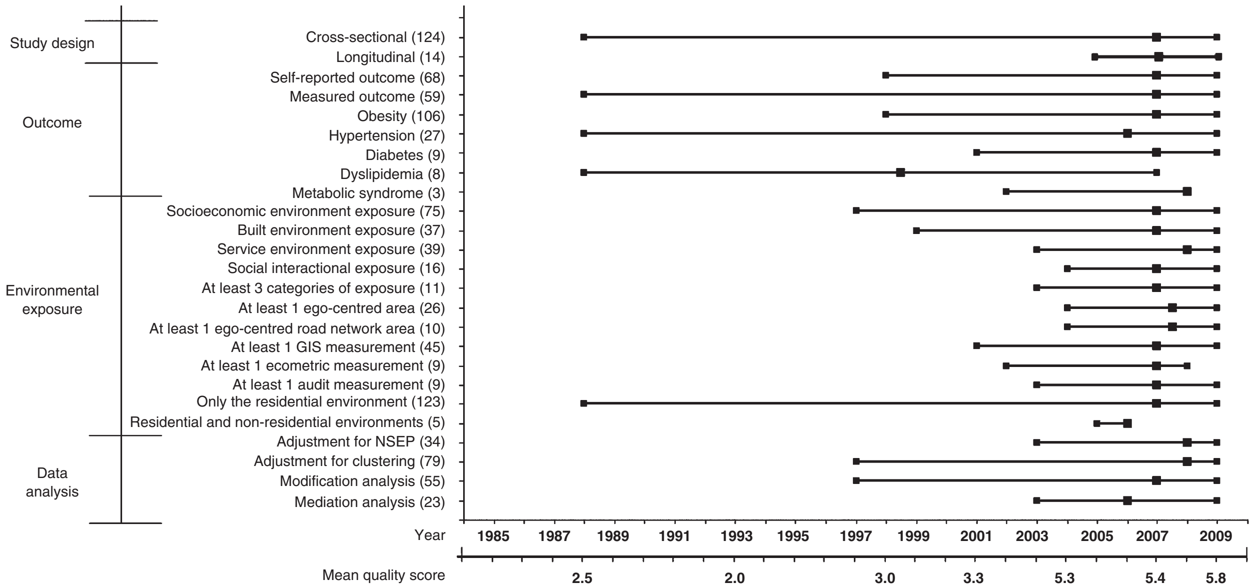

Figure 2 Progression of the quality of studies on geographic environments and cardiometabolic risk factors over the past 24 years (see Online Appendix S2 for details on the quality score). For each specific study characteristic (the number in parenthesis refers to the number of studies), we report the first, median, and last years of the corresponding studies that were reviewed. At the bottom of the figure, we report the progression of the mean quality score of these studies. GIS, geographic information system; NSEP, Neighborhood Socioeconomic Position.

6% dyslipidemias and 2% the metabolic syndrome. 55% of the studies relied only on self-reported outcomes.

Almost all weight-related studies relied on outcomes based on body mass index (BMI), either as a continuous or categorical outcome. Only five studies investigated specific measures of body fat: waist-to-hip ratio (e.g. (6)) and BMI and skin-fold measures combined in a single outcome (7).

Regarding blood pressure/hypertension, studies considered either (i) systolic and/or diastolic blood pressure as continuous outcomes (e.g. (8,9)); (ii) purely self-reported hypertension outcomes (e.g. (10)); or (iii) other outcomes combining information on systolic/diastolic blood pressure exceeding different thresholds with anti-hypertensive medication use (e.g. (11)) or a self-reported diagnosis of hypertension (12).

Four of the nine studies on diabetes (e.g. (13)) defined the outcome based only on participant-reported information, whereas four others involved measurement of insulin resistance or fasting glucose (e.g. (14)). Even the three studies related to the metabolic syndrome (e.g. (15)) considered different definitions of the outcome.

Longitudinal assessment

We devoted particular attention to longitudinal studies. Only 14 studies assessed an outcome longitudinally (Table 1). Of these studies, most (nine) considered weight status, three blood pressure and two diabetes. These studies included between two and seven (16) successive measurements of the risk factors. The shortest follow-up lasted 1 year and the longest 10 years (17). In obesity analyses, outcomes corresponded to the difference between two distinct measures of BMI over time (e.g. (18)) or repeated measures of BMI directly accounted for in regression models (16,17). Studies on hypertension involved hypertension incidence and blood pressure change (9,10), while the diabetes ones involved only measures of incidence (14).

Environmental exposures

Type of environment

Of the studies, 90% investigated exclusively residential environmental exposures, while 6% exclusively non-residential environmental exposures (e.g. (19)), and only 4% both residential and non-residential environments (e.g. (2)). The non-residential environments investigated were the school environment in most cases (e.g. (20)), the geographic work environment (2) and the shopping environment (21).

Spatial scale

As much as 73% of the studies relied only on pre-defined administrative area subdivisions to determine environmental exposures. 74% of the studies provided no information on area population size. In the remaining studies, area population size was less than 1000 in 26% and greater than 10 000 in 23% of the cases.

Twenty-six studies measured environmental variables within buffers (i.e. areas delimited by considering a certain

Table 1 Description of the longitudinal studies on the environmental correlates of CMRFs

