An Interactive Mapping Tool to Assess Individual Mobility Patterns in Neighborhood Studies

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Abstract: As their most critical limitation, neighborhood and health studies published to date have not taken into account nonresidential activity places where individuals travel in their daily lives. However, identifying low-mobility populations residing in low-resource environments, assessing cumulative environmental exposures over multiple activity places, and identifying specific activity locations for targeting interventions are important for health promotion. Daily mobility has not been given due consideration in part because of a lack of tools to collect locational information on activity spaces. Thus, the first aim of the current article is to describe VERITAS (Visualization and Evaluation of Route Itineraries, Travel Destinations, and Activity Spaces), an interactive web mapping application that can geolocate individuals' activity places, routes between locations, and relevant areas such as experienced or perceived neighborhoods.

The second aim is to formalize the theoretic grounds of a contextual expology as a subdiscipline to better assess the spatiotemporal configuration of environmental exposures. Based on activity place data, various indicators of individual patterns of movement in space (spatial behavior) are described. Successive steps are outlined for elaborating variables of multiplace environmental exposure (collection of raw locational information, selection/exclusion of locational data, defining an exposure area for measurement, and calculation). Travel and activity place network areas are discussed as a relevant construct for environmental exposure assessment. Finally, a note of caution is provided that these measures require careful handling to avoid increasing the magnitude of confounding (selective daily mobility bias).
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Introduction

Neighborhood and health studies have focused on the environmental correlates of diseases.[1–3] However, despite refinements to assess residential environments (e.g., in circular or street network areas centered on the residence; with geographic databases, audits, or survey of residents),[4,5] studies have not taken into account, with few exceptions,[6–9] individuals' nonresidential activity places.[1,4,10–15] The result has been a mischaracterization of environmental exposures.[16]

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A recent review[1] of studies on cardiometabolic outcomes indicated that as much as 90% of the 131 reviewed studies accounted only for the residential environment; 6% took into account only nonresidential exposures (e.g., workplace or school); and only 4% accounted for both residence and another "anchor" point. This failure to take into account an individual's intimate connection with multiple geographic places (or spatial polygamy)[15,17] is one of the main limitations of neighborhood and health studies.[13,18] Accounting for daily mobility patterns and activity spaces is important for health promotion, as it allows identification of low-mobility populations with access to only low-resource/high-exposure residential environments and mobile populations traveling across exclusively low-resource environments; accurate assessment of environmental exposures in multiple activity places; and determination of appropriate activity places (e.g., residence or workplace) for targeting specific interventions.

To aid in developing a new generation of neighborhood and health studies that fully account for individual mobility patterns, the present article first describes the VERITAS

Table 1. Glossary of technical terms/expressions

Activity space	Set of spatial locations visited by an individual over a given period, corresponding to her/his exhaustive spatial footprint; the regular activity space is the subset of locations regularly visited over that period
Contextual expology	Subdiscipline focusing on the spatiotemporal configuration of exposure (spatial and temporal patterns of mobility) for improving measurement of environmental exposures (not the "what" but the "where" and "when" of exposure[14]); it relates to the collection and transformation of locational information to define a spatial ground of measurement and to the extraction and aggregation of environmental information on this basis to derive environmental exposure variables
Daily mobility	Everyday movement of individuals over space between activity locations
Multiplace environmental exposure	Exposure to a given environmental characteristic across the multiple locations visited
Raw locational information	Any information on the spatial location of individuals at any point in time in their life in the format in which it was collected (e.g., in traditional studies, the identification code of the current residential administrative unit was the only raw locational information available)
Selective daily mobility	Selective daily mobility refers to the fact that people who visit particular activity places during their daily lives have particular characteristics (e.g., sociodemographic, psychological, or cognitive characteristics; behavioral habits) that also influence their health status
Spatial anchor points	Spatial anchors or pivots[14] (also termed reference locations,[19] fixed activity places,[20] bases, or core stops[21]) refer to daily life centers[12,22] (1) in which individuals spend a substantial portion of their time; (2) which have important material and symbolic meanings; (3) around which individuals organize their daily activities; and (4) to which people are relatively obligated to go (the spatial fixity and temporal rigidity[21] of these quasi-obligatory activities imply that they cannot be easily relocated or rescheduled[20,23])
Spatial basis/ground of measurement	Most commonly, one or several polygon(s) but possibly polyline(s) or point(s) derived through a transformation of raw locational information and used to extract environmental data to calculate the exposure variable of interest
Spatial behavior	Frequency and spatial patterns of mobility (multidimensional construct described in Table 2)
Travel and activity place network area	As a geographic system,[22] such a network comprises (1) local activity spaces centered on major or minor daily life centers (that are also travel hubs) and (2) optional destinations isolated or not from these activity spaces, all of which are related to each other by (3) transportation corridors (not collected in VERITAS-RECORD) allowing no exchange, little exchange, or substantial exchange with the surrounding environment depending on such factors as transportation modes, time constraints, and preferences[19,24]

