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Residential Environments and Cardiovascular Risk

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ABSTRACT *The article begins with a discussion of the rationale for studying the relationship between residential environments and cardiovascular health. Existing empirical research relating residential environments to cardiovascular outcomes and risk factors is summarized. The research areas discussed include neighborhood socioeconomic characteristics and cardiovascular disease, the effects of residential environments on physical activity, and the effects of residential environments on diet. Other mechanisms through which residential environments may affect cardiovascular health are also briefly noted. Key challenges in investigating the relationship between residential environments and health are discussed. These challenges include characterizing environments (including definition and geographic scale as well as conceptualization and measurement of relevant features), the limitations of observational studies, and the need to evaluate the health impact of interventions or "naturally" occurring changes in local environments. The need for interdisciplinary work is emphasized.*

Cardiovascular disease epidemiology is often considered to be the paradigm of risk factor epidemiology. Indeed, many features of modern epidemiology, including aspects of study design and data analysis and the use of large observational cohort studies to identify multiple disease risk factors, have been developed or elaborated in the study of cardiovascular disease. A key feature of this paradigm has been the focus on individual-level risk factors, both behavioral and biological, often divorced from the environments or social contexts that facilitated the emergence and persistence of these risk factors. A correlate of this approach has been that cardiovascular risk factors are often viewed as matters of individual choice and medical care. Consequently, their prevention has, by and large, centered on two individual-based strategies: (a) health education and motivation of individuals to change their habits, and (b) the early detection of risk factors and their treatment through the medical care system (as exemplified by campaigns for the early detection and treatment of high blood pressure and high cholesterol).

In parallel with these individual-centered approaches, there is a long history of attempts to view cardiovascular risk within environmental contexts. Perhaps one of the most insightful examples of this approach has been the work of Geoffrey Rose.[1,2] Rose highlighted the need to examine factors related to interpopulation differences in the distribution of risk factors, rather than factors related to interindividual differences in risk factors within a population. Rose illustrated how population-based strategies that shift the entire distribution of risk factors (e.g., that shift

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the distribution of blood pressure in the entire United States to a lower mean blood pressure level) are likely to have a much greater public health impact than strategies that target individuals at the high end of the distribution within a population (the usual individual-based approach). Implicit in Rose's idea is that distributions are likely to be influenced by environmental factors affecting the population as a whole.

Others have followed Rose in highlighting how environmental factors may shape the distribution of cardiovascular risk. Syme[3] has argued that the effectiveness of individually oriented risk-factor modification approaches may be substantially reduced in settings where environmental factors constrain the initiation or permanence of behavior change. Although intervention trials have demonstrated that it is indeed possible to modify individual behaviors with intensive one-on-one approaches,[4–6] the overall success of these programs in achieving sustained behavior change has been modest, particularly in view of the fact that many of these interventions were quite resource intensive and focused on high-risk and highly motivated individuals. Syme has argued that, contrary to an assumption implicit in much of the behavior change literature, changing individual behaviors in isolation may be more difficult than modifying the environment that facilitates and promotes them. The high prevalence of these behaviors in the community also makes one-on-one approaches highly inefficient. Indeed, the emphasis on individual-level education rather than environmental change has been put forward as one possible explanation for the lack of strong intervention effects in several US community trials to prevent cardiovascular disease. The fact that in some cases differences in behavioral changes between intervention and control communities were not observed despite differences in knowledge suggests that broader environmental changes are required to support and sustain behavior change[7].

Empirical studies of geographic differences and temporal change also suggest that environmental factors are likely to be important in shaping the distribution of cardiovascular risk. Epidemiologic studies have documented important geographic (county-level) differences in coronary heart disease mortality and in the decline of coronary heart disease mortality over time.[8–10] Researchers have argued for the need to examine how features of communities shape the context that gives rise to the presence of cardiovascular risk factors. The rapid increase in body mass index over recent years[11] also suggests that broad environmental factors affecting the population as a whole (rather than genetic factors) are important determinants of cardiovascular risk. Some have argued that the obesity epidemic may be linked to concomitant changes in mass-produced foods and portion size[12] as well as to changes in physical activity associated with urban sprawl.[13]

It is important to note that emphasis on the environmental causes of disease does not negate the importance of behaviors. As suggested by Wing,[9] community socioenvironmental characteristics should be included in the model for the causes of cardiovascular disease, not as competing with risk factor explanations but rather as providing the context that shapes the distribution of these risk factors. In the environmental approach to cardiovascular disease prevention, lifestyle characteristics and psychosocial factors are viewed not as exclusively individual characteristics but as the patterned response of social groups to the external environment, the material and social environment in which people live and work[14]. However, until recently, empirical examinations of the specific ways in which the environment influences cardiovascular risk have been rare.