Author (sample)	CMRF	Type of outcome	Measurement	# of measures	Length of follow-up	Spatial scale	Analyses	Contextual variables	Associations
Schootman (29) (*n* = 644)	Diabetes	Incidence	Self-reported	2	3 years	Block face	Non-multilevel logistic models	Air and noise pollution Street and road quality Physical deterioration	NS NS +
Auchincloss (14) (*n* = 2285)	Diabetes	Incidence	Measured	3	5 years	416 census tracts	Multilevel survival regression models	Availability of healthy foods (stores and restaurants) Sport or recreational facilities	– –
Cozier (10) (*n* = 36099)	Hypertension	Incidence	Self-reported	3	6 years	20 192 block groups	Generalized estimating equation	Socioeconomic level Ethnicity	– NS
Eriksson (12) (*n* = 2027)	Hypertension	Incidence	Measured	2	10 years	At the residential address	Non-multilevel binomial models	Noise pollution	+
Li (9) (*n* = 1145)	Blood pressure	Change	Measured	2	1 year	120 census block groups	Multilevel linear models	Fast-food restaurants Walkability score	+ –
Mujahid (32) (*n* = 13167)	BMI	Change	Measured	3	9 years	594 block groups	Multilevel linear models	Socioeconomic level	NS
Eid (18) (*n* = 5312)	BMI	Change	Self-reported	2	2 years	2-miles circular buffers	Non-multilevel linear models	Sprawl index Density of destinations	NS NS
Ewing (16) (*n* = 6677)	BMI	Change	Self-reported	7	7 years	938 counties	Multilevel linear models	Sprawl index	NS
Oliver (17) (*n* = 2152)	BMI	Change	Self-reported	5	10 years	Areas with 125–400 dwellings	Longitudinal two-level linear growth model	Socioeconomic level Urbanization degree	– NS
Plantinga (44) (*n* = 262)	BMI	Change	Self-reported	2	2 years	448 counties	Non-multilevel linear models	Sprawl index	+
Sturm (47) (*n* = 13828)	BMI	Change	Self-reported	3	3 years	Metropolitan area Home/ school Zip code	Multilevel linear models	Food stores Traditional or fast-food restaurants	+ NS
Bell (36) (*n* = 3831)	BMI	Change	Measured	2	2 years	1-km circular and road network buffer Census block groups	Non-multilevel linear models	Green spaces Residential density Socioeconomic level	– NS NS
Li (70) (*n* = 1221)	BMI Waist circumference	Change	Measured	2	1 year	120 census block groups	Multilevel linear models	Fast-food restaurants Walkability score	NS NS
Merten (37) (*n* = 7788)	Obesity	Chronic obesity	Self-reported	3	6 years	1 267 census tracts	Multilevel logistic models	Socioeconomic level	–

BMI, body mass index; CMRF, cardiometabolic risk factor.

radius around individuals' residences, workplaces, etc.). One of these studies defined buffers around both residence and workplace (2), another around both residence and school (20), and a third one defined buffers exclusively around schools (22). Buffers were of circular form in 65% of the cases, and were otherwise defined in terms of street network distance, as recommended (23). The radius of circular buffers varied in size from 100 (24) to 4800 m (25), while network buffer radii varied between 640 (26) and 2000 m (27).

Alternatively, other studies defined contextual variables at the street level (28) or at the block-face level (29).

Measurement approaches

Of the studies, 50% relied only on administrative data sources to define contextual variables (e.g. data from the population census or public administrations). The second most frequent measurement approach, used in 34% of the studies, was based on Geographic Information Systems, i.e. computer software relating spatially defined geographic shapes with descriptive information about these features. This approach was used to derive straight-line or street network distances to services or measure characteristics of the physical and service environments within buffers.

Other measurement approaches included the aggregation of individual perceptions of the environment from different inhabitants of the same neighbourhood to construct variables at the neighbourhood level (in 7% of the studies, e.g. (30,31)) and the audit of resources through systematic observation performed by independent and trained raters (in 7% of the studies, e.g. (28,29)).

Type of environmental characteristics

As previously proposed (3), we classified environmental factors in four categories related to the sociodemographic environment, physical environment, services available in the environment and local social interactions (see Table 2 for details). 57% of the studies considered contextual factors related to the sociodemographic or socioeconomic environment. Regarding more specific environmental exposures/resources, 36% of the studies measured variables related to the physical environment (e.g. vegetation, condition of buildings, road traffic noise, etc.), and 30% involved variables of the services available in the environment (e.g. food stores or sport facilities). Only 12% of the studies considered social interactions in the local environment (e.g. crime rate or social cohesion).

Statistical analyses and adjustment of associations

When investigating environmental effects, it is common to rely on population samples with individuals clustered within areas. As recommended, many studies relied on multilevel modelling (e.g. (32)) or generalized estimating equations (10) to account for the clustering of risk factors within areas.

A critical challenge is to ensure that the estimated environmental effects are not attributable to differences between areas in terms of individual characteristics intervening as confounders. 36% of the studies were adjusted for only one individual socioeconomic variable (which is insufficient), 53% for two or three individual socioeconomic variables and 10% for four or five such variables. Interestingly, one study considering obesity at adult age also controlled for childhood socioeconomic status (33).

Only 38% of the studies considering environmental exposures related to the physical, service or social- interactional environment reported analyses controlling for area socioeconomic characteristics as potential confounders (e.g. (28,33)), as recently recommended (3,34). Moreover, studies investigating the effects of different environmental exposures/resources often do not report analyses considering these variables simultaneously in a regression model (e.g. (35)).

Associations between environmental factors and cardiometabolic risk factors

Sociodemographic environment

The most investigated sociodemographic factor was socioeconomic level, followed by ethnic composition and population density (Table 2). After individual-level adjustment, low area socioeconomic level was generally significantly associated with an increased risk of CMRFs (in 42 of the 56 studies on obesity, 8 of the 12 studies on hypertension, 3 of the 4 studies on diabetes and dyslipidemia and 2 of the 2 studies on the metabolic syndrome).

Paying particular attention to longitudinal studies (Table 1), we identified only four studies on weight status (17,32,36,37) and one on hypertension (10) investigating socioeconomic environment effects. In one study on obesity, after individual-level adjustment, living in a poor neighbourhood was associated with an increase in BMI percentile over 10 years (17). However, in two other studies investigating BMI change over 2 and 9 years, there were no consistent differences in longitudinal trends in BMI by neighbourhood socioeconomic characteristics (32,36). Regarding hypertension, a significant inverse association was found between median housing value and hypertension incidence over 6 years (10).