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application (Visualization and Evaluation of Route Itineraries, Travel Destinations, and Activity Spaces), a tool for researchers to geolocate individuals' activity places, routes between locations, and area delimitations of interest. Second, the paper attempts to formalize the theoretic grounds of a contextual expology (Table 1) and discusses methodologic challenges related to the assessment of "spatial behavior" (individual patterns of movement in space) and multiplace environmental exposures.

An Interactive Geolocation Survey Tool

The VERITAS application relies on a questionnaire-form builder that allows development of custom strategies to collect spatial information. For ease of presentation, VERITAS is described using the example of the VERITAS-RECORD (Residential Environment and CORonary Heart Disease) questionnaire designed for the RECORD Study,[25–31] which focuses on relationships among geographic life environments, individual mobility, and risk factors for cardiovascular disease. VERITAS-RECORD, for which scientific rationale is provided below, is illustrated in Figure 1 and in a video (Appendix A, available online at www.ajpmonline.org).

The VERITAS application is a web-based computer tool that integrates Google Maps interactive mapping functionalities that allow one to search for, visualize, and geocode participants' activity locations and to geolocate routes between locations and area delimitations such as perceived/experienced neighborhoods. A computer-assisted questionnaire guides participants through a spatiotemporal cognitive journey (succession of screens with questions and interactive maps) intended to facilitate the reporting of spatial information (point data, polylines, polygons) and minimize memory bias. As the two components of the application, survey questions serve as prompts to stimulate recall, whereas electronic maps generate more geographically accurate information than does a simple questionnaire.