Several trends have converged in recent years to stimulate interest in how residential environments may influence cardiovascular risk. The first of these has been

increasing concern, in epidemiology, about how neighborhoods, or features of neighborhood environments, may affect health. This interest in residential environments has occurred within the context of revitalized emphasis within public health on the socioecological determinants of health[15, 16] or the multilevel determinants of health more generally. A second factor has been the growing visibility of obesity as a public health problem in industrialized nations (especially the United States); this has stimulated research into the determinants of obesity, including the role of environmental factors in shaping patterns of physical activity in children and adults. A third trend has been increasing interest in interdisciplinary work in understanding population health, motivated in part by the frustration experienced by researchers and practitioners working within a single discipline, which has resulted in increased collaboration and exchange between public health researchers and those in fields such as sociology, geography, and urban planning. These converging trends have resulted in a small but vibrant and growing literature relating neighborhood characteristics and environmental factors generally to cardiovascular risk factors and cardiovascular risk.

This article summarizes findings of this research, highlights its strengths and limitations, and suggests avenues for future development. The first section summarizes three areas of empirical research: work relating neighborhood socioeconomic characteristics to cardiovascular risk, research on residential environments and physical activity, and research on residential environments and diet. Work on other mechanisms through which residential environments may influence cardiovascular risk is also briefly noted. Although the focus is on neighborhoods or residential environments, other environmental determinants (which do not necessarily correspond to neighborhoods) is also mentioned. The emphasis is on the main findings and gaps in knowledge rather than on details of specific studies. The second section of the article outlines key conceptual and methodological challenges in the field, and suggests areas where additional work is needed.

EMPIRICAL EVIDENCE

Neighborhood Characteristics and Cardiovascular Risk

Over the past few years, several studies have documented associations between neighborhood socioeconomic characteristics and cardiovascular risk. Living in socioeconomically disadvantaged neighborhoods (as assessed by area socioeconomic characteristics derived from national censuses) has been linked to higher prevalence of coronary heart disease,[16–18] higher cardiovascular disease mortality,[17,19] and greater incidence of coronary heart disease.[20] These associations persist after controlling for personal measures of income, education, and occupation, suggesting that the socioeconomic characteristics of residents do not entirely explain them. Neighborhood socioeconomic characteristics have also been linked to the prevalence of cardiovascular risk factors, including smoking, dietary patterns, blood pressure, blood lipids, and body mass index.[18,21–24]

Although suggestive, this literature is far from conclusive regarding the presence or strength of neighborhood effects on cardiovascular risk. A major limitation has been the difficulty inherent in accounting for multiple confounders in an observational setting. Thus, the possibility that associations reflect unmeasured individual-level socioeconomic characteristics (rather than an effect of the neighborhood per se) remains. A related issue pertains to the use of aggregate neighborhood socio-

economic indicators as the sole measure of neighborhood attributes. These measures have been used because they are easily available from census data for the areas to which individuals with measured risk factor information can be linked. The rationale for their use has been that they serve as proxies for a variety of more specific features of neighborhoods relevant to cardiovascular risk that have not been directly measured. The inability to measure these specific attributes of neighborhoods and empirically test their effects remains a major limitation of this work. In addition, because the neighborhood characteristics investigated are measures of aggregate socioeconomic status (SES), their use also raises questions regarding whether any residual effects observed result simply from uncontrolled differences in the SES of individuals.

Despite these limitations, the reported associations between neighborhood socioeconomic characteristics and cardiovascular risk are compatible with a broad range of causal processes. Possible pathways linking residential environments to cardiovascular risk are shown in the Figure. Both physical and social features of neighborhoods may be relevant. Accessibility of recreational facilities (including both public and private resources), the presence of sidewalks and bike lanes, transportation, and the design of public spaces may influence participation in sports and other leisure-time physical activity. Availability of sidewalks and bike lanes, design of public spaces, features of urban form (such as building design and setback), land use mix, density of population and activities, patterns of street connectivity, and the aesthetic quality of the areas may affect the extent to which individuals walk as part of their daily lives. Neighborhood aesthetic quality (e.g., the presence of green spaces, interesting features, and pleasant surroundings) may also be related to the experience of stress or the ability to recover after exposure to stressors. Features of the local environment such as availability and cost of healthy

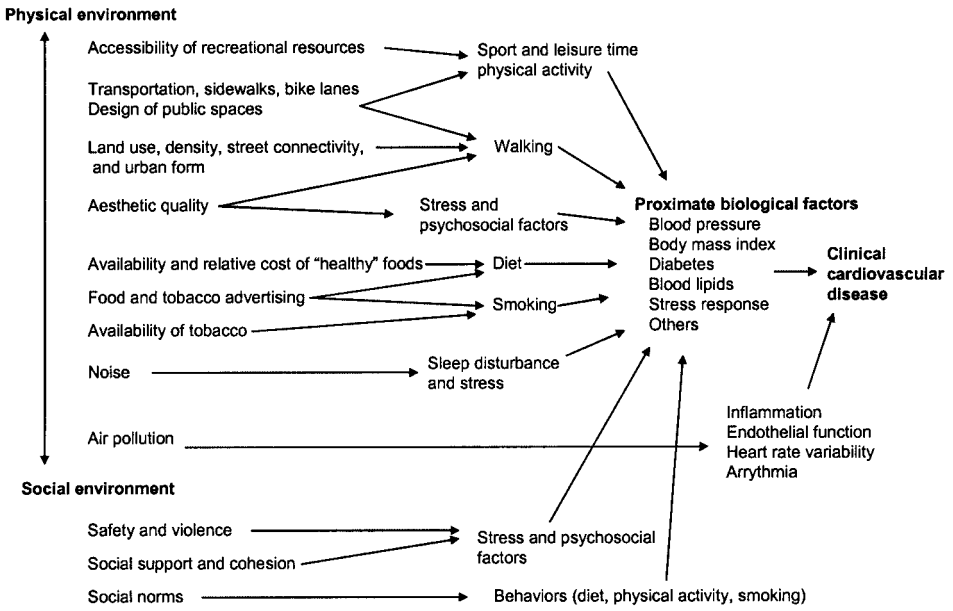

FIGURE Schematic representation of possible pathways linking residential environments to cardiovascular risk.

