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Neighbourhoods in eco-epidemiologic research: delimiting personal exposure areas. A response to Riva, Gauvin, Apparicio and Brodeur

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In their article “Disentangling the relative influence of built and socioeconomic environments on walking: the contribution of areas homogenous along exposures of interest” in this issue, Riva and colleagues propose an original approach for designing residential areas, to more accurately assess associations between environmental factors and health (Riva, Gauvin, Apparicio, & Brodeur, *in press*), following previous efforts in this domain (Chaix, Merlo, & Chauvin, 2005; Chaix, Merlo, Subramanian, Lynch, & Chauvin, 2005; Chappell, Funk, & Allan, 2006; Flowerdew, Manley, & Sabel, 2008; Tatalovich, Wilson, Milam, Jerrett, & McConnell, 2006).

Building on these efforts, our aim is to deal with this critical but largely unsolved question: how to define neighbourhoods and how to operationalise them? Even if both qualitative and quantitative investigations are needed, the present commentary explicitly restricts its scope to the design and treatment of neighbourhoods in large-scale quantitative studies, with a particular focus on urban environments. We successively discuss the theoretical conceptualisation, operational measurement, and analytical treatment of neighbourhoods, an omnipresent but poorly defined concept in the eco-epidemiologic literature.

Theoretical considerations on the definition of neighbourhoods

Referring to the “neighbourhood” as to a geographic area for which we aim to measure attributes, we now discuss a number of conceptual distinctions relevant to its definition (Chaix, 2009).

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Territorial neighbourhoods vs. ego-centred neighbourhoods (fixed vs. sliding boundaries)

As a start, an important distinction is that between *territorial neighbourhoods* and *ego-centred neighbourhoods*. As collective bodies (Merlo, Ohlsson, Lynch, Chaix, & Subramanian, *in press*), territorial neighbourhoods are entities that have a social consistency independent of a specific individual. As their key characteristic, territorial neighbourhoods often refer to the *mutually exclusive areas* that make up a territory (Guo, 2007). Administrative areas or service catchment areas correspond to this territory-subdividing approach to neighbourhood delimitation, but more complex definitions of territorial neighbourhoods may consider built environment features, population characteristics, historical or social processes, and collective representations (Chappell et al., 2006; Flowerdew et al., 2008; Gauvin et al., 2007).

In contrast, the eco-epidemiologic research conveys an ego-centred or personal definition of neighbourhood entities, which is also obvious in the notion of “context”. Considering the neighbourhood from an individual’s viewpoint, we define it as a *local exposure area*, i.e., an area allowing us to capture accurately the environmental conditions to which an individual is locally exposed.

Rather than mutually exclusive, ego-centred neighbourhoods, e.g., neighbourhoods centred on individuals’ residences, may clearly overlap with each other. Whereas territorial neighbourhoods have fixed boundaries, ego-centred neighbourhoods imply sliding boundaries (e.g., moving with the exact residence).

Territorial neighbourhoods are perfectly adequate for sampling participants, investigating between-area variability, or randomising

environmental interventions. However, except in specific cases (e.g., factors related to administrative functioning), territorial neighbourhoods may not be particularly suited to the measurement of individuals' exposures. Thus, in the remaining of the commentary, we particularly focus on ego-centred neighbourhoods, unless otherwise specified.

Residents' perceived vs. objectively experienced neighbourhoods

Participants' subjective experience of community is often cited as an ideal source to assess neighbourhood boundaries (Chappell et al., 2006). However, environmental psychologists have emphasised that resident-perceived delimitations, as a cognitive construct, are one component of the self-definition (we are where we live, in our own and others' definitions). Consequently, an individual may exclude a very close and particularly deprived block from her/his own neighbourhood definition, even if daily exposed to it. Thus, resident-perceived boundaries (what individuals want them to be), and to a greater extent resident-reported boundaries (expressed to others, e.g., during a survey), may not reflect true local exposure areas.