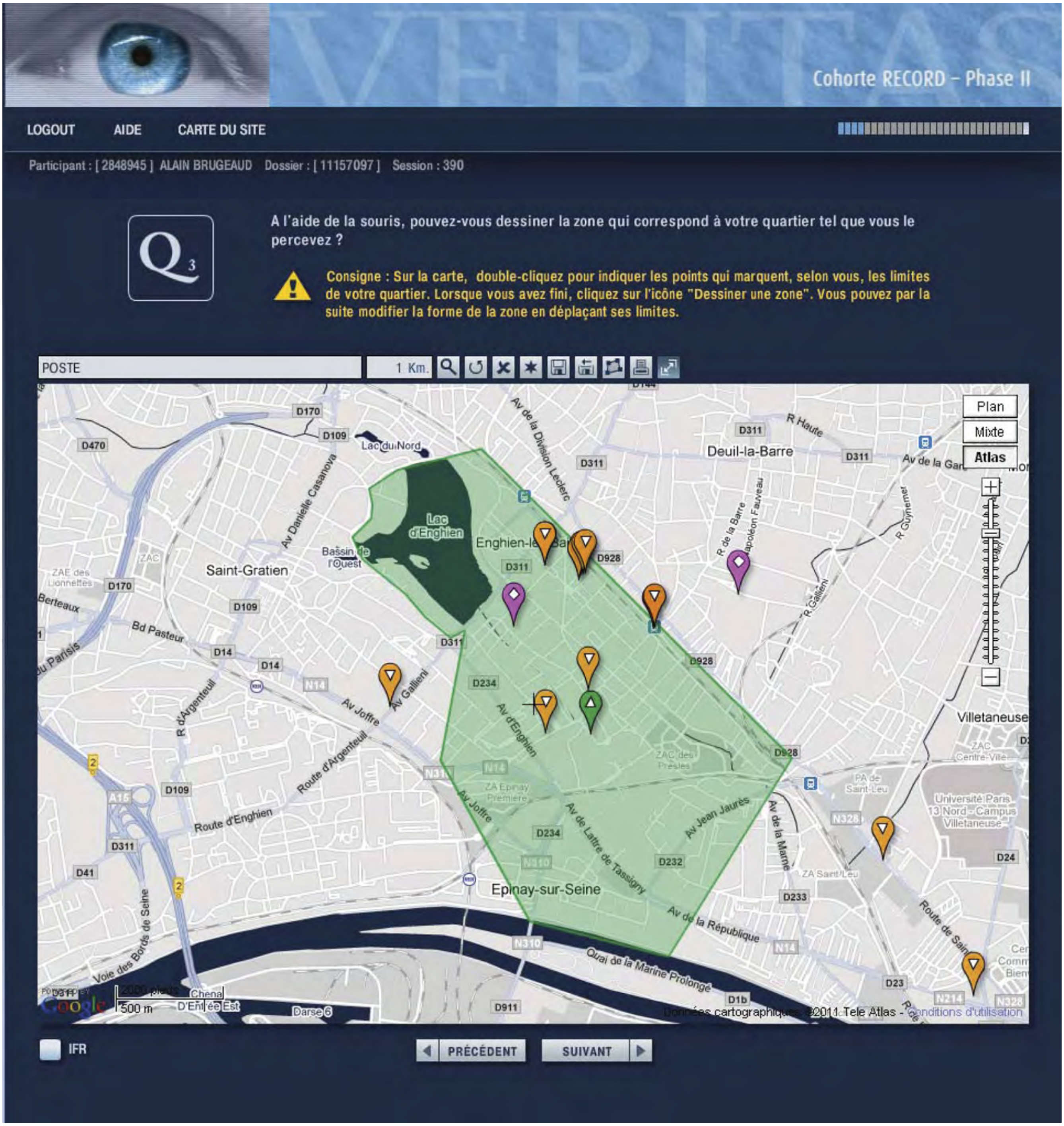

Figure 1. Screen copy of the VERITAS-RECORD application

Note: The application allows geolocation of participants' network of regular destinations and assessment of the perceived boundaries of their residential neighborhood (green polygon). The following activity places are geocoded in RECORD (not only places associated with health-related activities but any regular destination, as relevant to environmental exposure assessment): place of residence, secondary or alternative residences, workplaces, supermarkets, outdoor markets, bakeries, butcher shops, fruit and vegetable shops, fish stores, cheese merchants, other specialized food stores, tobacco shops, banks, post offices, hair salons/barbers, transportation stations used from the residence, sports facilities, entertainment facilities, places for cultural activities, places for community or spiritual activities, places where participants take relatives, and places where they visit people (healthcare destinations were assessed from another source).

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In VERITAS-RECORD, participants are successively asked to geolocate the list of activity places reported in Figure 1 (35,997 activity places have been geocoded for the first 2500 participants in the RECORD Study). For most activity types, participants are invited to report destinations they visit at least once a week. No particular recall period, such as "over the past 6 months," was specified. As exceptions to the once-a-week minimum frequency, participants are asked to geolocate workplaces where they spend at least one third of their working time; supermarkets they visit at least once a month; and regardless of frequency, their bank, post office, and hair salon/barber (constructing activity spaces from activity places with varying minimum-visit frequencies was found to be relevant).

These data do not allow distinctions between participants who do not engage in a specific activity regularly from those who do but in varying locations. This aspect of VERITAS-RECORD is an accepted consequence of its focus on visits to given locations, not on activities themselves. For each activity category, several activity places may be reported.

The interactive geolocating tool is based on the Google Maps Application Programming Interface, allowing users to search addresses and identify services around a location (with a parameterizable search radius). It is possible to save activity place markers retrieved by searches or to create markers by double-clicking on the map. A Google Street View screen is embedded in the application to help participants pinpoint activity places.

In VERITAS-RECORD, the polygon-drawing functionality enables participants to draw the perceived boundaries of their residential neighborhood (Figure 1). A video tutorial showing how to draw the polygon is presented to the participants before the assessment (explanatory multimedia material can be embedded in the application). Once drawn, the polygon shape can be remodeled by moving the vertices on the screen. The participants are asked to draw their perceived neighborhood boundaries, and then to geocode their regular destinations. This order of steps is used to ensure that representation of regular destinations on the map does not influence assessment of neighborhood boundaries. Thus, it will be possible to investigate whether and which regular destinations shape perceived neighborhood delimitations. By contrast, conducting the assessment in the reverse order (geocode local activity places first) may improve accuracy in the assessment of perceived neighborhood boundaries.

For each geolocated spatial object, whether a point (location); a polyline (e.g., a trip); or a polygon (e.g., one's perceived neighborhood), users can provide attribute data pertaining to the object through a small window connected to the object. In VERITAS-RECORD, participants are invited to report the frequency of visits to each destination; the extent to which they feel attachment to their residential neighborhood and geographic work environment; and additional information on particular types of activity places (e.g., indoor or outdoor workplace, transportation mode used, type of sport or entertainment activities).

