Residential buffer, perceived neighborhood, and individual activity space: New refinements in the definition of exposure areas – The RECORD Cohort Study

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ABSTRACT

Neighborhood effects on health have been widely investigated; yet the definition of neighborhoods is usually arbitrary. This study analyses how disparities in environmental exposure according to urbanicity vary when considering a home-centered network-buffer, the perceived residential neighborhood, or the activity space. Exposures to the density of destinations and proportion of green space were compared for three spatial definitions of exposure areas, overall and stratified by urbanicity of the residence. Environmental exposure levels and gradients by urbanicity were found to vary depending on the spatial definition of the exposure area.

Keywords: Environmental exposure, Residential buffer, Perceived residential neighborhood, Activity space, Selective daily mobility bias.

HIGHLIGHTS

Comparison of exposure estimates between residential and activity space exposure area

Exposure estimates vary depending on the spatial definition of exposure area

Gradient of exposure by urbanicity vary by exposure area definition

INTRODUCTION

The previous decades have witnessed a renewed focus on the effect of environmental factors on population health. More recently, technological developments in the collection of locational data and advances in spatial analytic methods have opened up new possibilities to observe and analyze space-time exposures and go beyond the commonly used residential neighborhood (Chaix, 2009; Diez Roux, 2001; Kerr, 2013; Pickett and Pearl, 2001; Riva et al., 2007). Yet, such advances call into question which environments or exposure areas are relevant.

Commonly used definitions of the exposure area in place and health studies include administrative neighborhoods (i.e. census tracts, postal codes) and residence-centered circular or street network buffers areas (Leal and Chaix, 2011). More recently, participants' perceived residential neighborhoods have been proposed as an alternative (Chaix et al., 2009; Vallée et al., 2014; Vallée and Shareck, 2014). The perceived residential neighborhood relies on the participants' cognitive construct of their neighborhood (Coulton et al., 2001; Guest and Lee, 1984). Substantial differences in the measures of environmental exposures (park availability, commercial physical activity facilities, restaurants, and food stores) were observed between the residential and the perceived neighborhood (Colabianchi et al., 2014).

These definitions of the exposure area are however exclusively focused on the residential neighborhood, even if individuals are mobile and get exposed within a variety of environments (Chaix et al., 2009; Matthews, 2011; Matthews and Yang, 2013; Perchoux et al., 2013; Shareck et al., 2014a; Shareck et al., 2014b). Exposure outside the residential neighborhood might differ from exposure within the residential neighborhood (Basta et al., 2010; Inagami et al., 2007; Kestens et al., 2012; Kestens et al., 2010; Lipperman-Kreda et al., 2015; Mason, 2010; Setton et al., 2011; Zenk et al., 2011). Most studies accounting for exposure beyond the residential neighborhood have used the concept of activity space - i.e. the set of daily visited activity locations (Golledge and Stimson, 1997) - to operationalize personal areas of exposure.

Despite the growing use of the concept of activity space, few studies were able to report how much residential and non-residential environmental exposures differ. For instance, a study based on the tracking of participants with GPS receivers in the Seattle area observed that more than 90% of the built environment measures differed between residential and non-residential locations (Hurvitz and Moudon, 2012). Similar differences were found elsewhere (Basta et al., 2010; Crawford et al., 2014; Kestens et al., 2010; Lipperman-Kreda et al., 2015; Shareck et al., 2014b; Zenk et al., 2011). Except one study (Crawford et al., 2014), these published reports have paid no attention to the difference in built environment measures between the perceived residential neighborhood and the broader activity space.

Whereas reducing measurement error in exposure measures has been recommended, accounting for the non-residential places visited does also require caution. Concerns about confounding related to the selective daily mobility bias have been raised (Chaix et al., 2012; Chaix et al., 2013; Kerr, 2013; Kestens et al., 2012). This bias arises when “measures of accessibility to given environmental resources are also determined from the locations that were specifically visited to use the corresponding resources” (Chaix et al., 2013, p.48). To overcome this potential source of confounding, Chaix et al. suggested to either exclude the activity places visited related to the behavior of interest when measuring exposure or to only retain major activity locations (Hägerstrand, 1970) corresponding to constrained activities that cannot be rescheduled or carried out in another location (Chaix et al., 2012). Such a selection of activity places could provide measures of exposure that mitigate the selective daily mobility bias.