Physical environment

Regarding physical environmental factors, the most commonly investigated dimensions in weight status studies were the urbanization degree and street and road network characteristics (e.g. type of road, connectivity and side-

Table 2 Main environmental exposures considered for each cardiometabolic risk factor in 120* studies included in the systematic review†

	Obesity	Hypertension	Diabetes	Dyslipidemia	Metabolic syndrome
Sociodemographic environment	63 (52)	12 (9)	4 (3)	4 (3)	3 (2)
Demographic dimension	24 (11)	3 (0)	0	0	1 (0)
Age	0	1 (0)	0	0	0
Ethnicity	14 (5)	3 (0)	0	0	1 (0)
Population size/density	14 (7)	0	0	0	0
Residential stability	2 (1)	0	0	0	0
Socioeconomic dimension	56 (49)	12 (9)	4 (3)	4 (3)	2 (2)
Socioeconomic level	56 (47)	12 (9)	4 (3)	4 (3)	2 (2)
Socioeconomic inequalities	8 (5)	1 (1)	0	0	0
Physical environment	36 (29)	13 (11)	2 (1)	3 (2)	0
Urbanization degree	14 (12)	3 (1)	1 (0)	1 (0)	0
Residential unit density	7 (3)	1 (1)	0	0	0
Street and road network	11 (6)	0	1 (0)	0	0
Type of road (e.g. highway)	3 (2)	0	1 (0)	0	0
Connectivity	8 (4)	0	0	0	0
Sidewalks	2 (1)	0	1 (0)	0	0
Outside building condition	5 (3)	0	1 (1)	0	0
Physical deterioration	5 (3)	0	1 (1)	0	0
Aesthetic architectural features	1 (0)	0	0	0	0
Air and noise pollution	2 (1)	10 (8)	1 (0)	2 (2)	0
Temperature/climate	2 (1)	2 (1)	0	0	0
Altitude/slope	2 (1)	0	0	0	0
Parks/green spaces	7 (5)	1 (1)	0	0	0
Services	37 (30)	3 (2)	2 (1)	1 (0)	0
Food environment	29 (22)	2 (1)	2 (1)	1 (0)	0
Food stores	21 (13)	2 (1)	2 (1)	1 (0)	0
Traditional or fast-food restaurants	20 (9)	1 (1)	0	0	0
Sport or recreational facilities	8 (3)	0	0	0	0
Healthcare resources	1 (1)	0	0	0	0
Density of destinations	5 (4)	0	0	0	0
Public transportation	4 (2)	0	0	0	0
Social interactions in the environment	14 (8)	2 (2)	0	0	0
Insecurity/crime	10 (4)	2 (2)	0	0	0
Social cohesion/social capital	7 (5)	2 (2)	0	0	0
All environmental factors	96 (89)	26 (21)	7 (5)	8 (5)	3 (2)

*Studies using composite indexes encompassing different environmental dimensions of our classification (e.g. on both the physical and service environments) are not reported in the present table. Such composite variables include indicators of sprawl (six studies [four reporting a significant association]), walkability (four [three]) and land-use mix (six [six]).
†We indicate the number of studies in each case, and in parenthesis the number of studies in which statistically significant associations were reported. We are aware that statistical significance or non-significance are arbitrary notions, especially in light of the major differences between studies in designs, adjustment strategies, measurement approaches, etc.

walks). Air and noise pollution was the most commonly considered physical risk factor for hypertension.

As regards urbanization, 12 of the 14 obesity studies observed that residing (e.g. (5,20)) or attending a school (38) in a less urbanized or in a rural environment rather than an urban one was associated with an increased body weight.

Regarding street and road network characteristics, four out of eight studies reported that living in areas with high street connectivity was associated with lower weight status (33,39) and two studies found that people in areas with higher densities of highways were more likely to be overweight (28,40)). Additionally, studies investigating whether environmental scores of walkability, land-use mix or sprawl (e.g. (41)) influence BMI confirmed that environments with a high density of residential units, street intersections, and services are associated with decreased BMI. Other reasonably consistent physical environmental predictors of obesity include physical deterioration of the neighbourhood (e.g. (35,42)) and the absence of parks or green spaces (e.g. (26,35)).

Eight out of 10 studies considering noise pollution found that exposure to high road traffic (e.g. (43)) and aircraft (e.g. (12)) noise was associated with higher blood pressure levels and hypertension prevalence. Regarding dyslipidemia, the only two studies available for example reported that a high traffic noise was associated with a higher triglycerides level (43).

Nine of the 14 longitudinal studies on the environment and CMRFs (e.g. (6,29)) investigated at least one aspect of the physical environment. Only two studies on BMI change (36,44) and two on blood pressure/hypertension (9,12) reported a significant association. The former study ($n = 262$ participants) reported that, after adjustment, individuals who had moved to a less sprawling county tended to have had a more favourable BMI change (44).

Services available in the environment

Services available in the environment were significantly associated with weight status in 81% of the studies (30 out of 37) that tested such relationships. Statistically significant associations were reported between aspects of the food environment and weight status in 22 of the 29 reviewed studies.

Accessibility to supermarkets and groceries was associated with a lower weight status in six studies (e.g. (31,45)), while exposure to convenience stores was associated with a higher weight status in four studies (e.g. (42)). Other studies, however, did not report any significant association between accessibility to food stores and weight status (46).

Only nine of the 20 studies considering restaurants reported a statistically significant association with obesity. Of the nine studies, six reported that an increase in fast-food restaurant density was associated with a higher body weight (e.g. (45)) while three studies observed that a higher availability of restaurants (2) or full-service restaurants (25) was associated with a lower body weight.

Regarding food prices, an increase in prices of fruits and vegetable was found to be associated with a higher body weight (47). In contrast, a study found that a one dollar increase in the price of a fast-food meal in the participant's school city was associated with a 2.2% reduction in prevalence of overweight (19).

It appears that fewer significant relationships were documented between sport or recreational facilities and body weight. Two studies indicated that a high level of accessibility to sport facilities was negatively associated with BMI (28,48), but one study reported an association in the opposite direction and the others no association.

Only few studies investigated the effects of the service environment on hypertension (49–51) and diabetes (30,49). One study found that residents of neighbourhoods with a higher availability of healthy foods were less likely to be hypertensive (50). Another study examining diabetes in the USA reported a positive association between the distance to a neighbourhood with good physical activity resources and insulin resistance (30), while another study did not find any association between the presence of food stores and diabetes (49). The latter study found no associations between the availability of food stores and cholesterol.

Longitudinal studies on obesity (6,18,47) found no effects of the service environment. However, other studies noted a detrimental effect of fast-food restaurant density on blood pressure change (9) and a beneficial effect of physical activity resources and healthy foods on the incidence of diabetes (14).