An alternative approach is to consider the extent of the local space of activity, to draw neighbourhood boundaries on the basis of each individual's most frequent local destinations. However, this approach only considers *direct* physical exposures to construct neighbourhood delimitations, neglecting more *indirect* physical exposures (e.g., visual contact with a nearby sharply different neighbourhood), which may not be adequate for certain exposures (e.g., environmental stress). Second, in specific cases, it may be relevant to measure environmental factors not in individuals' *actual* activity space, but in their *potential* activity space (e.g., employment market conditions in the area where someone would look for a job).

Fuzzy vs. sharp or clear-cut neighbourhood boundaries

In most applications of ego-centred areas, neighbourhood boundaries imply a binary definition of whether any part of space belongs or not to a given neighbourhood. Each spatial location is either ascribed to or excluded from the neighbourhood space, without any intermediary situation. When defining ego-centred neighbourhoods, such sharp or clear-cut neighbourhood boundaries may be adequate when a major physical obstacle (e.g., a highway, a river) is present. However, in most cases, probably much smoother transitions exist between the inner and outer neighbourhood space, resulting in fuzzy rather than clear-cut boundaries.

Individual-specific vs. uniform definition of the neighbourhood scale

As noted by Spielman (Spielman & Yoo, 2009), the spatial extent of neighbourhood is systematically defined in a uniform way for all study participants. However, social sciences have long recognised that the scale of one's perceived or experienced neighbourhood is individual-specific, i.e., dissimilar for distinct individuals even if they reside, e.g., in the same building. For example, researchers have shown that the neighbourhood scale is shaped by individual sociodemographic characteristics (e.g., age, length of residence in the neighbourhood, or socioeconomic position) (Guest & Lee, 1984).

Oriented vs. isotropic neighbourhoods

In the common approach defining circular buffers centred on residences, researchers make the assumption of *isotropic neighbourhoods*, i.e., neighbourhoods spreading equivalently in every

direction around the dwelling. However, this hypothesis contradicts basic observation.

From their residence, individuals are often more familiar with the streetscape in certain directions than others, i.e., more familiar with places in directions where they usually walk to. Thus, local exposure areas are often *oriented neighbourhoods*, with their shape distorted in the direction of, e.g., the closest major road, shops, or transportation station.

Multi-scale vs. single-scale definition

As commonly stated, different contextual exposures/resources often need to be measured on a different scale. It would be nonsense to measure on a similar scale the local environment to which an individual is exposed when walking from home for recreation and the employment market characteristics to which she/he would be exposed when looking for a job. Sociological research suggests that this hierarchical conception of place is compatible with the perception of residents, who often view their very local area as encapsulated within larger meaningful areas (Guest & Lee, 1984).

Residential vs. non-residential environments

With the increased spatial mobility of modern lives, daily trajectories of individuals are less than ever contained in their local residential environment. It is thus a critical limitation that virtually all studies, with remarkably rare exceptions (Inagami, Cohen, & Finch, 2007), have exclusively focused on the *local residential environment*. However, there is debate on how to conceptualise this major shortcoming. Is it most relevant, as suggested by Cummins (Cummins, 2007), to put the emphasis on the "*local trap*" of previous literature, i.e., on its implicit belief that the local level is always the best scale for analysis? Or is the most severe limitation of previous studies related to the *residential trap*, i.e., the fact that non-residential environments are systematically neglected?

Obviously, the appropriate strategy to incorporate information on geographic work environments is not to broaden the scale of measurement so as to include both the residence and workplace in large-scale contextual variables. A more promising avenue to account for non-residential environments is to consider a collection of local geographic environments, including the residential environment, the geographic work environment, leisure-time environments, etc.

Overall, these theoretical considerations suggest that complementary sets of neighbourhood boundaries, with distinct rationales, scales, and shapes, are needed to assess environmental exposures, depending on the study territory, the population, the specific individuals, the environmental factor, and the health outcome under study.

Operational delimitation of neighbourhoods

Based on this theoretical ground, we now review approaches to operationalise neighbourhood delimitations (Chaix, 2009).