In RECORD, the VERITAS questionnaire is administered by two trained survey technicians continuously supervised by a field coordinator, who is supervised by the principal investigator. Participants sit near the technician to see the computer screen and can show locations on the map to facilitate geocoding. Data are entered by the technicians but, if they wish, participants can draw their perceived neighborhood boundaries on the computer. Technicians are instructed to take the time needed to help participants less familiar with electronic mapping applications (e.g., older people, low-SES participants) correctly geolocate their destinations. Median time to administer VERITAS among the first 2500 participants was 19 minutes (interdecile range: 12–38 minutes). Self-administered questionnaires are possible with VERITAS but have not yet been tested.

The VERITAS-RECORD data are downloaded daily from the SQL database on a remote server and checked with a semiautomatic database management program. For example, the program verifies addresses, number of activity places geocoded per participant, supermarket names, other place attribute data, and whether the residence is actually within the self-drawn neighborhood. The resulting report is discussed every day with the technicians. The authors also are developing a parameterizable web-based version of VERITAS that allows users to collect declarative locational data with other spatial or temporal formats than those currently investigated in RECORD (e.g., routes, sequences of trips over a short period).

Accounting for Daily Mobility in Contextual Expology: Opportunities and Challenges

As distinct from life-course residential mobility[32] (which also can be surveyed using VERITAS), daily mobility is defined as the everyday movement of individuals over space between activity places. Daily mobility is of interest in environment–health research,[11] as both a potential source of transportation-related physical activity[33,34] and as a vector of exposure to geographic environments.[12,16,35–38] A diagram and accompanying text depicting the "environment, mobility, and health" triad (Figure 2) emphasize the rationale for investigating mobility.

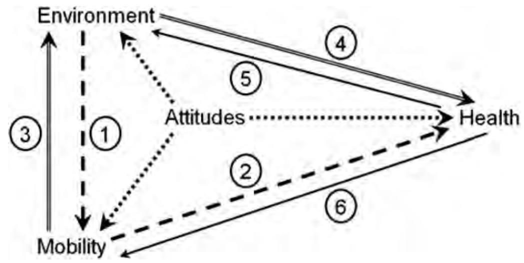

Figure 2. Theoretic illustration of the environment, mobility, and health triad

Note: The environment influences mobility (Relation 1) and health (Relation 4). Mobility, through the degree of engagement in active transport, influences health (Relation 2). Mobility is a vector of exposure to multiple environments (Relation 3). Health status may require people to live and travel in specific environments (Relation 5), and it may influence mobility through handicaps (Relation 6). The two mediated relationships with health as the final outcome are of particular interest: (1) the environment may influence health through mobility habits (thick dotted lines, Relations 1 and 2), suggesting that further investigation is needed of active transport as a mediator; (2) mobility influences health in shaping the environments to which individuals are exposed (double lines, Relations 3 and 4), indicating the need for development of a contextual expology. It is hypothesized that preferences related to activity places, mobility modes, and health behavior are correlated, thereby creating potential confounding (narrow dotted lines).

Strengths and Limitations of Surveys of Regular Destinations and GPS Tracking

How do surveys of regular destinations[25] (e.g., VERITAS-RECORD) compare with GPS tracking[16,39–44] and other strategies (e.g., travel surveys or diaries)[11,19] for collecting information on an individual's activity locations beyond the primary residence? Based on participants' recall, surveys of destinations provide declarative data, whereas passive tracking yields objective data. Additionally, the resulting data differ in both their spatial and temporal dimensions. For the spatial dimension, GPS technologies provide nearly continuous polylines, whereas classical surveys of destinations collect only point data (even if regular routes also could be surveyed).[45]

For the temporal dimension, surveys of regular destinations can assess travel destinations of significance over a long period, whereas GPS tracking identifies (almost) exhaustively destinations over more-restricted periods (i.e., chronic versus acute environmental exposures). Moreover, GPS data indicate the temporal sequence of places visited (space–time path[11]), whereas surveys of regular activity places provide nonsequential data on temporally disconnected activity locations.

In the RECORD study, assessment is made of both regular destinations that are meaningful over a long period (using VERITAS to investigate environmental determinants of chronic conditions) and mobility over 1 week (using GPS tracking to explore environmental determinants of behaviors such as physical activity). Short-term tracking data may represent poorly locations visited regularly over a long period of time. Therefore, surveys of regular destinations and GPS tracking provide complementary information for an improved contextual expology.