Objectives

This study aimed to investigate how environmental exposures vary according to the spatial definition of the exposure area, using two built environment characteristics conducive to walking, i.e. the density of destinations and green spaces (Chaix et al., 2014; Sugiyama et al., 2012). A first objective was to evaluate how exposure measurements varied depending on whether exposure areas were defined as i) street-network residential buffers, ii) self-reported perceived residential neighborhoods, or iii) activity space areas. Variations in exposure measures according to the urbanicity of the residence were compared according to these three spatial definitions. A second objective was to evaluate the selective daily mobility bias. To do so, we assessed whether activity space exposure measures and gradients differed when using either i) all reported destinations (full activity space) or ii) only destinations unrelated to the exposure of interest (truncated activity space, theoretically reducing the selective mobility bias).

METHODS

Population

The study relies on the second wave of the RECORD Cohort Study (Chaix et al., 2011). Overall, 5,542 participants were surveyed without *a priori* sampling (convenience sample) between February 2011 and October 2013 during preventive health checkups conducted by the Centre d'Investigations Préventives et Cliniques (IPC) in Paris. Participants were living in one of 10 (out of 20) administrative divisions of Paris or 111 *a priori* selected municipalities of the Ile-de-France region in 2011-2013 or had been living in these municipalities in 2007-2008 during the recruitment of the cohort (some of them had moved to other places since then). In addition to the RECORD Study inclusion criteria (residence and age 30-79 in 2007-2008), the present analyses retained only participants residing in the Ile-de-France region who reported at least one non-residential destination. The entire data collection protocol was approved by the French Data Protection Authority. All participants had to sign a consent form to enter the study.

Activity space data

Self-reported activity places were geocoded using the VERITAS application ('Visualization and Evaluation of Regular Individual Travel destinations and Activity Spaces') (Chaix et al., 2012). The VERITAS application is a web-based computer tool that integrates Google Maps interactive mapping functionalities, and allows users to self-report activity locations and perceived spaces (Chaix et al., 2012, p. 441). With help of a survey technician, participants geocoded their regular activity locations, and provided the frequency of visit to these locations (coded as at least once per month, once per week, or more often). Participants were successively asked to locate their places of residence, workplaces, services (supermarket, outdoor market, bakeries, butchers, fruit and vegetables shops, specific food stores, tobacco/press shops, bank, post offices, etc.), transportation stations used from home, recreational activities (sports facilities, place of cultural activity, place of labor organization, political, or religious activity), and social activities (place of social activities, place where participants take relatives, place where participants visit relatives). The participants were further asked to draw the boundaries of their perceived neighborhood. More details on the VERITAS data collection in the RECORD Study can be found in Chaix et al. (2012b).

Spatial definitions of exposure areas

'Classical' residential exposure area: A 1000 meter street network buffer was defined around each participant's home. This distance, previously used in place and health research studies, corresponds to a 15 minute walk (Brondeel et al., 2014; Chaix et al., 2014; Frank et al., 2005; Karusisi et al., 2013; Troped et al., 2010; Villanueva et al., 2014).

Perceived residential exposure area: The perceived residential neighborhood was obtained from participants' self-report drawing the perceived boundaries of their neighborhood using VERITAS.

Activity space exposure areas: Activity space exposure areas were defined using buffers around activity destinations. A *full* activity space included all regular activity places reported in VERITAS. In order to control for the selective daily mobility bias, a *truncated* activity space was further defined, by removing the activity places specifically referring to the activities related to the exposure of interest. For example, the spatial accessibility to services was measured from all activity locations reported except from services themselves. It means that only relatively constrained and fixed destinations were retained, including the residence, the workplace, the regular bank, and the places where participants take relatives. The spatial accessibility to green spaces was measured from all activity locations except from sport activity destinations, as such destinations include the green and open spaces that were specifically visited to exercise.

For both definitions of the activity space, street network buffers were constructed around each reported activity location. Because the degree of exposure plausibly depends on the time spent at the location or on the frequency of visit, varying buffer radiuses were used depending on the types of activity locations. As we had no data on the time spent around each location, it was decided to use larger buffers for major activity locations such as the residence and the workplace (1000 m), intermediary buffers for recreational/social activity locations (500 m), and smaller buffers for service activity locations (200 m) (Chaix et al., 2012). This hierarchy of buffer sizes has been used previously in a study examining built and social environment influences on recreational walking (Perchoux et al., 2015). **Figure I** illustrates the residential buffer, perceived neighborhood, and full activity space as areas of exposure.