foods and tobacco products as well as food and tobacco advertising may affect dietary patterns and smoking habits. Noise levels could be related to cardiovascular risk through the effects of noise on sleep disturbance and possibly stress. Air pollution may relate to a variety of biological factors that influence either the development or clinical manifestation of cardiovascular disease.

Features of the social environment may also be relevant. Safety and violence as well as levels of social support and cohesion may be related to the experience of stress and the development of psychosocial factors for cardiovascular disease. Social norms regarding acceptable behaviors may arise or be reinforced in the context of neighborhoods. There are also multiple interrelationships between the domains discussed above. The physical and social environments are likely to influence each other. For example, features of street connectivity and urban design may enhance or detract from social interactions among neighbors and may influence social cohesion as well as safety and violence. Physical features of neighborhoods may contribute to the development of social norms regarding appropriate behaviors. For example, the presence of sidewalks may influence the likelihood of walking and jogging in the area, and seeing others walk or jog may influence the likelihood that a given person will walk or jog. Reciprocal pathways are also likely to be present. For example, greater prevalence of bicycling to work may create advocacy for changes in physical environments more conducive to cycling (such as bike lanes or traffic-calming techniques).

Elucidating whether the differences across neighborhoods in cardiovascular disease outcomes observed in epidemiologic studies do in fact reflect causal processes will require the testing of hypotheses linking specific features of residential environments to specific risk factors and investigating the pathways and processes mediating these relationships. The investigation of these pathways is still in its infancy. Environmental impacts on two specific cardiovascular risk factors, physical activity and diet, have received special attention in the past few years. Existing research on each of these pathways is summarized below. Evidence for other plausible mechanisms linking residential environments to cardiovascular risk, including the effects of residential environments on the development of psychosocial risk factors for cardiovascular disease as well as the possible contributions of noise and air pollution, are also briefly discussed.

Residential Environments and Physical Activity

The investigation of the causes of the epidemic of obesity experienced by many industrialized nations over the past few years has reinvigorated research into the determinants of physical activity. Part of this trend has been increasing interest in identifying environmental and policy determinants of physically active lifestyles in both adults and children.[25, 26] The recognition that short daily episodes of moderate physical activity may be sufficient to produce health benefits has also stimulated research into the factors that promote being physically active in daily life.[27] This work has developed in parallel with (and independently from) research on neighborhoods and cardiovascular risk, although both are obviously closely related.

Humpel et al.[28] have conducted a systematic review of public health research on the environmental determinants of physical activity in adults. They identified 19 quantitative studies that assessed the relationship between perceived and objectively determined physical environment attributes and physical activity behavior. Humpel et al. classified the environmental variables investigated into five domains: accessibility of facilities, opportunities for activity, aesthetics, safety, and weather. Accessi-

bility refers to the presence of recreational facilities and distances to them. Opportunities for activity includes awareness of facilities and satisfaction with them, the availability of sidewalks and equipment, and residents' perceptions regarding opportunities for physical activity in their area. Aesthetics includes the extent to which the local area is perceived as pleasant, attractive, and friendly. Safety includes crime, perceived neighborhood safety, street lights, and traffic. Weather refers to the presence of poor weather. The vast majority of studies reviewed were cross-sectional (18 out of 19) and most (15 out of 19) focused exclusively on perceived features of the environment as opposed to objective measures. Some studies asked participants to report on perceived barriers to starting or increasing physical activity. Others asked participants to report on the existence and location of physical activity facilities in the environment.[28] Only two of the studies reviewed by Humpel et al. used geographic information systems (GIS) approaches to construct objective measures of relevant environmental features.[29,30]

Humpel et al. conclude that the most consistent evidence regarding effects of environmental factors on physical activity in adults is observed for accessibility of facilities, opportunities for activity, and aesthetic qualities of the area. A few representative examples are summarized below. In a population phone survey of nearly 3,400 adults in Australia, Ball et al.[31] found that the men and women reporting a more convenient environment (including proximity of a park or beach, a cycle path, or shops) or a more aesthetically pleasing environment (a friendly, attractive, or pleasant neighborhood) were more likely to report walking for exercise or recreation. Booth et al. also found that access to local facilities was positively associated with physical activity participation in a sample of 450 Australian elderly adults.[32] The presence of enjoyable scenery and the frequency of seeing others exercise were positively associated with being physically active in a population-based multiethnic sample of 2,900 middle-aged US women.[33] Sternfeld et al.[34] found that self-reported lack of facilities was associated with decreased sports and exercise in a sample of 5,000 US women enrolled in a large health maintenance organization. Brownson et al.[35] conducted a national phone survey of nearly 2,000 US adults and found that the odds of meeting physical activity recommendations were significantly higher in persons who reported access to places to exercise, walking or jogging trails, or a park. The presence of sidewalks and enjoyable scenery in the neighborhood was also associated with increased odds of meeting physical activity recommendations. These associations persisted after adjustment for socioeconomic indicators. Awareness of facilities, satisfaction with facilities, and the perception that the area offers opportunities to be physically active were also found to be associated with greater physical activity in other studies.[36–38]