Biases from Integrating Regular Mobility in Contextual Exposure Evaluation

Accounting for mobility in contextual exposure assessment is a promising avenue, but researchers need to be aware of potential biases. With multiplace exposure variables, the aim is to improve stratification of true environmental exposures. However, if not carefully constructed, such measures simultaneously may increase stratification relating to other constructs that influence health. Thus, although accounting for multiplace exposure can improve exposure stratification, it may at the same time increase residual confounding. The potential for *selective residential migration* to confound residential neighborhood effects is widely recognized.[46–48] Similarly, *selective daily mobility* (Table 1), through which possibly unmeasured factors influence both daily destinations and health, is an additional source of confounding that can distort associations between multiplace environmental exposures and health.

Assessment of environmental determinants of a behavioral outcome is particularly prone to bias[16] if the locations to which people specifically travel to do the behavior are incorporated in the measures of multiplace exposure to the environmental characteristics investigated. For example, including the parks where people actually exercise when defining spatial access to such facilities would likely result in a biased estimate of the corresponding effect. Indeed, in cases where frequenting locations associated with a behavior is often a marker of willingness to do the behavior (e.g., frequenting fast-food restaurants as an indication of a personal taste for high-fat foods), measures of multiplace exposure that directly take into account such behavioral contexts could spuriously stratify individuals according to their willingness to practice the behavior.

Although confounding is particularly expected for environmental resources supporting behavior, it is also possible when direct health effects of environmental hazards (e.g., air pollution, low SES, social violence) are examined. For example, being exposed to a given hazard in multiple environments provides information not only on exposures but also, for example, on preferences/aversions for particular aspects of neighborhoods and related life values, which are themselves potential health determinants. Overall, nonresidential environmental effects are particularly prone to bias, because the nonresidential environments visited are, to a larger extent than residential neighborhoods, a matter of immediate and flexible choice. Any increase in the strength of associations when taking into account multiplace rather than exclusively residential exposures may be attributable to not only improved stratification of exposure but also confounding from selective daily mobility.

Deriving Indicators of Spatial Behavior and Multiplace Environmental Exposure

Characterizing Spatial Behavior

It is of general interest in neighborhood and health studies to characterize individuals' spatial behavior (frequency and spatial patterns of mobility).[8] The extent to which individuals' daily trajectories are circumscribed by residential neighborhoods likely modifies residential neighborhood influences, with weaker effects expected for mobile populations.[49] This fact may explain why specific groups (e.g., seniors, the disadvantaged) are more sensitive to residential neighborhood exposures. In a more elaborated contextual expology, spatial behavior is a key determinant of exposure: individual sociodemographic and psychological profiles and specific environmental characteristics (e.g., access to public transportation) influence individual spatial behavior,[50] which in turn determines environmental exposures.

The VERITAS-RECORD survey of regular destinations and assessment of perceived neighborhood boundaries allow characterization of spatial behavior as a multidimensional construct. Based on VERITAS-RECORD, quantitative indicators of spatial behavior can be developed (Table 2) that relate to the overall extent and shape of individuals' activity space[8,50,51,53,55] (individuals' spatial range[17] or spatial scope[53]); to the internal structure of the activity space; and to the status and importance of the residential neighborhood in the overall activity space. A relevant summary of these indicators also can be generated by defining typologies of spatial behavior.

Such measures are useful in identifying low-mobility populations and spatial exclusion or captivity.[50] It is ac-

Table 2. Summary of options (among others) to characterize spatial behavior[a]

I – Geometric representation of the activity space through overall convex polygons as ecologic containers[51] (and related quantitative parameters)
A – Application
1 – Overall activity space (all types of destinations)
2 – Domain-specific activity space (e.g., food-purchasing space, healthcare-seeking space)
B – Tools
1 – Standard deviational ellipse[52] or confidence ellipse[50] (centrographic measure, point pattern analysis): reflects, with its optimally oriented major and minor axes, the location, coverage, dispersion (ratio of major to minor axes), and orientation of a set of points[51–53] (weighted or not by visit frequencies)
2 – Home–work ellipse[54]: with the major axis of the ellipse going from the residence to the workplace as the two foci of the ellipse, with the minor axis determined by the farthest other activity place
3 – Convex envelope[53]: smallest convex polygon containing a set of points
II – Internal structure of the activity space
A – Number of regular destinations and related visit frequencies
B – Activity space structured around a unique or multiple daily life centers
C – Distance between destinations (standard distance[53]) or daily life centers
D – Extent of clustering of minor activity locations around daily life centers[22]
III – The residential neighborhood in the overall activity space
A – Extent of the self-drawn residential neighborhood
B – Extent to which activity destinations are comprised in the self-drawn residential neighborhood or in fixed-radius street-network residential buffers
C – Relative indicators comparing residential environment characteristics to nonresidential environment characteristics
D – Comparison of the effectively used resources to the resources available from the residence
IV – Summary typologies characterizing individual patterns of mobility (e.g., through the application of cluster analysis to numerous spatial-behavior variables)