Environmental data

Two exposure measures that have been related to walkability were computed for each of the four area definitions: the proportion of green space and the density of destinations (number per km²). The location of green spaces was obtained from a 2008 geographic layer of the Institute of Urban Planning of the Ile-de-France Region (IAU-IDF) on public parks and green spaces. Destinations were obtained from the 2011 Permanent Database of Facilities of the National Institute of Statistics and Economic Studies (INSEE) and included administrations, public/private shops, health services, and entertainment facilities.

The location of the residence in the Paris Ile-de-France region was examined as a proxy of urbanicity (City center, inner suburbs, and outer suburbs). This categorization of urbanicity is based on a recognized and official administrative subdivision of the Ile-de-France region, previously used to look at spatial dynamics in the Ile-de-France region (Charreire et al., 2012; Feuillet et al., 2015; Perchoux et al., 2014). It distinguishes the city of Paris itself, the first crown of counties ("Départements") around Paris, and the second crown of counties.

Statistical analyses

Analyses of variance were used to examine variations in the size of the street-network residential buffer, the perceived residential neighborhood, and the full and truncated activity spaces in relation to age, sex, income, urbanicity of the residence, proportion of green space, and density of destinations.

Paired sample t-tests were used to assess differences in exposure measures between the different definitions of exposure areas. Jonckheere-Terpstra (JT) tests were performed to assess trends in exposure between ordered classes. All analyses were conducted with SAS version 9.2.

RESULTS

Description of the study sample

From the initial sample of 5542 participants, we excluded 55 participants living and 996 participants regularly traveling outside the Ile-de-France region, and 108 participants regularly visiting a secondary home. Two participants were further excluded due to missing socio-demographic data. The final sample included 4,383 individuals with a mean age of 53 years (range: 32-85), predominantly male (67%), French (87%), and with a stable employment status (56%). Of our sample, 26% lived in Paris City, 46% in the inner, and 27% in the outer suburbs.

Participants reported a median number of 13 distinct activity locations (range: 2-42). The median size of the exposure area was of 1.8 km^2 (0.5-2.9) for the street-network residential buffers, 0.5 km^2 (range: 0.0-277.5) for the perceived residential neighborhood, 3.8 km^2 (1.1-11.4) for the full activity space, 3.7 km^2 (range: 1.0-10.8) for the sport places-truncated activity space, and 3.1 km^2 (range: 0.5-10.0) for the services-truncated activity space. Unadjusted relationships between individual/environmental characteristics and the size of the different exposure areas are reported in **Appendix I**. Sizes of both the street-network residential buffer and activity space increased with urbanicity (possibly due to higher street connectivity in more urban environments). A particularly strong positive association was documented between the proportion of green spaces in the area and the size of the perceived residential neighborhood (suggesting that participants located close to green spaces may extend their perceived neighborhood so as to include a greater surface of green spaces in it).

Differences in environmental exposure by neighborhood definition

Table I shows average values of environmental measures by exposure areas, and **Table II** differences between the different types of exposure areas.

Overall, the proportion of green space in the exposure area was larger in the outer suburbs than in the city center (**Table I**). Regardless of the exposure area, the density of services in the exposure area increased with urbanicity.

Street-network residential buffer vs. perceived residential neighborhood

The mean proportion of green space was higher in the perceived residential neighborhood (0.080) than in the street-network residential buffer (0.071) (**Table I**). This difference increased from the inner suburbs to the city center ($p<0.001$) (**Table II**).

Again, the density of destinations was greater in the perceived residential neighborhood than in the street-network residential buffer (**Table I**). The observed difference of exposure between these areas revealed an increasing trend from the outer suburbs (59.4) to the city center (127.5) ($p<0.001$) **(Table II)**.

Street-network residential buffer vs. truncated activity space

Regarding the proportion of green space, no overall differences were found between the street-network residential buffer and the truncated activity space **(Table II)**. However, participants living in the center had higher exposure to green spaces in their truncated activity space than in their street-network residential buffer, while the contrary was true for suburbanites ($p<0.001$).