Social interactions in the environment

Eight of 14 studies reported significant associations between local social interactions and body weight (e.g. (31,48)), while it was the case in two of the two studies on hypertension/blood pressure (8,50). Most of the studies considering social interactions assessed insecurity or criminality levels. Four (e.g. (48,52)) of the 10 studies investigating associations between insecurity/criminality and body weight found statistically significant relationships. Regarding hypertension/blood pressure, the only two studies on this issue reported that neighbourhood crime experience was associated with increased blood pressure (8,50).

Social cohesion/capital was the second most commonly investigated dimension. Five of seven studies on weight status (e.g. (31,42)) and two of two on hypertension/blood pressure (8,50) found that residing or attending a school in areas with more supportive social interactions was associated with a lower body weight and blood pressure.

Importantly, no longitudinal study and no study related to dyslipidemias, diabetes or the metabolic syndrome investigated social interactions in the environment as the exposure.

Modification and mediation of the environment–cardiometabolic risk factor associations

Modification of environmental effects

Overall, 42% of the studies examined interactions between environmental effects and individual/contextual characteristics or performed stratified analyses, allowing the identification of populations at a particular risk from environmental exposures. To facilitate the literature assessment, we classified individual-level modifiers in four categories: sociodemographic variables, health variables, health behaviour and psychosocial aspects (see Online Appendix S6). Clearly, the modification effects most frequently examined were related to individual sociodemographic characteristics, i.e. to gender, ethnicity and individual socioeconomic characteristics (in 45 studies).

Although few consistent findings emerged, it was frequently reported that associations were stronger among women and low-socioeconomic-status individuals. For example, studies reported stronger associations between income inequalities (53), recreational values of the environment (54), sidewalk condition (55) and CMRFs among low-socioeconomic-status individuals.

Besides individual-level modifiers, only six studies on obesity (e.g. (21,56)) and one on blood pressure (9) examined whether effects of environmental variables were modified by other environmental factors. For example, a study evaluated whether neighbourhood crime modified relationships between distance to the nearest playground or fast-food restaurant and overweight, but found no significant interactions (56).

Mediating mechanisms between environmental factors and cardiometabolic risk factors

To identify the mechanisms involved in the relationships, 18% of the studies investigated the mediating role of individual or contextual characteristics (Online Appendix S6), generally reporting changes in environmental effects on CMRFs before and after inclusion of the suspected mediators.

As shown in Online Appendix S6, the mediating mechanisms most investigated were related to individual health behaviour such as physical activity and dietary behaviour, corresponding to 13 and 2 studies on obesity and diabetes, respectively. Four studies reported that physical activity (modelled alone or with other mediators) had a mediating role in associations between physical environmental factors and obesity. In one study, adding physical activity to the model (with no other mediator simultaneously) decreased the strength of the association between land use mix and BMI by only 5% (57). Dietary behaviour was the second most commonly investigated mediator (in six and two studies of obesity and diabetes, respectively), but always with physical activity and other mediators introduced simultaneously into the model.

Other studies considered health variables as mediators. For example, two studies found that area-level socioeconomic effects on diabetes were reduced when controlling for BMI (and for physical activity and diet) (30,58), whereas another study did not find any change in material deprivation effects on diabetes after adjustment for BMI and other physiological factors (59).

Only four studies examined whether relationships between environmental characteristics and CMRFs (always obesity) were mediated by another contextual variable. For instance, one study reported that area social capital did not mediate the association between county sprawl index or mean household income and obesity (60).

Discussion

Our systematic review summarizes the methods and findings of studies on the associations between geographic life environment and CMRFs published between 1985 and 2009. Based on this review and on an assessment of the strengths and weaknesses of the literature, we propose a research agenda for future research (see Table 3).

Strengths and limitations of the review

Contrary to previous reviews that only considered obesity, a particular strength of our work is that we assessed a broad range of CMRFs. So far, the evidence for environmental effects on hypertension, diabetes and the metabolic syndrome has not been summarized. A second strength of our study is the systematic review methodology and the very large number of abstracts ($n = 5357$) and selected articles ($n = 131$) that were screened.

Regarding limitations, we may have missed relevant studies when screening references and citations of the selected articles if their investigation of environmental determinants of CMRFs was not detectable from the title. Second, we were not able to evaluate how publication biases towards positive findings affected our evaluation. Finally, the small number of studies examining a specific environmental exposure and outcome prevented a quantitative meta-analysis.

Overview of the associations estimated

The most consistent associations reported were between socioeconomic characteristics of residential neighbourhoods and weight status and blood pressure, with more unfavourable CMRF profiles in socially deprived neighbourhoods after adjustment for individual socioeconomic characteristics.

Regarding aspects of the physical environment, another remarkably consistent association was higher obesity levels in less urbanized settings, a pattern of association in the opposite direction from developing countries where increased urbanization is related to higher body weight (52). Coherently, a number of studies reported that residing in a neighbourhood with a high density of street intersections, residential units and services was associated with a lower risk of obesity (e.g. (33,57)). Other reasonably consistent physical environmental predictors of CMRFs include physical deterioration of the neighbourhood (e.g. (35,42)) and the absence of parks (e.g. (26,35)) for obesity, and noise pollution for blood pressure (e.g. (43)).

Regarding the food environment, reasonably consistent associations were reported between accessibility to a supermarket and lower body weight (e.g. (45,49)), and between convenience store (e.g. (42,61)) and fast-food restaurant (6,62) accessibility and higher body weight.

