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Neighborhood environments, mobility, and health: Towards a new generation of studies in environmental health research

Quartier, mobilité et santé : vers une nouvelle approche des recherches en santé environnementale

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Abstract

While public policies seek to promote active transportation, there is a lack of information on the social and environmental factors associated with the adoption of active transportation modes. Moreover, despite the consensus on the importance of identifying obesogenic environmental factors, most published studies only take into account residential neighborhoods in the definition of exposures. There are at least three major reasons for incorporating daily mobility in public health research: (i) to identify specific population groups, including socially disadvantaged populations, who experience mobility or spatial accessibility deficits; (ii) to study the environmental determinants of transportation habits and investigate the complex relationships between transportation (as a source of physical activity, pollutants, and accidents) and physical activity and health; and (iii) to improve the assessment of spatial accessibility to resources and exposure to environmental hazards by accounting for daily trajectories for a better understanding of their health effects. There is urgent need to develop novel methods to better assess daily mobility. The RECORD Study relies on (i) an electronic survey of regular mobility to assess the chronic exposure to environmental conditions over a relatively long period, and (ii) Global Positioning System tracking to evaluate precisely acute environmental exposures over a much shorter period. The present article argues that future research should combine these two approaches. Gathering scientific evidence on the relationships between the environments, mobility/transportation, and health should allow public health and urban planning decision makers to better take into account the individual and environmental barriers to the adoption of active transportation and to define innovative intervention strategies addressing obesogenic environments to reduce disparities in excess weight.

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Keywords: Active transport; Environmental health; Exposure assessment

Résumé

Alors que les politiques publiques cherchent à promouvoir la mobilité active, les connaissances sur les facteurs environnementaux favorisant l'adoption du transport actif restent insuffisantes. De plus, malgré le consensus sur l'importance d'identifier les facteurs environnementaux obésogènes, les études ne tiennent souvent compte que du quartier de résidence pour définir les expositions. Pourtant, il y a au moins trois raisons de tenir compte de la mobilité quotidienne dans l'espace, et pas uniquement du quartier de résidence: afin (i) d'identifier des groupes de population, notamment défavorisés, qui subissent un déficit de mobilité ou d'accessibilité spatiale aux ressources ; (ii) d'étudier les déterminants

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environnementaux du transport actif et les relations complexes entre le transport (comme source d'activité physique, de polluants et d'accidents) et la santé ; et (iii) de mieux appréhender l'accessibilité spatiale aux ressources et les expositions aux nuisances environnementales en tenant compte des trajectoires de mobilité quotidienne. Il est urgent de développer de nouvelles méthodes pour mieux tenir compte de la mobilité quotidienne. L'étude RECORD s'appuie sur une enquête électronique de la mobilité régulière, afin d'appréhender l'exposition chronique aux conditions environnementales, ainsi que sur un suivi par GPS afin d'évaluer précisément les expositions environnementales sur une période plus courte. Le présent article soutient que les travaux futurs devraient combiner ces deux approches. L'obtention de données probantes sur les relations entre environnements, mobilité/transport et santé devrait permettre aux décideurs de santé publique et de l'aménagement urbain de mieux tenir compte des barrières individuelles et environnementales dans l'adoption de modes de transport actif ; cela devrait également leur permettre de définir des stratégies innovantes visant à modifier les environnements obésogènes pour réduire les disparités d'excès de poids.

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Mots clés : Transport actif ; Santé environnementale ; Évaluation des expositions

1. Theoretical background: review of societal issues and scientific literature

The past 15 years have witnessed the emergence of a flourishing neighborhood and health research field [1]. Studies have reported associations between a wide range of environmental factors measured in local residential neighborhoods and a large number of health-enhancing or damaging behaviors, risk factors of diseases, and health conditions [2]. However, there is a growing consensus that one of the most striking limitations of neighborhood and health studies is their almost systematic focus on residential neighborhoods [3]. This is a major concern because most people spend only a limited fraction of their time in their residential neighborhood.

Following recent calls to incorporate daily mobility in neighborhood and health research [4,5], the present article is interested in the relationships between social position (term 1), geographic life environments (term 2), mobility (term 3), and physical activity and metabolic health (term 4) (overall theoretical framework reported in Fig. 1). Couples or groups of the four key terms on Fig. 1 are successively considered.