Manual delineation of neighbourhood boundaries

Considering well-known limitations of administrative boundaries, recent studies have developed manual strategies to define territorial units taking into account population characteristics, physical or historical specificities, field assessment reports, and perception of local key actors. However, as our focus is on ego-centred neighbourhoods, these territory-subdividing approaches

are not further reviewed here (Chappell et al., 2006; Gauvin et al., 2007; Lebel, Pampalon, & Villeneuve, 2007; Weiss, Ompad, Galea, & Vlahov, 2007).

Manual approaches also exist to define ego-centred neighbourhood delimitations. Coulton and colleagues have relied on residents' mental maps, i.e., maps drawn by study participants, to define neighbourhood boundaries (Coulton, Korbin, Chan, & Su, 2001). They suggest that this procedure may be applicable to much larger samples than theirs. And indeed, it is not unreasonable in eco-epidemiologic survey protocols to spend as much time to assess neighbourhood boundaries as to measure health outcomes, e.g., overweight or blood pressure.

Using the same manual strategy, a complementary approach may be to assess, not residents' perceived neighbourhoods, but residents' objectively experienced neighbourhoods through map-based surveys of their most common local destinations, allowing researchers to apprehend the scale and shape of their neighbourhood.

Automatic approaches to define neighbourhood boundaries

As an alternative strategy, we now review automatic procedures to define neighbourhood boundaries.

Homogeneity as a criterion to define neighbourhoods? Homogeneity of environmental exposures is commonly cited as a criterion to define neighbourhood boundaries (Riva et al., in press). This conception is rooted in the criticism towards studies defining contextual variables at a very broad area level that true local environmental exposures are dissolved in these heterogeneous areas. While this is true, it does not necessarily imply that true environmental exposures on a local scale must be assessed within strictly homogeneous areas.

Indeed, individuals may be exposed to differing environmental conditions in their local environment. For example, in her/his 4-min morning walk to the transportation station, an individual may cross a particularly unsafe block that is sharply different from her/his quiet nearby block. If individuals are exposed to heterogeneity in their residential environment, then our measures should capture it. Moreover, considering homogeneity to define neighbourhoods is likely to result in extremely irregular areas that have nothing to do with realistic exposure areas. Finally, this approach in the end ascribes to each individual the exposure level prevailing in her/his own parcel.

Overall, area homogeneity is perhaps relevant for defining primary sampling units or implementing interventions (Gauvin et al., 2007), but not as the sole criterion to define exposure areas.

Operational approaches to define ego-centred neighbourhoods. The most common approach to operationalise ego-centred boundaries is to draw circular buffers around individuals' residences (Fig. 1, part A). However, a limitation of this technique is to ignore that every portion of the local space is not equivalently accessible, because of the structure of the local street network. As shown in Fig. 1 (part B), a refined approach is to define street network-based ego-centred neighbourhoods. Varying in size and shape, street network-based buffers may allow researchers to account for certain physical barriers in neighbourhood definition or reflect that certain portions of the street network (enclaves) are not importantly connected to the other parts of the city (Grannis, 1998). In addition to impermeable barriers (e.g., a railway, a river), refined network analysis algorithms may incorporate permeable barriers that contribute to restrict neighbourhood extension (e.g., a major road that one would only occasionally cross, major changes in population characteristics).

In most cases, there are no sharp or clear-cut neighbourhood boundaries. As another refinement of automatic procedures (Fig. 1 part C), an approach to operationalise fuzzy neighbourhood delimitations may be to incorporate weights defined as a decreasing function of the street distance from residence in the computation of contextual exposures (Chaix, Merlo, & Chauvin, 2005).

Street-centred vs. block-centred measures? Because of census block data, we have been used to conceptualise neighbourhood elementary units in terms of housing blocks. In contrast, recent work in social sciences has highlighted the importance of residential streets in shaping neighbourhood space, indicating that what matters is "who or what is down the street rather than mere physical distance" (Grannis, 1998).