Regarding social interactions, certain studies reported that insecurity/criminality was associated with an increased body weight (e.g. (48,52)) and blood pressure (e.g. (8,50)),

Table 3 Research agenda for the future investigations of the environmental determinants of CMRFs

Outcomes
• Avoid studies relying on self-reported CMRF outcomes.
• Take into account, in addition to body mass index, parameters of abdominal adiposity and visceral fat.
• Develop studies on diabetes, dyslipidemias and the metabolic syndrome.
• Prioritize studies with a longitudinal assessment of the outcome.
Environmental exposures
• Define ego-centred geographic areas that approximate the actual space of activity of individuals in their local environment.
• Take into account non-residential geographic environments (e.g. the geographic work, school or shopping environments) in addition to the residential environment.
• Assess the spatial scale on which environmental factors affect the outcomes.
• Distinguish between acute and chronic environmental exposures.
• Perform studies with a longitudinal assessment of environmental exposures.
• Develop and apply efficient protocols to characterize the food environment and social interactions that take place in the neighbourhood.
• Take into account the accessibility to healthcare services, a particularly neglected dimension in the reviewed studies.
Analytic design
• Apply multilevel or spatial regression techniques to assess the magnitude and scale of geographic variations in CMRFs.
• Rely on directed acyclic graphs to present research hypotheses in an explicit way and identify individual or neighbourhood variables that should be considered as confounders, modifiers, mediators or sources of selection bias.
• Take into account area-level confounding by adjusting the environment–CMRF associations for area socioeconomic characteristics and other area characteristics (pay attention, however, to the risk of collider bias).
• Measure selective migration processes and take them into account during the analyses.
• Investigate and disentangle the individual-level mechanisms mediating associations between environmental variables and CMRFs.
• Develop questionnaires to measure the experiences individuals have in their environment, as possible contributors to the environment–CMRF associations of interest.

CMRF, cardiometabolic risk factor.

but other studies reported negative findings. Studies investigating social cohesion were perhaps more consistent in finding that geographic life environments with supportive social interactions are associated with lower odds of obesity (e.g. (31,42)) or high blood pressure (8,50).

Methodological limitations and recommendations

Study design

Most of the studies relied on a cross-sectional design, not permitting inference on the direction of the underlying causal effects. Selective migration and the selective location of resources represent two major sources of confounding (3). First, relationships between the availability of resources (e.g. fast foods, sport facilities) and CMRFs are probably biased by the selective location of resources by public or private agents near populations willing to use them. A second source of bias is related to selective migration, by which people with specific characteristics tend to move towards particular areas. Three reviewed studies (16,18,44) investigated health-related selective migration to specific areas. Given the small number of longitudinal studies (14 out of 131), a key recommendation is to undertake more cohort studies involving repeated measurements of CMRFs, to account for selective migration and model growth curves in these outcomes.

However, even longitudinal designs may be unable to remove all selective migration biases, as migrations bring specific individuals into specific neighbourhoods before the follow-up. Investigators should therefore collect specific information on participants' a priori reasons for selecting their particular neighbourhood (3,63), to better adjust their models.

Cardiometabolic risk factors and their measurement

First, in 52% of the studies, outcomes were self-reported. As it is difficult to predict in which direction associations are distorted when relying on self-report, investigators should restrict their efforts to measured outcomes. Second, it is critical to focus on the environmental correlates of hypertension, diabetes, dyslipidemias and the metabolic syndrome, which have received much less attention than obesity. Third, only 3% of the studies examined specific measures of body fat and no studies considered measures of visceral fat, which future environmental research should therefore address.

Finally, to facilitate comparison across studies, investigators could report findings on environmental influences using different approaches to the outcome (e.g. both a continuous and a binary variable when appropriate, or the different definitions of a condition).

Measurement of environmental exposures

A considerable number of studies defined contextual variables within administrative areas. It is now widely recognized that these measures may not reflect the environmental conditions to which individuals are exposed (3). Whenever possible, investigators should rely on ego-centred definitions of areas that approximate individuals' local activity spaces (23), i.e. areas centred on individuals' residences. Also, researchers should define these ego-centred geographic areas on different scales (by considering different area radii in sensitivity analyses), and should not exclusively focus on residential environments but account for other geographic life environments (21).

Whereas early studies exclusively investigated neighbourhood sociodemographic characteristics, recently released databases and geographic information systems allow researchers to ascertain various characteristics of the physical and service environment. Regarding the latter, more studies are needed to assess whether the availability of recreational and sport facilities has any detectable effect on body weight. A particular challenge relates to the assessment of the food environment, for which measures of the type of food stores and restaurants need to be completed by in-store and in-restaurant assessments. Also, future research should investigate effects of the accessibility to healthcare services on CMRFs, which have been almost entirely ignored (except in (64)).

Interestingly, we found that investigators have devoted more attention to the physical and service environments than to the social interactions in the environment. However, there is evidence supporting the hypothesis that neighbourhood social interactions may influence CMRF incidence, either through their effect on health behaviour or through direct stress effects (3). Importantly, our recommendation of a greater focus on area social interactions implies particular efforts to measure these characteristics, which are inadequately documented in administrative sources. As systematic observation (involving trained raters with checklists assessing aspects of the environment) is known to be less accurate for the assessment of social interactions than for aspects of the physical environment (65), a promising avenue is to develop ecometric approaches aggregating individual responses to survey questions on the environment to construct indicators at the neighbourhood level (3).

Analytic approaches

Before estimating associations with environmental characteristics, investigators should investigate the geographic distribution of CMRFs, using multilevel and spatial regression techniques to assess the magnitude and spatial scale of geographic variations of these outcomes (66,67).

We recommend relying on directed acyclic graphs to present hypotheses explicitly and to identify individual or neighbourhood variables intervening as confounders, modifiers, mediators or sources of selection bias for the associations of interest (34). Importantly, in addition to individual socioeconomic variables, neighbourhood socioeconomic status may intervene as an important source of bias in a number of studies of the associations between environmental exposures and CMRFs. For example, Morland (49) did not investigate whether the association between the availability of supermarkets and overweight persisted after adjustment for neighbourhood socioeconomic position. We thus recommend that investigators report their findings on environment–health associations also adjusted for neighbourhood socioeconomic variables at least in sensitivity analyses, even if such adjustment may induce other biases in specific situations (34).

In future research, it is important to assess whether associations between particular environmental factors and CMRFs are stronger in specific population subgroups, e.g. among women and low-socioeconomic-status groups as often documented. However, beyond basic individual sociodemographic or health characteristics, future research should examine whether psychological characteristics, social support and experiences in or perceptions of the neighbourhood modify environment–CMRF associations.

Assessing mediating pathways explaining associations between environmental characteristics and CMRFs may lead to proposing more efficient interventions targeting mechanisms. Ideally, the aim would be to rank the different mechanisms according to their importance in mediating the environment–CMRF associations of interest. However, such information is lost when all potential mediators are included, all together at a time, into the model (3), as commonly done in the reviewed studies. Related approaches to investigate mediating mechanisms include path analysis (68) or a recent framework to estimate direct and indirect effects under various assumptions (69). Based on these techniques, a challenge for future research is to examine whether the affective, cognitive and relational experiences that individuals have in their environments influence health behaviours (including healthcare utilization, a particularly neglected mediator), which in turn contribute to cardiometabolic risk.