1.1. Obesogenic environmental factors and their social stratification

1.1.1. Environmental determinants of obesity

Recent environmental and associated behavioral changes related to the agri-food industry and marketing, food provision in restaurants, urban sprawling, transportation habits (private car), the reduction of energy expenditure at work, and the development of sedentary leisure have created a favorable context for the obesity epidemic (terms 2 and 4 on Fig. 1). In addition to differences between countries, obesogenic environmental factors exhibit spatial variations within countries, with an unequal geographic distribution of environmental resources and exposures influencing obesity even on a local scale (sport facilities, green spaces, fast food restaurants, etc.). To propose innovative and efficient interventions, it is important to assess the extent to which such environmental factors actually influence physical activity, weight status, hypertension, lipid disorders, and type 2 diabetes.

In a systematic literature review that we performed [6], only one of the 131 articles published between 1985 and 2009 on the relationships between geographic life environments and

metabolic risk factors was based on French data [7]. In this body of literature, the identified contextual determinants of excess weight are related both to the effects of the food environment [8,9] and to the effects of the built environment on the adoption of active transportation modes [10].

Ninety percent of the studies examined were exclusively focused on the residential environment and only 4% of them considered information on both the residential neighborhood and another non-residential environment such as the geographic work or school environments [6]. One pioneering study was able to geocode a number of regular destinations of participants – where they lived, worked, shopped, sought medical care, worshipped, and spent other time – but mainly accounted for these locations to correlate neighborhood socioeconomic information with self-reported health [11]. As another approach to account for daily mobility, recent studies have started to rely on GPS technologies to assess the exposure of individuals to their multiple daily environments, in an attempt to explain variations in physical activity levels and dietary behavior [12].

1.1.2. Social determinants of spatial accessibility to resources

The accumulated knowledge in the transportation field suggests that disadvantaged populations face numerous barriers to mobility, and thereby to spatial access to resources (terms 1, 2, and 3 on Fig. 1). A number of barriers to transport are related to individual socioeconomic characteristics (e.g. difficulties to

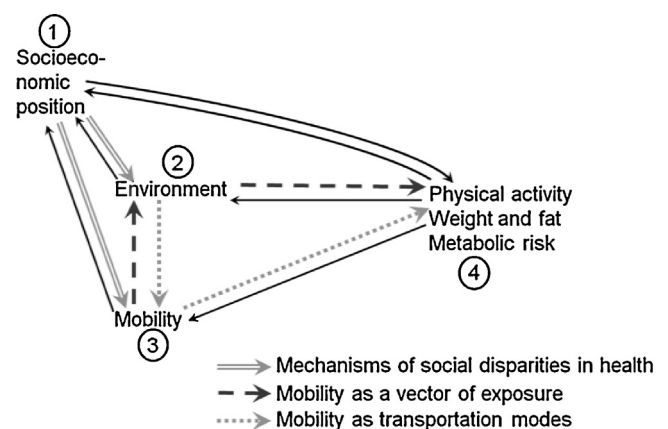


Fig. 1. Conceptual framework for incorporating daily mobility in neighborhood and health research.

access to a driving license, shifted work schedules [13]). Additionally, disadvantaged neighborhoods of urban territories are known for their inadequate provision of public transport in France. This is problematic because the experts emphasize the importance of ensuring the access to mobility to integrate disadvantaged populations and overcome the isolation of certain neighborhoods [14].

Some studies have examined whether the distances covered during trips or the overall surface of the resulting activity space vary according to individual social characteristics or contextual factors [15]. Preliminary findings based on the regular destinations geocoded for each participant in the second wave of the RECORD Study indicate that unemployed people, participants with fixed-term and short-term contracts, and participants with financial problems had a much smaller activity space than more advantaged ones.

Ideally, studies should distinguish three sets of factors to improve our understanding of the determinants of spatial accessibility to resources in disadvantaged neighborhoods:

- individual factors (related to transportation resources, mobility needs, space-time budgets, incapacities for mobility, and mobility preferences);
- the transportation system (cost, type, maintenance of the network, and service arrangements);
- the spatial distribution of services and activities of interest for the individual.