Studies using objective measures have also documented associations between accessibility of facilities or aesthetic quality of the area and physical activity. For example, Sallis et al. found that local density of pay-for-use facilities was positively associated with frequency of exercise.[39] In a probability sample of 1,800 Australian adults, a composite measure of spatial access to built and natural recreational facilities (assessed using GIS methods) and observer ratings of the functional environment (proximity of footpaths and stores) and of the appeal of the environment (low traffic and presence of trees) was positively associated with the likelihood of being physically active.[29] GIS-based measures of distance to bikeways were negatively associated with bikeway use in a cross-sectional study of 400 adults in Massachusetts.[30]

In contrast to the findings for accessibility, opportunity, and aesthetic quality, findings for weather and safety have been mixed. The few studies that have exam-

ined weather as a predictor have found no associations with physical activity.[33, 40] Among approximately 13,000 persons in five US states who responded to a special module included in the Behavioral Risk Factor Surveillance System, those who reported that their neighborhood was unsafe were more likely to be physically inactive.[41] Safety of footpaths was found to be positively associated with physical activity in elderly Australians,[32] but other studies based on US samples have failed to find a relationship between safety or crime and physical activity.[33, 42]

Despite the findings highlighted above, evidence for the impact of residential environments on physical activity remains limited. Associations are often weak and results are not always consistent.[28] Some studies, for example, have found either no positive associations or weak associations between neighborhood features and physical activity,[34,40,43,44] although this may be due to limitations in the measures used. It is also impossible to assess consistency in the strength of associations observed due to differences in the environmental features measured (as well as how they were measured) and in the variables for which results are adjusted.

A major limitation of existing work pertains to the conceptualization and measurement of the environmental features of interest. Most evidence to date comes from isolated questionnaire items as opposed to validated scales. A few studies have combined often disparate items into scores that are hard to interpret. Objective (as opposed to self-reported) measures of environmental features are extremely rare. A limitation of self-reported measures is the possibility that residents who report low levels of physical activity are more likely to also report poor recreational resources in their local area, resulting in spurious associations. On the other hand, poor measurement of the relevant environmental features is likely to result in important underestimates of associations. Promising trends in the development of objective measures include the use of GIS-based measures of resource accessibility[29] and systematic ratings of areas by trained observers on prespecified criteria.[45, 46] More fundamentally, additional work is needed on the conceptualization of the features of residential environments that are likely to be relevant to different types of physical activity (for example, walking, sports, or other leisure time activities).

The development of measurement instruments for theoretically relevant environmental constructs that may be linked to specific types of physical activity remains a key challenge in the field. Thus, future work will need to combine improved environmental assessment with greater specificity regarding the aspect of physical activity studied. One example of this type of approach used multiple observers to rate neighborhoods on attributes related to their "walkability" and related the scores obtained to the likelihood that residents would walk to work.[45] The measurement was enhanced through the use of a scale and multiple raters, whose ratings were used to estimate area attributes using recently developed ecometric techniques.[47] This dimension was then investigated in relation to a specific type of physical activity.

Another important limitation of existing work pertains to its cross-sectional nature. This makes it vulnerable to the critique that the associations observed result from the fact that persons who are more likely to be physically active may choose to live in areas that are more conducive to physical activity. Longitudinal studies, especially studies that relate change in environmental conditions to changes in behavior, are important to strengthen the evidence of a relationship between the environment and physical activity.

In parallel with the public health research summarized above, a growing body of work in urban planning and transportation has investigated how features of the

built environment influence the travel behaviors of individuals, including walking and cycling.[48] Although the determinants of transportation choices and transportation behavior (especially automobile use) have long been of interest to transportation planners, interest in physical activity itself as an outcome is relatively new. The built environment, as defined in this literature, comprises urban design, land development and land use, and the transportation system.[48] Urban design refers to the design of the city and the physical elements within it, including their arrangement and appearance, such as street design and building design, orientation, and setback. Land development and land use refer to the distribution of activities across space, including the location and density of residential, commercial, office, industrial, and other activities. The transportation system includes the physical infrastructure of roads (including street connectivity), sidewalks, bike lanes, railroads, and characteristics of public transport systems. Extensive reviews of how land use and transportation patterns may influence travel choices and physical activity are available (see, e.g., Frank and Engelke,[49] Ewing and Cervero,[50] and Handy[51]) and only selected aspects will be highlighted here.