[a]All the indicators described can be defined with the VERITAS-RECORD data.
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Table 3. Summary of decisions/options related to the assessment of multiplace environmental exposures

I – Collection of raw locational information
A – Data collection tool: survey of regular destinations, GPS tracking, travel diary over few days
B – Data available
1 – Geocoding at the area level → area-level information
2 – Assessment of experienced or perceived neighborhood → area-level information (calculation of exposure in Step IV without any preliminary transformation)
3 – Collection of activity locations → point data
4 – Collection of activity locations and imputation of shortest paths → point and linear data (determination of *shortest path network areas* in Step III)
5 – Collection of activity locations and travel paths → point and linear data (determination of *travel path network areas* in Step III)[a]
6 – Collection of chronologic activity locations, travel paths, and time constraints → point and linear data (determination of *daily potential path areas* in Step III)[a]
II – Selection of locational information
A – To minimize confounding from selective daily mobility:
1 – Exclude activity places visited for the behavior of interest
2 – Only retain major/minor spatial anchor points
B – Remove from locational data routes traveled by transportation modes that hinder contact with the environment (e.g., underground trains or subways)[a]
III – Transformation: deriving a spatial basis of measurement
A – Overall convex activity space polygons: likely inappropriate
B – Measurement in travel and activity place network areas
1 – Simple buffering of raw locational information
a – Type of buffering (e.g., straight-line or road-network distance, time of access)
b – Radius size depending on:
the nature of and frequency of visit to each component of the route and activity place network
the environmental resource/exposure to measure
individual characteristics (e.g., with shorter radii for low-mobility individuals[12,60])
the study territory
the health outcome
whether a measure of potential or actual contact is of interest
2 – Kernel density estimation to derive measurement areas on the basis of a certain threshold in the intensity of visits to the area (as determined from the distance from individual spatial locations and frequencies of visit of these locations)[50]
3 – Clustering techniques applied to the raw locational information to derive measurement areas (e.g., spatial scan statistics)[61]
IV – Algorithm for the calculation of exposure
A – Operator to apply (e.g., average exposure, minimal exposure, maximal exposure[12])
B – Cumulative environmental exposure or separate variables for residential and nonresidential exposures
C – Weighting function: according to distance from participants' locations, proportional to the frequency of visit, dependent on travel speed and type of transportation mode[62,a]

[a]Refers to data that were not collected and approaches that cannot be implemented with the RECORD Study version of VERITAS.
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knowledged that these crude indicators of spatial behavior (rather than spatiotemporal behavior,[53] which was only partially assessed in VERITAS-RECORD) do not capture complex spatial and temporal interdependencies among activity places[17] (e.g., multistop trip chains[56]). In addition, activity spaces reflect actual spatial behavior, as distinct from both potential activity spaces (all places where an individual could have been, given her/his space–time constraints) and mental maps (perceptual action space[21]). The latter are personal cognitive constructs and, as such, include both locations to which people go and locations to which they do not go or have never been but of which they have a mental representation.[50,57]

Deriving Indicators of Environmental Exposure: Moving Toward a Contextual Expology

Recent work promotes improved measurement of neighborhood characteristics with random-effect modeling of survey/audit data[58] or GIS (a field referred to here as to ecometrics).[59] Whereas ecometrics focuses on the *content of exposures*,[4] there is a need to develop a contextual expology (Table 1) as another subdiscipline focusing on the *spatiotemporal configuration of exposures*. Such a focus will allow researchers to define multiplace or activity space–bounded measures of exposure.[38]

A contextual expology involves four steps (Table 3): (1) *collection* of raw locational information for participants (where and when); (2) *selection* of raw locational information to retain for exposure measurement; (3) *transformation* of raw locational information collected as point data (activity places), polylines (travel paths), or polygons (perceived neighborhood geolocated, area-level geocoding) in a spatial basis or spatial ground for the measurement of environmental exposures (most often areas but possibly polylines or points as the basis to extract environmental information); and (4) linkage of environmental information for *calculation* of exposure measures. Data collection (Step 1) is discussed above; below is a discussion of the selection (Step 2) and transformation (Step 3) of locational information for measuring environmental exposures.