1.2. Social and neighborhood contexts, active transportation, and health

1.2.1. Active transportation, physical activity, and health

In a context where physical activity levels remain too low in France, leading experts recommend, in addition to recreational physical activity, the promotion of active transportation (walking, cycling, use of public transport that increases walking times) [16,17] (terms 3 and 4 on Fig. 1).

While certain publications have reported inconclusive findings [18], a number of studies that relied on individual longitudinal data have documented benefits of active transportation for health. For example, a British study [19] showed that older adults who were using public transportation had a lower risk to become obese over four years (2004–2008). A recent quantitative review that concluded that using public transportation is associated with an increase in physical activity [20] is coherent with this study demonstrating benefits of the use of public transportation for metabolic health. Conversely, in a Chinese study, the use of motorized transportation for more than 5 years over 1997–2006 was related to a 1.2 kg greater weight gain [21].

1.2.2. Transportation habits by social contexts

In addition to the influence of mobility on the spatial access to resources, a second reason for socio-epidemiologists to investigate daily mobility is that social differences in transportation habits have repercussions on the physical activity levels of the different social groups (terms 1, and 4 on Fig. 1). French mobility surveys such as the National Survey

on Transport and Travel (ENTD 2008) suggest that high white collar workers' jobs tend to concentrate in a small number of urban centers and that high white collar workers therefore more frequently use public transport than other groups to go to work. On the opposite, blue-collar workers have their workplaces and residences more frequently located in territories with poor public transportation opportunities, leading to a particular dependence on cars of this social group.

2. Hypotheses in the study of the relationships between the environments, mobility, and health

2.1. The need for an overall theoretical framework

In the theoretical framework reported on Fig. 1, daily mobility refers to the everyday mobility circumscribed by the daily life territory and centered daily on the residence (as opposed to lifelong residential mobility and tourist mobility). The present framework is particularly interested in the two indirect relationships between the environment or mobility and health represented on Fig. 1 by the two successive dotted arrows and by the two successive dashed arrows.

Regarding the “environment → mobility → health” relationship (two successive dotted arrows on Fig. 1), the built environment and land uses influence the adoption (or not) of active transportation modes, which in turn influences physical activity levels, weight status, and metabolic health. Accordingly, transportation behavior may explain part of the effects of social conditions and related geographic life environments on physical activity levels and metabolic risk factors, intervening as a mediator to investigate.

The “mobility → environment → health” relationship (two successive dashed arrows on Fig. 1) points to a second reason of accounting for daily mobility in these studies. This second path suggests that mobility, as a vector of exposure to the various geographic environments visited, determines the environmental resources and hazards to which people are exposed in their daily trajectories. Accordingly, an important reason for measuring mobility is to improve the assessment of environmental exposures.

2.2. Examples of objectives for neighborhood and health research incorporating daily mobility

2.2.1. Social and environmental determinants of daily mobility

Based on Fig. 1, an important aim is to characterize daily mobility in its different components and investigate their social and environmental determinants: the overall spatial behavior of individuals (which refers to the “where” and “when” of spatial mobility), their transportation habits and use of transportation modes (“how”), and transportation-related physical activity (health consequence of mobility).

2.2.1.1. Spatial behavior. Spatial behavior (in fact space-time behavior) refers to the patterns of daily movement in space over time. Spatial behavior has been relatively neglected in the

neighborhood and health literature, which has tended to overlook geographic life environments other than the residential environment.

Intertwined components of spatial behavior include the spatial extent and shape of movement (e.g. overall pattern, internal structure of the activity space), the time structure of spatial behavior (e.g. frequency of movement), and the nature of activities involved. A pragmatic approach for neighborhood and health researchers is to investigate, in a hypothesis-driven perspective, the facets of spatial behavior that matter most for estimating neighborhood effects on health or provide important background information in these studies.