A large number of studies have focused on relating land development patterns (such as density and land use mix) and transportation systems (such as transit availability and street characteristics) to transportation choices, including walking.[52–56] In a cross-sectional study with Puget Sound census tracts as the units of analysis, Frank and Pivo[54] showed that population density, employment density, and mixed land use are positively related to transit use and walking for shopping and work-related trips. Using data from a household survey of five selected neighborhoods in the San Francisco Bay area, Kitamura et al.[53] showed that residence in a high-density area was positively related to the fraction of nonmotorized trips, and distances to the nearest park and bus stop were negatively related to the fraction of nonmotorized trips. These associations persisted after controlling for household socioeconomic characteristics. Other researchers have also found less travel by car and more nonmotorized travel (such as walking and cycling) in neighborhoods characterized by a mix of land uses, high density, and pedestrian-friendly designs.[55,57] Neighborhoods characterized by proximity and connectivity of trip origins and destinations also appear to enhance nonmotorized travel such as walking.[58,59]

Other aspects of the built environment such as building design, building orientation toward the street, and details of the distribution of homes, stores, and workplaces have also been investigated in relation to walking and travel behavior.[60–63] For example, Cervero and Kockelman[63] found that pedestrian-oriented design (including features of sidewalks, street lighting, and planted strips) encouraged non-auto travel. Cervero and Kockelman[63] and Handy[61] found that residents of "traditional" neighborhoods walked to the store much more frequently than did those in "late modern" neighborhoods. Age of home (as a proxy measure of features of urban form related to pedestrian friendliness) has been found to be positively associated with walking in a national sample of US adults.[64]

Overall, although results from the urban planning and transportation literature suggest that features of the built environment are related to travel and transportation choices, important questions remain.[50,51,59,65] As in the case of public health research on environmental determinants of physical activity, most of the work has been cross-sectional.[66] Until recently, the bulk of the work has focused on decisions regarding automobile travel rather than walking or cycling. Travel choices are influenced by many different variables,[53,57,66] and the complexities of the full range of factors affecting travel choice and behavior are often not fully addressed in analy-

ses.[50,51,65–67] The relative importance of features of the built environment compared to individual attitudes and other individual-level characteristics is still a matter of research and debate. Features such as urban design, transportation characteristics, and land use are often interrelated, making it difficult to disentangle their effects. Different studies have arrived at different conclusions regarding which variables are most important.[49]

From the public health perspective, an additional limitation of the urban planning and transportation literature is that it has focused on transportation choices (of which walking and cycling are two examples) rather than on physical activity itself.[59] Although travel diaries, activity diaries, and time use surveys[48] have allowed detailed quantification of travel behaviors, they often do not provide adequate estimates of physical activity (which may take place as part of travel, e.g., with the purpose of arriving at a specific destination, or not). Handy et al.[48] noted how the models used to predict transportation behavior (both number of trips and choice of transportation mode) have been largely based on the desire to study predictors of automobile use and may not be entirely adequate when studying predictors of walking or cycling. Moreover, in most of the urban planning literature, walking and cycling are studied as modes of travel, not as walking or cycling per se. Predictors of walking and cycling for travel may be different from predictors of walking or cycling during leisure or for physical activity. In addition, walking and cycling are only two of the many forms of physical activity. Other forms of physical activity such as sports or other leisure time activities may also be influenced by features of the built environment. Despite the presence of often sophisticated measures of travel behavior, measures of physical activity in these studies are often limited or absent.

An additional difficulty in research on the effects of the built environment on physical activity pertains to the measurement of relevant features. The measurement of aspects of the built environment (such as land use mix or pedestrian friendliness) that are especially relevant to walking and cycling (as well as other forms of physical activity) is complex and often costly. Few operational measures that can be used in health studies exist. The use of existing data sources and GIS methods to develop measures of specific features of the built environment for both neighborhoods and regions (such as density, land use mix, street connectivity, street scale, aesthetic qualities) is a promising trend in the field.[48,59] Greater specificity in the aspect of physical activity examined (e.g., differentiating leisure time from non–leisure time physical activity) is also important, since specific aspects of residential environments (or of the built environment generally) may be related to some types of activity but not others. Different types of physical activity may show different trends over time[68] and different patterns by neighborhood, and may have made differential contributions to recent increases in obesity rates.

Residential Environments and Diet

There has been growing interest in the ways in which features of the local food environment may be related to the dietary habits of individuals. There is some evidence that the dietary patterns of individuals differ across neighborhoods and that these differences may not be wholly attributable to individual-level socioeconomic characteristics.[21,23]

Neighborhoods may differ in the cost and availability of different types of foods. Small-scale (and often exploratory) studies in the United Kingdom and the United States, usually focusing on the comparison of small numbers of contrasting

neighborhoods, have suggested that healthy foods are less available in deprived communities compared to more affluent ones.[69–71] In the United States, reports from consumer groups and government agencies have also documented differences in the availability and cost of foods across neighborhoods.[70,72–74] Recent research has suggested that in the United States, supermarkets are more likely to be located in wealthier and predominantly white areas,[75] and fruit and vegetable intake was found to be positively associated with the presence of a supermarket in the area, after controlling for personal socioeconomic factors.[76] Other researchers have also found that the availability of healthful (low-fat and high-fiber) products (as assessed by shelf space occupied in community stores) is related to the consumption of healthful foods by individuals living in the area.[77]

Despite the findings noted above, research examining variability in food availability and cost across neighborhoods remains rare, possibly due to difficulties in measuring these constructs in a systematic fashion across multiple areas. Findings may also be highly context specific (differing by city, country, and time period). For example, some studies have found that healthy foods cost more in poorer areas,[71] whereas others have not.[69] In the United States, Morland et al.[75] found more supermarkets in wealthier areas, but in the United Kingdom, Cummins and Macintyre found more large superstores (with greater food availability) in the more deprived areas.[78] Most work has focused on location of stores and, in some cases, availability and costs of some foods. There has been little research relating specific features of the local food environment to the actual dietary behaviors of individuals. In particular, changes in dietary patterns in response to local changes in food availability and cost have not been examined.