Conclusion

Our systematic review of 131 studies published over 24 years allowed us to identify methodological limitations and underinvestigated areas of research, leading to a number of recommendations related to the study design and outcomes, assessment of environmental exposures and analytic approaches (Table 3). We hope that this research agenda will allow us to strengthen evidence regarding environmental influences on CMRFs, and develop more efficient multilevel public health interventions targeting both the environmental exposures, the individual circumstances that modify their influence, and their mechanistic pathway to cardiometabolic risk.

Acknowledgements

As part of the RECORD project, the present work was funded by the National Research Agency (Agence Nationale de la Recherche) (Health–Environment Program 2005 #00153 05); the Institute for Public Health Research (Institut de Recherche en Santé Publique); the National Institute for Prevention and Health Education (Institut National de Prévention et d'Education pour la Santé) (Prevention Program 2007 074/07-DAS); the National Institute of Public Health Surveillance (Institut de Veille Sanitaire) (Territory and Health Program); the French Ministries of Research and Health (Epidemiologic Cohorts Grant 2008); the National Health Insurance Office for Salaried Workers (Caisse Nationale d'Assurance Maladie des Travailleurs Salariés); the Ile-de-France Health and Social Affairs Regional Direction (Direction Régionale des Affaires Sanitaires et Sociales d'Île-de-France); the Ile-de-France Public Health Regional Group (Groupement Régional de Santé Publique) and the Ile-de-France Youth and Sports Regional Direction (Direction Régionale de la Jeunesse et des Sports). The authors also thank David Evans for his comments on the final version of the manuscript.

Conflict of Interest Statement

No conflict of interest was declared.

References

1. Sharma AM, Chetty VT. Obesity, hypertension and insulin resistance. *Acta Diabetol* 2005; **42**(Suppl. 1): S3–S8.
2. Jeffery RW, Baxter J, McGuire M, Linde J. Are fast food restaurants an environmental risk factor for obesity? *Int J Behav Nutr Phys Act* 2006; **3**: 2.
3. Chaix B. Geographic life environments and coronary heart disease: a literature review, theoretical contributions, methodological updates, and a research agenda. *Annu Rev Public Health* 2009; **30**: 81–105.
4. Espinosa de Los Monteros K, Gallo LC, Elder JP, Talavera GA. Individual and area-based indicators of acculturation and the metabolic syndrome among low-income Mexican American women living in a border region. *Am J Public Health* 2008; **98**: 1979–1986.
5. Neovius M, Rasmussen F. Place of residence and obesity in 1,578,694 young Swedish men between 1969 and 2005. *Obesity (Silver Spring)* 2008; **16**: 671–676.
6. Li F, Harmer P, Cardinal BJ, Bosworth M, Johnson-Shelton D, Moore JM, Acock A, Vongjaturapat N. Built environment and 1-year change in weight and waist circumference in middle-aged and older adults: Portland Neighborhood Environment and Health Study. *Am J Epidemiol* 2009; **169**: 401–408.
7. McMurray RGHJS, Bangdiwala SI, Deng S. Effects of road traffic noise on prevalence of hypertension in men: results of Luebeck Blood Pressure Study. *J Rural Health* 1999; **15**: 365–374.
8. Agyemang C, van Hooijdonk C, Wendel-Vos W, Ujcic-Voortman JK, Lindeman E, Stronks K, Droomers M. Ethnic differences in the effect of environmental stressors on blood pressure and hypertension in the Netherlands. *BMC Public Health* 2007; **7**: 118.
9. Li F, Harmer P, Cardinal BJ, Vongjaturapat N. Built environment and changes in blood pressure in middle aged and older adults. *Prev Med* 2009; **48**: 237–241.
10. Cozier YC, Palmer JR, Horton NJ, Fredman L, Wise LA, Rosenberg L. Relation between neighborhood median housing value and hypertension risk among black women in the United States. *Am J Public Health* 2007; **97**: 718–724.
11. Dragano N, Bobak M, Wege N, Peasey A, Verde PE, Kubinova R, Weyers S, Moebus S, Mohlenkamp S, Stang A, Erbel R, Jockel KH, Siegrist J, Pikhart H. Neighbourhood socioeconomic status and cardiovascular risk factors: a multilevel analysis of nine cities in the Czech Republic and Germany. *BMC Public Health* 2007; **7**: 255.
12. Eriksson C, Rosenlund M, Pershagen G, Hilding A, Ostenson CG, Bluhm G. Aircraft noise and incidence of hypertension. *Epidemiology* 2007; **18**: 716–721.
13. Cubbin C, Sundquist K, Ahlen H, Johansson SE, Winkleby MA, Sundquist J. Neighborhood deprivation and cardiovascular disease risk factors: protective and harmful effects. *Scand J Public Health* 2006; **34**: 228–237.
14. Auchincloss AH, Diez Roux AV, Mujahid MS, Shen M, Bertoni AG, Carnethon MR. Neighborhood resources for physical activity and healthy foods and incidence of type 2 diabetes mellitus: the multi-ethnic study of Atherosclerosis. *Arch Intern Med* 2009; **169**: 1698–1704.
15. Diez Roux AV, Jacobs DR, Kiefe CI. Neighborhood characteristics and components of the insulin resistance syndrome in young adults: the coronary artery risk development in young adults (CARDIA) study. *Diabetes Care* 2002; **25**: 1976–1982.
16. Ewing R, Brownson RC, Berrigan D. Relationship between urban sprawl and weight of United States youth. *Am J Prev Med* 2006; **31**: 464–474.
17. Oliver LN, Hayes MV. Effects of neighbourhood income on reported body mass index: an eight year longitudinal study of Canadian children. *BMC Public Health* 2008; **8**: 16.
18. Eid J, Overman HG, Puga D, Turner MA. Fat city: Questioning the relationship between urban sprawl and obesity. *Journal of Urban Economics* 2008; **63**: 385–404.
19. Powell LM, Auld MC, Chaloupka FJ, O'Malley PM, Johnston LD. Access to fast food and food prices: relationship with fruit and vegetable consumption and overweight among adolescents. *Adv Health Econ Health Serv Res* 2007; **17**: 23–48.
20. Nelson MC, Gordon-Larsen P, Song Y, Popkin BM. Built and social environments associations with adolescent overweight and activity. *Am J Prev Med* 2006; **31**: 109–117.
21. Inagami S, Cohen DA, Finch BK, Asch SM. You are where you shop: grocery store locations, weight, and neighborhoods. *Am J Prev Med* 2006; **31**: 10–17.
22. Janssen I, Boyce WF, Simpson K, Pickett W. Influence of individual- and area-level measures of socioeconomic status on obesity, unhealthy eating, and physical inactivity in Canadian adolescents. *Am J Clin Nutr* 2006; **83**: 139–145.
23. Chaix B, Merlo J, Evans D, Leal C, Havard S. Neighbourhoods in eco-epidemiologic research: Delimiting personal exposure areas. A response to Riva, Gauvin, Apparicio and Brodeur. *Soc Sci Med* 2009; **69**: 1306–1310.
24. Berke EM, Koepsell TD, Moudon AV, Hoskins RE, Larson EB. Association of the built environment with physical activity and obesity in older persons. *Am J Public Health* 2007; **97**: 486–492.
25. Seliske LM, Pickett W, Boyce WF, Janssen I. Association between the food retail environment surrounding schools and overweight in Canadian youth. *Public Health Nutr* 2009; **12**: 1384–1391.