First, it is useful to quantify the extent to which spatial behavior is circumscribed by a given area container that includes the residence (the residential neighborhood, one's municipality of residence, or a definite buffer centered on the residence). Such indicators of spatial behavior (on the extent of clustering of daily trips around the residence) are useful as modifiers in regression models to assess whether residential effects on health are stronger for participants whose daily life is anchored in their residential area.

Second, investigating spatial behavior is useful in subpopulations with a restricted mobility (socially disadvantaged groups, children, elderly people). For example, it is important to determine whether certain socially disadvantaged groups have their activity space restricted by constraint rather than by choice to a local environment with a low level of resources and a high level of stressors [22].

Third, a detailed investigation of the regular destinations of people in a given territory may be useful to list the main types of places that matter (in addition to the residence and the workplace) and that may serve as spatial anchors around which to assess the spatial accessibility to resources (a list of such meaningful anchor points likely varies from one territory to another).

2.2.1.2. Transportation habits. Beyond spatial behavior, it is of interest for epidemiologic research to assess the transportation habits of participants (choices of transportation modes or chain of modes) rather than to only focus on the physical activity levels that result from transport (e.g., through accelerometry). It is useful if the aim is to intervene on physical activity levels through transportation policies.

Of importance, transportation data are analyzable both at the individual level and at the trip level. Individual-level analyses, i.e., with individuals as statistical units, typically analyze outcome variables on transportation habits defined on the basis of the observation period (e.g., 7 days). Examples of indicators include the cumulated length of the trajectory over the period and the time devoted to transportation; and the number of kilometers covered with and the time spent in the different transportation modes.

Conversely, in analyses conducted at the trip level, the database comprises one observation per trip (in the transportation field, a trip refers to the travel between two activity places, while a trip stage is the component of a trip based on a unique transportation mode). Trip-level data make it possible to

investigate individual choices of transportation modes according to individual characteristics, according to the characteristics of the trip (home–work trip or not, distance covered, hour of the day, week or weekend trip, etc.), and according to the environmental characteristics measured at the origin of the trip, at the destination of the trip, and along the trip itself.

2.2.1.3. Transportation-related physical activity. To establish links between active transportation and physical activity or metabolic health, an innovative strategy is to collect over a follow-up period exhaustive information on the transportation modes that are used with the start and end times of the trips and contemporaneous information on physical activity levels. Accelerometry is a valid and reliable method for deriving high-resolution estimates of physical activity intensity, frequency, and duration, in addition to the time spent sedentary, the number of steps taken, and (indirectly) the energy expenditure related to physical activity [23].

Based on these data, an approach to investigate associations between transportation modes and physical activity may be to aggregate these accelerometry outputs:

- at the level of each transportation “stage” (corresponding to the use of a unique transportation mode);
- at the level of each trip (possibly comprising different transportation modes);
- at the level of each transportation mode over the observation period;
- at the level of the entire transport activity over the week and;
- over the whole week.

Such aggregated accelerometry data would permit analyses both at the individual level and at the trip level. Individual-level analyses could focus on the physical activity related to each transportation mode, on the overall transportation physical activity, on the overall physical activity, and on the proportion of the overall physical activity that is related to transportation. Analyses at the trip level would allow one to determine the extent to which trips that include a travel stage by public transportation imply a larger number of steps walked and energy expenditure than trips that include a travel stage by car (e.g., for each 10 min of travel).

2.2.2. Incorporating daily mobility in analyses of the relationships between environmental factors and metabolic condition

Incorporating daily mobility in the determination of environmental exposures should allow researchers to capture in a more realistic way the effects of environmental exposures on health (e.g., obesogenic environmental effects). There are at least two strategies to incorporate daily mobility in the study of the effects of geographic environments on health. A first approach is to rely on tracking technologies to assess daily mobility, often only over a short period (e.g., 7 days). Another approach is to rely on a survey of regular mobility to gather data on destinations that are meaningful over a longer period. In the second wave of the RECORD Study [4], participants are

surveyed with the VERITAS electronic survey application, which integrates interactive electronic maps to facilitate the geocoding of regular activity places. In RECORD, in order to compare these alternative or complementary strategies, we rely both on the VERITAS survey of regular mobility to assess “chronic” environmental exposures and on GPS tracking over 7 days to capture “acute” environmental exposures.