Other mechanisms through which the environment may influence dietary patterns include food consumption in restaurants and food advertising. Some work suggests that eating out and consumption of fast foods are associated with increased body mass.[79,80] Larger portion sizes have been shown to be associated with greater energy intake.[12] Food portion sizes are greater at fast-food restaurants than at other types of restaurants and have increased in the United States over the last three decades, with the greatest increases observed for food consumed at fast-food establishments.[81] However, the relation between local availability of different types of eating places and dietary patterns has not been examined. Food advertising is yet another mechanism through which the local environment may affect dietary patterns.[82] Differences in tobacco advertising across neighborhoods have been documented.[83–85] The extent to which these differences also exist for food advertising has not been determined.

Complexities in studying the effects of the local food environment on dietary patterns include disentangling the types and number of stores available from the actual foods offered for sale at these stores. Although some of the research looking at distribution of types of stores is predicated on the notion that large stores often offer better prices and more choice, this may not always be empirically true. Moreover, the location of these large stores (as well as what they offer compared to smaller stores) may differ from context to context (or in different countries) as well as over time, based on economic conditions and the locational strategies of large store chains.[86] Availability of foods and their consumption are likely to be reciprocally related and mutually reinforcing. Cultural factors may play a role in shaping neighborhood consumption patterns, and neighborhood consumption patterns may in turn influence food availability and cost.[77,87] This makes it difficult to empirically

isolate the effects of food cost and availability on dietary patterns in observational studies.

Other Mechanisms Possibly Linking Residential Environments to Cardiovascular Disease

There is some evidence that social support and depression, two psychosocial factors for cardiovascular disease, may be affected by neighborhood physical environments. It has been hypothesized that features of the built environment of neighborhoods (such as the presence and attractiveness of public spaces or the design of homes) may facilitate or discourage social interactions among neighbors.[88,89] The presence of multiple activities within a neighborhood (including residential, commercial, and recreational activities, for example) is likely to enhance connections between residents. People's sense of attachment to their neighborhood may also be influenced by the quality of the built environment. All these factors may influence the social support experiences by residents. Limited data also suggest that living in socioeconomically disadvantaged neighborhoods and other features of the built environment may be associated with increased risk of depression, even after individual-level factors are taken into account.[90–92] Features of residential environments, including aesthetic quality, absence of natural environments, and noise, may serve as stressors. Studies have suggested that exposure to natural environments (as opposed to urban environments) has a stress-reducing or restorative influence.[93,94] Some work has linked exposure to noise with cardiovascular risk factors such as elevated blood pressure and with risk of myocardial infarction, but evidence of this relationship is mixed.[95] Noise and lighting may also affect quantity and quality of sleep, and sleep disturbance has been linked to glucose metabolism[96] as well as cardiovascular risk factors and mortality.[97] Evidence is mounting regarding the possible effects of air pollution (especially small airborne particulates) on the development of cardiovascular disease and the clinical expression of underlying disease.[98,99] Thus, although research remains scant, it is conceivable that noise, air pollution, and traffic could contribute to area differences in cardiovascular risk.

CHALLENGES TO FUTURE RESEARCH

Although existing research suggests that features of residential environments are related to cardiovascular risk, important questions remain regarding whether the observed associations reflect causal processes. Addressing a series of conceptual and methodological challenges in future research may help strengthen causal inferences regarding the presence of these effects. A first set of challenges, which pertains to identifying the relevant environments and characterizing them, is closely related to the need to better specify the theoretical models and processes that may link residential environments and cardiovascular health and empirically test specific hypotheses derived from these models. A second set of challenges is related to study design and the inherent limitations of observational studies in drawing causal inferences.

Characterizing Environments

Definition and Geographic Scale A key issue is defining the appropriate geographic scale for which features of the environment should be measured. In study-

ing the effects of residential environments on health, it is important to recognize that geographic areas of different sizes may be relevant for different processes and outcomes. Features of the immediate residential environment (e.g., the block) may be important for some outcomes (such as social interactions), whereas much broader areas (e.g., the geographic area within which shopping is done) may be relevant for other outcomes (such as dietary habits). Area sizes, features of the area, processes, and outcomes are therefore linked. Different scales may thus be relevant for different research questions.