Overall, the truncated activity space contained a higher density of destinations (441.1) than the street-network residential buffer (360.1) **(Table I)**. However, while individuals living in the city center had a higher density of destinations in their street-network residential buffer (907.8) than in their truncated activity space (868.1), outer suburbanites had a 2.4 times higher density of services in their truncated activity space than in their street-network residential buffer **(Table I & II)**.

Perceived residential neighborhood vs. truncated activity space

The proportion of green spaces and the density of destinations were lower in the truncated activity space than in the perceived residential neighborhood **(Table II)**.

Differences in exposure to green spaces between the two varied by urbanicity of the residence ($p<0.001$), with a lower exposure to green spaces in the truncated activity space than in the perceived residential neighborhood for residents of the city center or inner suburbs (-0.013) as opposed to those of outer suburbs (0.002**) (Table II)**.

The differences in the accessibility to destinations varied by urbanicity **(Table II)**. A strong trend ($p<0.001$) in the difference between the perceived residential neighborhood and the truncated activity space showed that urban individuals had a higher exposure to destinations in their perceived residential neighborhood, whereas suburbanites had a higher exposure to destinations in their truncated activity space.

Full Activity Space vs. Truncated Activity Space

The exposure estimates were higher in the full than in the truncated activity space **(Table II)**.

Accessibility to green spaces increased from the city center to the outer suburbs, but considering the truncated rather than the full activity space slightly attenuated this gradient.

Stratification by urbanicity of the residence shows higher accessibility to destinations when considering the full rather than the truncated activity space, with more pronounced differences for suburban rather than urban residents ($p<0.001$) **(Table II)**.

DISCUSSION

This study had two major objectives. First, we compared measures of environmental exposure conducive to walking between a classical street network-buffer centered on the residence, the perceived residential neighborhood, and the activity space, by urbanicity of the residence.

Second, we examined to which extent selective daily mobility might result in biased estimates of environmental exposures.

Regarding the first objective, the estimates of environmental exposures differed according to the definition of the exposure area. Compared to the street network buffer, we observed higher levels of exposures in the perceived residential neighborhood, as reported before (Colabianchi et al., 2014). This is likely attributable to the fact that the perceived residential neighborhood is likely shaped by the main local destinations of people, potentially the services or green spaces. Measures of environmental exposure that account for daily mobility (full and truncated activity spaces) differed from those based on the street-network residential buffer and on the perceived residential neighborhood. Exposure to destinations was higher in the activity space than in the street-network residential buffer, in accordance with other studies on the food environment (Basta et al., 2010; Crawford et al., 2014; Hurvitz and Moudon, 2012; Kestens et al., 2010). Again, this is probably attributable to the fact that the participants' activity space is shaped to some extent by the visits that they make to destinations of various kinds. Finally, in most cases, differences in exposure between definitions of exposure areas showed a gradient associated with urbanicity. Such variations suggest that the measurement bias induced by the exclusive use of a given exposure area compared to another one is differential among participants living in the city center, and inner and outer suburbanites. We finally observed disparities in access to urban resources. Participants living in the city center had higher densities of destinations in their residential neighbourhood than in their activity space (i.e. accounting for non-residential destinations lowered the observed densities), whereas the contrary was true for suburban participants.

Regarding the second objective, we observed no clear difference in the gradient of exposure according to urbanicity between the truncated activity space and the full activity space. However, additional analyses by household income (**Appendix II**) showed that exposure to green spaces increased with household income when considering the full activity space, while the trend was absent with the truncated activity space. A potential explanation is that despite the fact that people of different socioeconomic background have comparable accessibility to green spaces from their core daily activity locations, high-income participants are more likely to regularly visit parks than low-income participants. This hypothesis is consistent with current literature that reported a positive relationship between household income and park visitation frequency (Mowen et al., 2005; Scott and Munson, 1994). Therefore, as previously emphasized (Chaix et al., 2012; Chaix et al., 2013), our expectation is that the exposure to green spaces assessed in the full activity space may generate bias when associated with health outcomes (e.g., walking). Using the truncated activity space may be useful to mitigate the selective daily mobility bias.