Previous analyses of GPS data conducted at the individual level generally examined the relationship between environmental exposures assessed around GPS locations and physical activity from accelerometry or dietary behavior assessed over the same period (e.g., 7 days). Despite the objectivity and precision of GPS tracking data, a debatable issue is whether it is theoretically relevant to correlate environmental exposures related to mobility over such a short period with a metabolic outcome such as obesity that is determined by chronic processes. A drawback of relying on GPS data to assess environmental determinants of chronic health outcomes is that they may not be representative of mobility patterns over a longer period. Even if 7-day mobility data are more informative than mobility data over one day, they are unable to capture the seasonality of mobility habits; moreover, if one of the days of the follow-up is not representative of regular mobility habits, there is a relatively high probability that some of the other 6 days are non-representative as well (e.g., vacation week, episode of sickness).

Ideally, a strategy may be to assess daily mobility through 7-day GPS tracking a second time, e.g. after 6 months. Such an experiment would allow one to determine the extent to which a second set of GPS data provides additional information and permit to construct more reliable environmental exposure variables.

3. Methodologies for incorporating mobility in environmental health research

As noted above, our RECORD project relies both on an electronic survey of regular mobility (so far 73,200 regular activity places have been geocoded for 5080 participants) and on GPS tracking. The present section focuses on methodological issues related to the hardware and software infrastructure to deploy for the continuous monitoring of mobility with GPS.

3.1. Different strategies to collect data on trips and mobility

3.1.1. Limitations of the classical methodologies of survey of transportation

Retrospective surveys of the trips of the previous day(s) are a classical approach to investigate the transportation habits of populations. However, it is well known that this methodology leads to an underreporting of short trips. Moreover, car drivers tend to underestimate their travel time while users of public transport tend to overestimate it [24]. To address these concerns, travel diaries (filled by the participants during the follow-up period) were increasingly used at the end of the 1990s [25]. However, due to the significant burden for the

participants, this approach often leads to a high non-response rate [26].

Another limitation of declarative data is that they do not provide information on the exact itineraries followed by people. Geomatic algorithms that automatically determine the itinerary between the origin and the destination of the trip are sometimes used to address this concern. However, this approach does not allow one to retrieve the actual itineraries followed by pedestrians and cyclists, overestimating the distances covered on heavy traffic roads. Overall, declarative data are particularly inaccurate to investigate active transportation.

3.1.2. Strengths and limitations of studies based on GPS tracking

GPS technologies may, to some extent, replace traditional methodologies of survey of mobility. First, the use of GPS technologies allows one to improve the precision of trip data: the departure and arrival times at the different places and the time devoted to trips are objectively recorded. Second, studies have shown that GPS tracking permits to capture short trips (including walking trips) underreported with traditional survey methods. Third, GPS technologies make it possible to collect detailed information on itineraries. Fourth, data collection by GPS decreases the burden of work for the participants. Finally, the data collected in this way are immediately accessible in a digital format.

However, there are also difficulties associated with the use of GPS [27]. A first issue is related to the intrusiveness of this data collection approach and to the resulting effect on the rate of participation in studies and on study representativeness. Apart from refusal to participate in the study, a lack of compliance with the protocol (device battery not reloaded every day, etc.) leads to missing data. Moreover, temporary losses of signal result in missing portions of the trajectory [28]. Finally and most importantly, a critical issue is that GPS data do not directly indicate the activities practiced at the different places and the transportation modes that were used, requiring methods of imputation and/or survey of participants.

3.2. Selected methodological issues related to the continuous monitoring of mobility

3.2.1. Integrating the Public Health approach and Transportation approach to GPS studies

GPS tracking is used in different fields of research, including public health and nutrition on the one hand and transportation sciences on the other hand. In public health and nutrition, studies combine GPS tracking with accelerometry. However, these studies often lack information on the activities practiced at the different places and on the transportation modes that were used between each two places. A few studies from the Public health/Nutrition fields have collected information on transportation modes, but collected this information only for a subset of the trips (e.g., only for home–school or home–work journeys) [29,30] or could not establish an exact time correspondence between the trips and the accelerometry data [29]. Alternatively, in transportation sciences, researchers usually combine GPS

tracking with a precise mobility survey, though often only over one day. However, transportation researchers often do not rely on accelerometers, and therefore lack reliable information on the physical activity performed during transportation, as well as complementary information for the identification of transportation modes. Therefore, a key objective for future research is to integrate the Public health/Nutrition approach and the Transportation approach to GPS studies [31].