Most research to date has paid little attention to issues of the relevant scale in studying the effects of residential environments on health, due in part to the necessary reliance on existing data, which is often available only for certain levels of aggregation (and is often not available for the most theoretically relevant level). The need to pay more attention to issues of scale has also been noted in the urban planning literature. In studying transportation choices, for example, Handy et al.[48] note how features of the region may be more important to automobile trips than features of the immediate neighborhood, whereas features of the neighborhood may be more relevant to decisions regarding walking. Thus, comprehensive examinations of how residential environments (or the built environment) are related to cardiovascular risk may need to incorporate multiple measures at multiple scales. A priori theorizing on what constructs and what scales are most relevant to a specific outcome will be key. Qualitative investigations of how individuals relate to their immediate and more distant environments and how features of these environments may affect their decisions and behaviors may also provide guidance on what specific features of built environment are likely to be especially relevant, and therefore worthy of investigation in large-scale quantitative studies.

Although neighborhoods have been the focus of recent research, other built environments such as the work or school environments may be especially relevant for some population groups. The importance of the immediate residential environment and the relevance of other environments to daily life may vary by personal characteristics, time, and place. Thus, research on environmental determinants of cardiovascular risk will need to include the multiple environments that people interact with in their daily lives. It is also important to note that certain factors may be pervasive across a society and thus difficult to identify as determinants of cardiovascular risk in a study that focuses on interindividual differences within a society, even if their impact on the risk of cardiovascular disease is large.[100] For example, mass production and marketing of foods and reliance on the automobile for transportation (with its associated effects on public transportation and facilities for walking and cycling) are pervasive in many industrialized societies. Thus, almost everyone is exposed to environments that stimulate consumption of large amounts of food often high in fat and salt, and everyone is exposed to environments that hinder walking and cycling in daily life. The relevant scale in this case may be the country as a whole, rather than the neighborhood. Studies that focus on interindividual differences within a country will be unable to detect the effects of these ubiquitous conditions.

Conceptualization and Measurement of Relevant Features Another important limitation of existing work pertains to the conceptualization and measurement of the relevant area features. As has been noted in both the public health and urban planning and transportation literatures,[48,59,101,102] a large part of existing empirical work has relied on existing databases to characterize areas. Available data is often used

as a crude proxy for the relevant variables of interest. Promising trends in the measurement of area-level constructs include systematic social observation,[103,104] surveys of area residents, and the use of GIS. Systematic social observation is the technique by which trained observers are sent to the areas of interest to rate them on a series of dimensions in a systematic fashion. Special statistical techniques (ecometrics)[47] are then used to aggregate the ratings of multiple observers per area in order to obtain more valid and reliable measures. Surveys can also be used to obtain information on the characteristics of areas from area residents using validated scales. The responses of different residents within a given area to a series of scale items are then also aggregated to obtain a measure for the area as a whole. An advantage of the use of surveys is that information on area characteristics, such as the aesthetic quality of the area or the availability of recreational resources, can be obtained from a different set of respondents than the outcome measures (e.g., reported frequency of walking or physical activity), thus avoiding the possibility of same-source bias (i.e., when the same person is asked about the availability of recreational resources in an area and the extent to which he or she is physically active). Both of these techniques have been successfully applied in the social sciences to study neighborhood effects on violence and criminal behavior.[105] Their use to investigate how features of the built environment may be related to health outcomes is a promising trend in the field.

The enormous development of GIS technology[106] over the past few years and the increasing availability of geographically coded information have generated enormous possibilities for the study of residential environments and health. The flexibility of GIS measures allows estimation of measures for areas of varying sizes, depending on the research question. A wide variety of measures can be investigated. Examples include measures of density of resources, average distances to resources, and street connectivity.[107,108] However, the conceptualization and development of GIS-derived measures relevant to a specific outcome remains a key challenge.

Study Design and the Limitations of Observational Studies

A large part of existing research linking residential environments or features of the built environment to health outcomes has been cross-sectional, relating health behaviors to features of places of residence at a single point in time. Although some studies have investigated how area characteristics (usually aggregate measures of the socioeconomic environment) are related to mortality, the incidence of disease, or changes in health over time,[17,20,109,110] longitudinal studies that relate changes in area characteristics to changes in health behaviors are still rare. The longitudinal approach would help reduce the possibility of reverse causation as an explanation for the associations observed if changes in residential environments can be related to changes in outcomes. For example, existing work reporting cross-sectional associations between the local food environment and dietary habits is prone to the criticism that food availability may result from dietary patterns, rather than the other way around. Demonstrating a relationship between changes in food availability and subsequent changes in dietary habits in a longitudinal study would help strengthen inferences regarding a causal relationship between food availability and diet.