Deciding Which Locational Information to Retain/Discard for Exposure Assessment

A relevant distinction when selecting locational information for exposure assessment is whether the focus is on direct effects of environmental hazards on health or on the influence of accessibility to environmental resources on health behavior. For assessments of accessibility to environmental resources that influence behavior, it is critical to exclude from the set of locations considered for measurement places that people intentionally go to for doing an activity related to the behavior investigated (e.g., exclude places visited for outdoor recreational activities when assessing accessibility to green/open spaces). To correct the expected bias, which has been described recently,[16] it is important, with a regular destination survey or GPS tracking, to collect information on activities practiced at the various places visited, in order to select locations to use in assessing spatial access to behavioral opportunities.

A safer but restrictive strategy to compute accessibility to resources is to determine it from spatial anchor points only[12,22] (defined in Table 1). Such anchor points primarily include the residence and workplace, but also minor daily life centers such as a child's school or parents' residence around which it is meaningful to compute accessibilities.[63] However, restricting measurement areas to a limited number of anchor points may lead to discarding too much relevant locational information.

Finally, selection of activity places for measurement is necessary but insufficient, as choices of daily life centers such as the residence or workplace are themselves determined by preferences that also influence outcomes of interest. Therefore, a complementary strategy is to develop questionnaires that capture personal criteria for choosing daily life environments and cognitive variables related to health behavior (e.g., attitudes/beliefs related to the behavior, willingness and motivation to engage in the behavior) that influence which environments are visited. This strategy can provide improved adjustment of regression models.[4,48,64]

Transformation of Raw Data to Define the Spatial Basis of Measurement

Convex activity-space polygons (ellipses or convex envelopes derived from all activity places collected in VERITAS-RECORD) are likely not appropriate for assessing exposures. Even after elimination of outliers,[53] a convex activity-space polygon based on all travel destinations and routes often does not reflect the territories that are familiar to an individual[50]: such a polygon may indeed encompass areas to which the individual does not go[38] (Figure 3).

Rather than using overly broad convex areas (*joint transformation* of all activity places in an overall polygon), it is likely more relevant to derive measurement areas by buffering all or part of the travel and activity-place network geometry[13,22] (defined in Table 1, Figure 3). Such *feature-by-feature transformation* of the components of the network provides a travel and activity-place network area that more closely reflects hazards or re-