26. Tilt JH, Unfried TM, Roca B. Using objective and subjective measures of neighborhood greenness and accessible destinations for understanding walking trips and BMI in Seattle, Washington. *Am J Health Promot* 2007; **21**: 371–379.
27. Rundle A, Neckerman KM, Freeman L, Lovasi GS, Purciel M, Quinn J, Richards C, Sircar N, Weiss C. Neighborhood food environment and walkability predict obesity in New York City. *Environ Health Perspect* 2009; **117**: 442–447.
28. Giles-Corti B, Macintyre S, Clarkson JP, Pikora T, Donovan RJ. Environmental and lifestyle factors associated with overweight and obesity in Perth, Australia. *Am J Health Promot* 2003; **18**: 93–102.
29. Schootman M, Andresen EM, Wolinsky FD, Malmstrom TK, Miller JP, Yan Y, Miller DK. The effect of adverse housing and neighborhood conditions on the development of diabetes mellitus among middle-aged African Americans. *Am J Epidemiol* 2007; **166**: 379–387.
30. Auchincloss AH, Diez Roux AV, Brown DG, Erdmann CA, Bertoni AG. Neighborhood resources for physical activity and healthy foods and their association with insulin resistance. *Epidemiology* 2008; **19**: 146–157.
31. Cohen DA, Finch BK, Bower A, Sastry N. Collective efficacy and obesity: the potential influence of social factors on health. *Soc Sci Med* 2006; **62**: 769–778.
32. Mujahid MS, Diez Roux AV, Borrell LN, Nieto FJ. Cross-sectional and longitudinal associations of BMI with socioeconomic characteristics. *Obes Res* 2005; **13**: 1412–1421.
33. Grafova IB, Freedman VA, Kumar R, Rogowski J. Neighborhoods and obesity in later life. *Am J Public Health* 2008; **98**: 2065–2071.
34. Chaix B, Leal C, Evans D. Neighborhood-level confounding in epidemiologic studies: unavoidable challenges, uncertain solutions. *Epidemiology* 2010; **21**: 124–127.
35. Ellaway A, Macintyre S, Bonnefoy X. Graffiti, greenery, and obesity in adults: secondary analysis of European cross sectional survey. *BMJ* 2005; **331**: 611–612.
36. Bell JF, Wilson JS, Liu GC. Neighborhood greenness and 2-year changes in body mass index of children and youth. *Am J Prev Med* 2008; **35**: 547–553.
37. Merten MJ, Williams AL, Shriver LH. Breakfast consumption in adolescence and young adulthood: parental presence, community context, and obesity. *J Am Diet Assoc* 2009; **109**: 1384–1391.
38. Bruner MW, Lawson J, Pickett W, Boyce W, Janssen I. Rural Canadian adolescents are more likely to be obese compared with urban adolescents. *Int J Pediatr Obes* 2008; **3**: 205–211.
39. Scott MM, Dubowitz T, Cohen DA. Regional differences in walking frequency and BMI: what role does the built environment play for Blacks and Whites? *Health Place* 2009; **15**: 882–887.
40. Lin G, Spann S, Hyman D, Pavlik V. Climate amenity and BMI. *Obesity (Silver Spring)* 2007; **15**: 2120–2127.
41. Frank L, Kerr J, Saelens B, Sallis J, Glanz K, Chapman J. Food outlet visits, physical activity and body weight: variations by gender and race-ethnicity. *Br J Sports Med* 2009; **43**: 124–131.
42. Grafova IB. Overweight children: assessing the contribution of the built environment. *Prev Med* 2008; **47**: 304–308.
43. Babisch W, Ising H, Gallacher JE, Sharp DS, Baker IA. Traffic noise and cardiovascular risk: the Speedwell study, first phase. Outdoor noise levels and risk factors. *Arch Environ Health* 1993; **48**: 401–405.
44. Plantinga AJBS. The association between urban sprawl and obesity: is it a two-way street? *J Reg Sci* 2007; **47**: 857–879.
45. Spence JC, Cutumisu N, Edwards J, Raine KD, Smoyer-Tomic K. Relation between local food environments and obesity among adults. *BMC Public Health* 2009; **9**: 192.
46. Millstein RA, Yeh HC, Brancati FL, Batts-Turner M, Gary TL. Food availability, neighborhood socioeconomic status, and dietary patterns among blacks with type 2 diabetes mellitus. *Medscape J Med* 2009; **11**: 15.
47. Sturm R, Datar A. Body mass index in elementary school children, metropolitan area food prices and food outlet density. *Public Health* 2005; **119**: 1059–1068.
48. Mobley LR, Root ED, Finkelstein EA, Khavjou O, Farris RP, Will JC. Environment, obesity, and cardiovascular disease risk in low-income women. *Am J Prev Med* 2006; **30**: 327–332.
49. Morland K, Diez Roux AV, Wing S. Supermarkets, other food stores, and obesity: the atherosclerosis risk in communities study. *Am J Prev Med* 2006; **30**: 333–339.
50. Mujahid MS, Diez Roux AV, Morenoff JD, Raghunathan TE, Cooper RS, Ni H, Shea S. Neighborhood characteristics and hypertension. *Epidemiology* 2008; **19**: 590–598.
51. Lovasi GS, Neckerman KM, Quinn JW, Weiss CC, Rundle A. Effect of individual or neighborhood disadvantage on the association between neighborhood walkability and body mass index. *Am J Public Health* 2009; **99**: 279–284.
52. Singh GK, Kogan MD, van Dyck PC. A multilevel analysis of state and regional disparities in childhood and adolescent obesity in the United States. *J Community Health* 2008; **33**: 90–102.
53. Diez-Roux AV, Link BG, Northridge ME. A multilevel analysis of income inequality and cardiovascular disease risk factors. *Soc Sci Med* 2000; **50**: 673–687.
54. Bjork J, Albin M, Grahn P, Jacobsson H, Ardo J, Wadbro J, Ostergren PO. Recreational values of the natural environment in relation to neighbourhood satisfaction, physical activity, obesity and wellbeing. *J Epidemiol Community Health* 2008; **62**: e2.
55. Boehmer TK, Hoehner CM, Deshpande AD, Brennan Ramirez LK, Brownson RC. Perceived and observed neighborhood indicators of obesity among urban adults. *Int J Obes (Lond)* 2007; **31**: 968–977.
56. Burdette HL, Whitaker RC. Neighborhood playgrounds, fast food restaurants, and crime: relationships to overweight in low-income preschool children. *Prev Med* 2004; **38**: 57–63.
57. Frank LD, Andresen MA, Schmid TL. Obesity relationships with community design, physical activity, and time spent in cars. *Am J Prev Med* 2004; **27**: 87–96.
58. Auchincloss AH, Diez Roux AV, Brown DG, O'Meara ES, Raghunathan TE. Association of insulin resistance with distance to wealthy areas: the multi-ethnic study of atherosclerosis. *Am J Epidemiol* 2007; **165**: 389–397.
59. Andersen AF, Carson C, Watt HC, Lawlor DA, Avlund K, Ebrahim S. Life-course socio-economic position, area deprivation and Type 2 diabetes: findings from the British Women's Heart and Health Study. *Diabet Med* 2008; **25**: 1462–1468.
60. Kim D, Subramanian SV, Gortmaker SL, Kawachi IU. S state- and county-level social capital in relation to obesity and physical inactivity: a multilevel, multivariable analysis. *Soc Sci Med* 2006; **63**: 1045–1059.
61. Galvez MP, Hong L, Choi E, Liao L, Godbold J, Brenner B. Childhood obesity and neighborhood food-store availability in an inner-city community. *Acad Pediatr* 2009; **9**: 339–343.
62. Li F, Harmer PA, Cardinal BJ, Bosworth M, Acock A, Johnson-Shelton D, Moore JM. Built environment, adiposity, and physical activity in adults aged 50–75. *Am J Prev Med* 2008; **35**: 38–46.
63. Frank LD, Saelens BE, Powell KE, Chapman JE. Stepping towards causation: do built environments or neighborhood and travel preferences explain physical activity, driving, and obesity? *Soc Sci Med* 2007; **65**: 1898–1914.