Consider two blocks A and B separated by a street, with block faces A_1 and B_1 being face to face. Obviously, an individual residing in block face A_1 would be affected to a greater extent by block face B_1 than by block face A_3 on the other side of block A. Thus, *street-level measures* combining data on A_1 and B_1 are certainly more relevant than block-level measures combining data on A_1 , A_2 , A_3 , and A_4 . Data on socioeconomic variables, services, etc. geocoded at the address level incorporating street

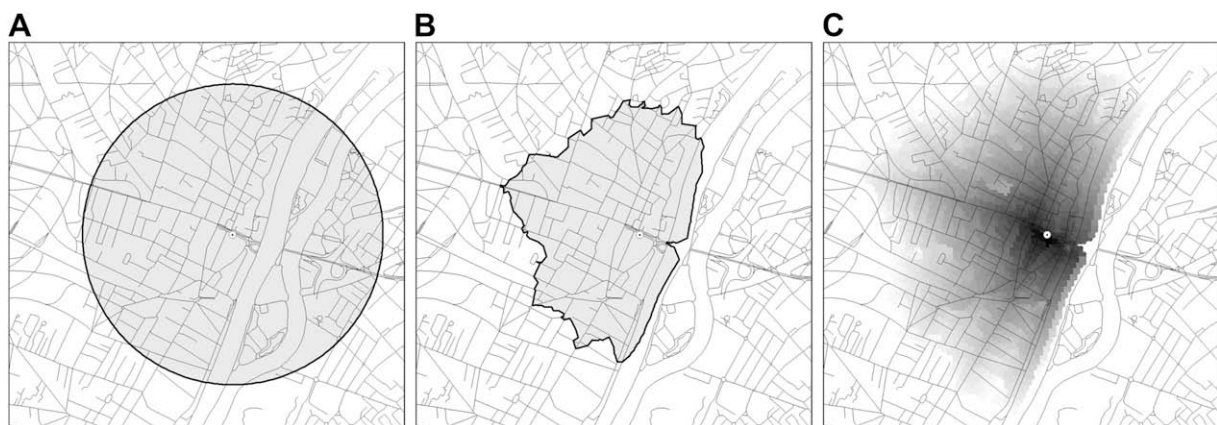


Fig. 1. Procedures to implement ego-centred neighbourhoods, e.g., neighbourhoods centred on individuals' residences: circular buffer (part A); street network-based buffer (part B); neighbourhood with fuzzy delimitations operationalised with a decreasing function of the street network distance, allowing investigators to weight data when computing contextual variables – the darkest the colour, the higher the weight (part C).

identification codes may allow researchers to operationalise street-level variables.

Incorporating individual-specific information on the neighbourhood scale in automatic design processes. Is there any way to integrate individual-specific information into automatic procedures to define neighbourhood delimitations? If precise knowledge was available on how individual characteristics influence the size of one's local neighbourhood in the territory under study, it would be conceivable to adapt the scale of exposure areas in function of individual characteristics during the design process.

A second approach, intermediary between the latter and mental maps, is to develop a series of close-ended questions, e.g., asking whether one's perceived neighbourhood includes only one's residential street or a larger number of streets; or inquiring about the walking time to cover one's neighbourhood. Using this information, individual-level adjustments may be incorporated in procedures to design neighbourhood boundaries with a reasonable level of accuracy.

As a conclusion, challenges for future research include the development of both manual strategies and automatic procedures to define neighbourhood boundaries.

Operational issues for the measurement of non-residential environments

Clearly, a critical preliminary step is to account for geographic work environments (distinct from work environments themselves) in eco-epidemiologic studies. However, practical difficulties include the fact that in many occupations, the geographic work environment is not centred in a specific location. Thus, protocols to geocode geographic work environments considering particular occupational situations need to be developed.

Perhaps still more difficult is the geocoding of other geographic life environments (e.g., those for leisure activities). Many of these environments may only have a diffuse spatial centre, or people may ignore the exact street addresses needed for the geocoding. Moreover, many people may have no specific environment for e.g., shopping or leisure activities, either if they do not accomplish these activities, if they accomplish them in their residential or geographic work environment, or if they go in a large number of different environments for these activities. For these reasons, it may be more difficult to compare individual health on the basis of these other geographic life environments characteristics than on the basis of their residential or geographic work environments, which are likely to be more influential.