Clearly, studies of the effects of residential environments on health must include data on both areas and individuals. The individual-level data are of crucial importance for several reasons. Because the persons residing in different types of areas

differ in their individual-level characteristics, it is important to control for these characteristics in estimating area effects. For example, because income is known to be inversely related to physical activity, and persons of low income may live in areas with less resources, it is important to control for personal income in studying whether the area availability of recreational resources is related to physical activity. Another reason for including information on individual characteristics is that area effects may be especially important for some types of individuals and less important for others. For example, the aesthetic quality and safety of the local area may be especially relevant to physical activity in the elderly, who may derive most of their activity from walking in a relatively restricted geographic area. Features of the local area may be less relevant to working adults, who may be less likely to spend time around their homes. The fact that many health-related behaviors are established early in life highlights the importance of studying environmental effects on children, who may be especially vulnerable to the effects of the environments they are exposed to at home or at school.[111–113]

Additional complexity results from the fact that individuals may compensate for deficiencies in their local areas through a variety of mechanisms. For example, persons who live in areas with few recreational resources may still be physically active because they use resources at the workplace. Wealthy persons may live in suburbs with no sidewalks where walking to the store is virtually unheard of, but they may get physical activity by joining expensive sports facilities or health clubs near their workplaces. Relationships may sometimes be complex and extend in unexpected directions. Despite having fewer and poorer quality recreational resources in their local areas, low-income persons living in more disadvantaged neighborhoods may be more physically active than wealthier persons in the suburbs, simply because they walk more due to differences in transportation and features of land use in rich and poor neighborhoods.[114] Failure to consider these compensatory mechanisms and complex relationships would result in an incorrect estimate of area effects on health.

The vast majority of work linking residential environments to cardiovascular risk has been observational. The key problem in observational studies in this field is that persons may be selected into different types of residential areas based on individual-level characteristics that may themselves be related to cardiovascular risk. Although researchers have attempted to account for these individual-level differences by statistically controlling for individual-level variables, the possibility that the area differences that persist after adjustment are due to mismeasured or omitted individual characteristics remains. (It is worth noting that this problem, often referred to technically as residual confounding, is common to observational studies generally and is not unique to this area of research.) This limitation, sometimes referred to as the selection problem, has been repeatedly noted in the social sciences, public health, and urban planning literatures.[53,66,67] Another problem is that, because there is often relatively little overlap between the personal characteristics of persons living in different types of neighborhoods, the statistically adjusted estimates are based on a series of assumptions that may not be empirically testable. One option to avoid the confounding by SES issue noted above is the comparison of neighborhoods selected to be different in built environments (e.g., different mixes of land uses) but similar in socioeconomic composition.[59] Unfortunately, this approach is not always possible because socioeconomic and other features are often correlated.

The limitations of observational studies have led some researchers to call for increasing the use of intervention studies and randomized community trials in the

study of the effects of residential environments on health.[115] Although experimental approaches would obviously solve many of the problems of observational studies, they have their own set of methodological problems, as noted in past work on community interventions to prevent cardiovascular disease.[116–118] One crucial limitation is that it may not always be logistically feasible to conduct a community trial of how features of the residential environment (or of the built environment) affect health. Although the reliance on observational studies is likely to continue, exploring the use of natural experiments or community trials when feasible would be an important step forward in this field. An area likely to yield useful information is the evaluation of the behavioral and health effects of interventions that modify the built environment (e.g., changes in transportation policies such as policies that reduce automobile traffic or interventions that modify features of residential environments such as sidewalks, traffic flow, or green spaces). This approach has been used in the transportation literature, where, for example, case studies of the effects of traffic-calming policies have shown that they generally increase walking and bicycling.[59] To date, the changes in the built environment that occur frequently in many neighborhoods, as a result, for example, of community actions, commercial interests, or government policy, have not been systematically evaluated with respect to their health effects.

CONCLUSION

The recent interest in residential environments is part of a new paradigm in public health which recovers the notion that the determinants of health can be defined at multiple levels. Thus, health depends not only on the biological characteristics of individuals but also on the environments where people live, and these environments are in turn shaped by the economic and social policies driving residential differentiation, and shaping the features of residential environments. This new paradigm views health behaviors as constrained, at least in part, by the environmental contexts in which they occur. Importantly, the word *environment* is used to encompass not only physical and chemical exposures but also features of built environments at multiple levels ranging from the walkability of neighborhoods to the organization of transportation in a large metropolitan area. Under this paradigm, transportation and urban planning policies are, in fact, health policy. Modifying these broad environmental factors may be a more effective mechanism to increase physical activity (e.g., increasing walking by making walking easier, more pleasant, and less costly than driving) than encouraging individuals to go to an exercise facility once a day.[15] Modifying the availability and relative cost of healthy foods may also do more for improving diet than relying on health education campaigns. Environmental and individual-based strategies are likely to be synergistic: environmental change is likely to enhance and facilitate the effects of strategies that focus on individuals, and individual-based strategies may increase awareness of the need for environmental change and may enhance support for this change.

The need to consider environmental contexts in preventing cardiovascular risk continues to emerge in policy documents[119] and initiatives (e.g., the Active Community Environments Initiative at CDC, www.cdc.gov/nccdphp/dnpa/aces.htm). Although the impact of environmental contexts on cardiovascular health may appear to many to be self-evident, rigorous empirical evidence is needed to support calls for policy change and also to help identify the interventions and policies that are likely to be most effective. Key areas for future work include: (a) increasing the

specificity of the hypotheses tested in terms of both environmental factors and health outcomes; (b) improving the measurement of the environmental features of interest; and (c) evaluating the health effects of "naturally" occurring environmental changes (e.g., the creation of a new public space, changes in food availability, or changes in automobile, transportation, or land use policies). In addressing these research needs, work that transcends disciplinary boundaries, bringing together urban planners, sociologists, geographers, behavioral scientists, environmental scientists, and epidemiologists, will be key.

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