3.2.2. *The hardware infrastructure to survey mobility*

Studies following participants with GPS and accelerometers were constrained to rely on two separate devices. Even if participants do not have to reload the battery of accelerometers, two devices are less convenient to handle than a unique one. Another improvement of such devices would be to incorporate a GPRS module that permits real-time transmission of data through the GSM network, allowing to detect problems of data collection or nonwear of the device, to immediately process the data and present the GPS tracks in an application, and to improve geolocation by GSM triangulation in the absence of GPS signal.

Apart from smartphones, the few devices available on the market that combine a GPS and a SIM card or a GPS and an accelerometer lack a battery that permits tracking of activity over the whole day from wakeup to bedtime. A device combining a GPS, an accelerometer, a SIM card, and a more powerful battery is under development at the University of Montreal.

3.2.3. *Automatic interpretation of trip data*

After data collection, an automatic interpretation of the data is generally conducted [32]. This data interpretation phase relies on algorithms that attempt to clean the GPS data and segment the trajectory into pieces (through the identification of activity places and trips between these places) [33]. Imputation algorithms subsequently attempt to generate information on the activities practiced at the different places and on the transportation modes. For example, algorithms of detection of activities can rely on geocoded information on the regular activity places of each participant and on geomatic data on land uses, services and facilities, and other points of interest. The aim of such algorithms, at the end of the collection period or during the follow-up in case of real-time transmission, is to impute as much information as possible so as to reduce the burden of the survey for the participants.

3.2.4. *Validation, correction, and complementation of trip data through an electronic mobility survey*

The automatic interpretation of GPS data only provides partial information on the transportation modes and on the activities practiced at the different places. Three options exist in the transportation literature in relation to this concern:

- it is possible to rely only on the imperfect information imputed;
- it is possible to survey only a fraction of the participants and to use the information collected to feed imputation algorithms applied to the other participants (as in the Ohio Department of Transportation study in Cincinnati);

- it is possible to collect survey information on the trips and activities for the whole sample (as we do in our RECORD GPS Study).

Regarding survey methods to collect these data, an approach is to rely on electronic survey applications that stimulate the recall by presenting to the participants their own GPS tracks on a map [34]. These applications are based on online mapping services and allow the users to validate or correct the information imputed by the algorithms.

Advanced functionalities of interest in these applications include tools to edit and complement the itineraries. In order to reconstruct the entire trajectory over the follow-up period, such edit tools allow survey technicians to add undetected stops along the path; to decompose trips into trip stages by geolocating missing points of change of transportation mode; and to report entirely missing portions of trajectories by geolocating a succession of activity places and exact itineraries between them.

4. Conclusion

We believe that the incorporation of daily mobility in neighborhood and health studies and environmental health research will be one of the most striking evolutions of the field in the coming years. There is a clear need to experiment various strategies to assess daily mobility and compare their merits and weaknesses for each particular research design (e.g., electronic survey of regular mobility and short-term GPS tracking).

For an efficient integration of daily mobility in public health research, health researchers will need to establish strong partnerships with transportation researchers (urban planning). For example, relying on a precise mobility survey as performed in the transportation field in combination of a data collection with GPS and accelerometers is almost a necessary development to overcome the limitations of current GPS studies in the field of public health and nutrition.

As concluding considerations, incorporating daily mobility in studies of environmental effects on health is a major step forward towards more realistic models of the interactions between people and their environments. It has important implications for the identification of vulnerable populations, for investigating the health benefits and hazards of transportation, and for a better characterization of the environments to which people are exposed.

More broadly, the advent of a new generation of studies combining multiple sensors of geographic location, environmental exposures, activity and behavior, and health condition will lead to a novel research perspective, with analyses performed at an infra-individual level that permit to investigate the daily circumstances that influence behavior.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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