Analytic treatment of neighborhood entities

In this final section, we are interested in strategies to compare alternative definitions of neighbourhood boundaries, to determine which is the most appropriate to capture the effect of an environmental exposure on health.

Fixed effect modelling

A standard approach is to compare different sets of area delimitations for an environmental factor on the basis of its strength of association with health. This intuitive approach is grounded on the assumption that an improper assessment of exposure area boundaries would result in the dilution of the effect, thus only in the underestimation (not the overestimation) of the strength of the environment–health association. Based on a recent claim that this approach is flawed (Spielman & Yoo, 2009), it is

important to assess whether or not the most efficient risk stratification based on a contextual exposure (e.g., between the 25% with the highest and lowest exposure levels) necessarily corresponds to the situation where the environmental factor is measured on the true exposure scale.

A complementary strategy is to rely on model fit indicators to compare models with neighbourhood effects assessed with different area delimitations. In published studies, changing the scale sometimes had a non-negligible impact on model fit indicators (Chaix et al., 2006). Overall, even if changes in neighbourhood definition are likely to result in modest model fit improvements, a better definition of exposure area boundaries is part of a more global process aimed at reducing multiple sources of bias and measurement error in eco-epidemiology.

Overall, we do not fully agree with Spielman's conclusion that "theoretical not technical criteria should be used to evaluate different conceptualisations of geographic context". Of course, theory is a preliminary necessary step, but an empirical criterion is critically needed to assess whether additional refinements in measurement are analytically relevant or superfluous.

A possibly efficient strategy to delimitate exposure areas may be to correlate an environmental factor defined for different neighbourhood scales and shapes, not with a health outcome, but with individuals' perception of the extent to which the environmental attribute is present in *their* neighbourhood (e.g., correlate the surface of green spaces with the perceived availability of parks in one's neighbourhood).

Random effect modelling

As recently suggested (Merlo, 2003; Merlo et al., in press), random effect modelling and estimation of health clustering is an efficient way to assess the relevance of alternative definitions of area boundaries, and their usefulness to public health intervention. Clearly, this approach may be suited to the identification of territorial neighbourhoods defined as socially meaningful collective bodies. However, it is not adapted to the assessment of ego-centred neighbourhoods as *personal* exposure areas, within which it would be pointless to assess health similarities between individuals. Thus, sensitivity analyses in risk stratification based on associations between different formulations of an environmental factor and health may be one of the only approaches available to evaluate ego-centred area delimitations.

Analytic treatment of non-residential exposures

Future research will have to explore strategies to incorporate non-residential exposures into analytic designs (Inagami et al., 2007). It will be relevant to explore correlations between residential and non-residential exposures, to assess whether the latter may confound the effects estimated in the literature. Distinct approaches include testing the independent effects of residential and non-residential exposures, considering cumulative measures combining them, and investigating modification hypotheses (e.g., if non-residential environment resources moderate harmful effects of the residential environment).

Conclusion

Our aim was to emphasize that eco-epidemiologic studies correlating neighbourhood characteristics with health should often conceptualise neighbourhoods as personal exposure areas, which should be carefully distinguished from territorial neighbourhoods as social collective entities. Overall, our recommendations for future research are (i) to consider both perceived and objectively

experienced neighbourhoods, (ii) to account for the possibility of fuzzy rather than sharp, individual-specific rather than uniform, oriented rather than isotropic, and multi-scale rather than single-scale neighbourhood delimitations, and (iii) to incorporate both residential and non-residential environments into the analyses. Several strategies, either based on manual or automatic procedures, were suggested to achieve these objectives. Critically, we also note that this research avenue will be fruitful only if we can rely on an empirical criterion allowing us to reliably distinguish between analytically sound and superfluous refinements in the measurement of neighbourhood delimitations.

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