64. Santana P, Santos R, Nogueira H. The link between local environment and obesity: a multilevel analysis in the Lisbon Metropolitan Area, Portugal. *Soc Sci Med* 2009; **68**: 601–609.
65. Zenk SN, Schulz AJ, Mentz G, House JS, Gravlee CC, Miranda PY, Miller P, Kannan S. Inter-rater and test-retest reliability: methods and results for the neighborhood observational checklist. *Health Place* 2007; **13**: 452–465.
66. Merlo J, Chaix B, Yang M, Lynch J, Rastam L. A brief conceptual tutorial of multilevel analysis in social epidemiology: linking the statistical concept of clustering to the idea of contextual phenomenon. *J Epidemiol Community Health* 2005; **59**: 443–449.
67. Chaix B, Merlo J, Subramanian SV, Lynch J, Chauvin P. Comparison of a spatial perspective with the multilevel analytical approach in neighborhood studies: the case of mental and behavioral disorders due to psychoactive substance use in Malmo, Sweden, 2001. *Am J Epidemiol* 2005; **162**: 171–182.
68. Chaix B, Ducimetiere P, Lang T, Haas B, Montaye M, Ruidavets JB, Arveiler D, Amouyel P, Ferrieres J, Bingham A, Chauvin P. Residential environment and blood pressure in the PRIME Study: is the association mediated by body mass index and waist circumference? *J Hypertens* 2008; **26**: 1078–1084.
69. Petersen ML, Sinisi SE, van der Laan MJ. Estimation of direct causal effects. *Epidemiology* 2006; **17**: 276–284.
70. Li F, Harmer P, Cardinal BJ, Bosworth M, Johnson-Shelton D. Obesity and the built environment: does the density of neighborhood fast-food outlets matter? *Am J Health Promot* 2009; **23**: 203–209.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Description of the PubMed search strategy
Appendix S2. Quality assessment of the reviewed articles
Appendix S3. Systematic review of 131 studies investigating associations between geographic life environments and cardiometabolic risk factors, adjusted for at least one socioeconomic characteristic
Appendix S4. Systematic review of 131 studies investigating associations between geographic life environments and cardiometabolic risk factors, adjusted for at least one socioeconomic characteristic (full details reported in Online Appendix S3)
Appendix S5. Detailed lists of studies presenting specific characteristics
Appendix S6. Types of individual variables analysed as modifiers (Mo) or mediators (Me) of the environmental effects on cardiometabolic risk factors in the 131 studies reviewed

Please note: Wiley-Blackwell is not responsible for the content or functionality of any supporting materials supplied by the authors. Any queries (other than missing material) should be directed to the corresponding author for the article.