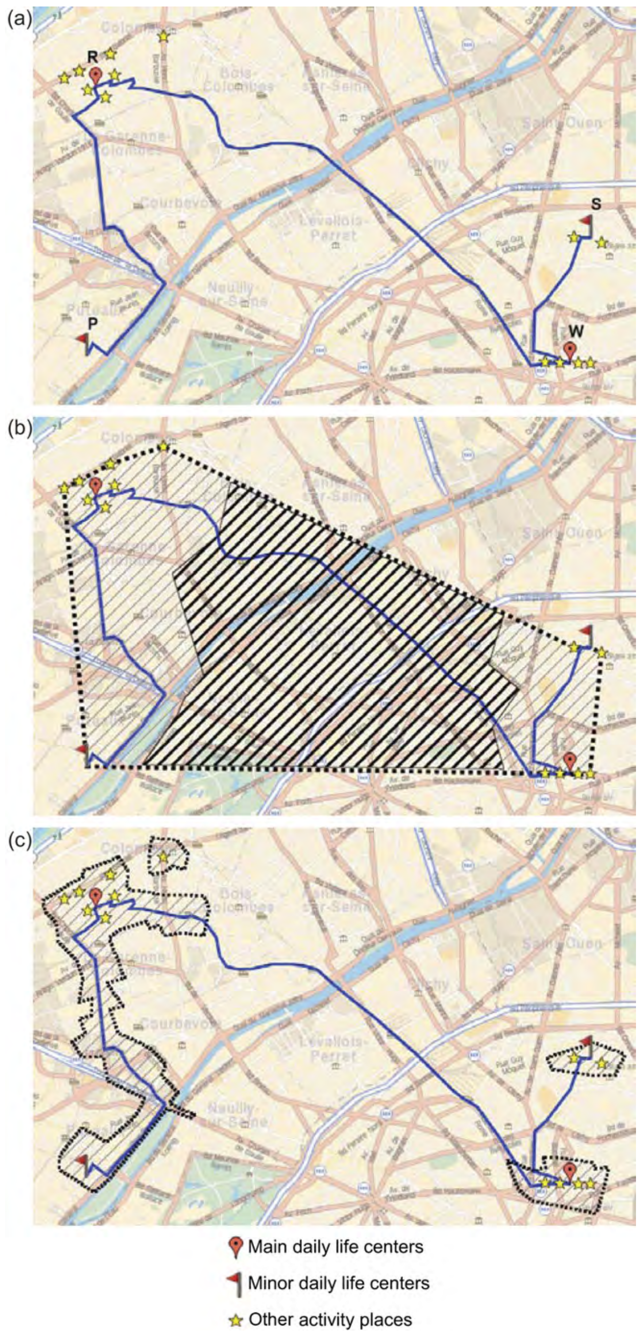

Figure 3. Difference between overall convex activity spaces and travel and activity-place network areas in measurement of environmental exposures (hypothetic example)

Note: (a) The raw locational information collected: main daily life centers, minor daily life centers, other activity places, and travel paths to the main activity places (e.g., collected from VERITAS). (b) An overall convex activity space defined as the convex envelope of all activity places and routes. The bold dashed lines in the middle refer to areas with which the participant is not at all familiar, given that a high-speed train is used to travel from home to work. In (c), an exposure area based on the notion of travel and activity place network is derived by buffering the activity places and walking and driving travel paths, after excluding trips with the high-speed train or underground train (from home to work and from work to the sports club, respectively).

P, an individual's parents' residence; R, residence; S, regularly visited sports club; VERITAS-RECORD, Visualization and Evaluation of Route Itineraries, Travel Destinations, and Activity Spaces-Residential Environment and CORonary Heart Disease; W, workplace

sources along daily trajectories. Other transformations to derive measurement areas include kernel density estimation and cluster detection techniques (Table 3).[50,61]

Buffering provides various types of measurement areas depending on the raw locational information collected (Table 3). When regular destinations are surveyed but not the routes between them (as in VERITAS-RECORD), an approximate[54] strategy is to generate road-network travel paths between daily life centers (e.g., between the residence and workplace) and between daily life centers and nearby functionally affiliated activity places.[50] Buffering of these imputed travel routes (shortest-path network areas) may improve measurement of environmental exposures.[8,19,24]

To take data requirement one step further, Kwan's space–time measures of potential access[19,24] account for the chronologic order of activities in the daily schedule; for time–budget constraints between consecutive activity places (in fact the time that was actually used rather than the time that was available[54]); and for the speed of travel between locations. However, such measures inspired by time geography,[23] in which spatial access depends on the time budget, generally are based on short-term travel diaries (e.g., 2 days). Thus, they would be difficult to construct for assessment of chronic environmental exposures over a longer period.

Buffering of raw locational information implies specifying the type of buffering and radius size (Table 3). An important criterion in determining radius size is whether the measure of interest should reflect potential contact or actual contact with the environment (i.e., potential versus experienced activity spaces[12,13]). Measures of potential contact are derived by buffering the observed spatial footprint with a certain radius, whereas measures of actual contact are obtained by restricting the radius size to zero (and extracting exposure values at the exact locations of activity places and travel paths) or close to zero. Measures of potential contact are useful, for both environmental resources and exposures, in approximating the exposure area of participants when no information is available on an individual's usual patterns of movement around geocoded locations.

By contrast, when the exact spatial footprint over a time period is known, measures of potential contact are not useful for evaluating exposures to environmental hazards (measures of actual contact are more informative). But potential contact measures remain useful in evaluating accessibility to environmental resources (e.g., services). Strategies to determine buffering-radius size include a mixture of hypothesis-based reasoning and exploratory sensitivity analyses comparing radius sizes.

Conclusion

The VERITAS application and related theoretic considerations aim to help foster a next generation of studies, with refined research questions, novel data, and a fresh set of analytic strategies. Such developments can contribute to a paradigm shift from the "neighborhood and health" classical dyad to a "neighborhoods, mobility, and health" triad. These more realistic empirical models of contextual/ecologic determinants of health that integrate rich information on individual spatial behavior will provide more-informative support for public health decision-making. An important issue for service provision is to identify low-mobility or spatially isolated populations that lack spatial access to resources. Moreover, accurate assessment of (multiplace) environmental exposures and their health effects will help in prioritizing public health interventions.

BC and YK made equal contributions to this paper.

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Appendix

Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.amepre.2012.06.026.