Toward refinements in the definition of exposure areas

Our findings illustrate that the spatial definition of the exposure area has a strong impact on exposure estimates and thus potentially on estimations of contextual effects on health. Although exploratory, this paper advances three conceptual and methodological points. First, accounting solely for the residential neighborhood may provide an incomplete and somewhat biased understanding of environmental effects on health behaviors. Future research should thus move toward a more comprehensive spatial definition of the exposure area that considers individuals' mobility patterns.

Second, the perceived residential neighborhood is markedly different from the activity space and from the street-network residential buffer, both in terms of size and related exposure. The higher levels of spatial accessibility to resources in the perceived residential neighborhood combined with its smaller size denotes its anisotropic character. In short, it avoids low density areas where individuals do not go, compared to the isotropic and non-discriminant street-network buffer (Chaix et al., 2009). Further research investigating the sociodemographic, psychological, and environmental determinants of the shape of the perceived residential neighborhood is needed. However, since the perceived residential neighborhood as a cognitive construct may not exactly match the local area to which individuals are exposed (Chaix et al., 2009), future research should elaborate the conceptual grounds for relying on a subjective rather than objective definition of spatial exposure areas.

Third, while accounting for daily mobility in place and health research is increasingly recognized as a step forward in the specification of environmental exposures and analysis of their influence on health (Chaix et al., 2013; Kestens et al., 2016), further attention should be paid to potential selection biases in studies of mobility-based measures of exposures and health. Sophisticated methods using GPS data have been proposed in order to address the selective daily mobility bias, as accounting for trip chaining and how a specific behavior in a specific place and time might be influenced by the "structure of opportunities observed at the previous or next activity location" (Chaix et al., 2013; Thierry et al., 2013, p. 3).

Strengths and limitations

The definition of the activity space used in this study encompassed areas around all reported destinations, including the residential neighborhood. It made it difficult to assess whether participants actually compensated for the lack of resources in their residential neighborhood by visiting activity places in their non-residential environments. The definition of the truncated activity space might also be questioned in relation to the specific locations excluded to mitigate the selective daily mobility bias. The methodological choice to remove sport activity destinations to define a truncated activity space for assessing green space exposure might not have allowed us to correctly exclude the green spaces visited by purpose by the participants as we intended to do. On the one hand, sport activity locations can take place both inside and outside, and on the other hand, social activities such as picnics could be organized in parks, and should also be removed from the exposure estimates. The present study illustrates that truncating the activity space is a particularly straightforward strategy when applied to specific environmental exposures such as green spaces or fast food restaurants and when such places can be reliably identified among the participant's visited places.

The lack of temporal information did not allow us weighting the environmental exposures by the time spent at each activity location. The mismatch in the source year of green spaces exposure data compared to individual data might have introduced a potential misestimation of the actual exposure. Finally, we might have introduced a selection bias by excluding the participants traveling outside the Ile-de-France Region, since these participants have significantly higher educational attainment and income. Thus, socio-economic disparities in exposure differences are potentially under or over-estimated, if the exposure itself had a causal effect on participation.

The strengths of the study include a large sample geographically dispersed in the whole metropolitan area of Paris, with precise geographical information of participants' activity places and perceived neighborhood boundaries that were collected through the use of an interactive mapping application. Our study is also one of the first to properly address concerns related to the selective daily mobility bias.

CONCLUSION

While more and more studies are currently collecting real-time exposure data through GPS receivers eventually in combination with environmental sensors, our study strengthens the theoretical ground for assessing multiple-place exposure by underlining the difference between residential and activity space exposures. It also sheds light on the extent to which errors in residential exposure measures may vary in magnitude according to urbanicity if one definition of the exposure area is employed rather than the one that should be ideally used. Our findings also highlight the need to address the selective daily mobility bias in health and place studies accounting for individual-level mobility. Failing to do so might lead to confounding and preclude causal inference. Future research will have to examine whether accounting for the full range of environmental exposures in a multi-place perspective provides stronger evidence on the places and populations that public health interventions should target.

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References

Basta, L.A., Richmond, T.S., Wiebe, D.J., 2010. Neighborhoods, daily activities, and measuring health risks experienced in urban environments. Social Science & Medicine 71, 1943-1950.

Brondeel, R., Weill, A., Thomas, F., Chaix, B., 2014. Use of healthcare services in the residence and workplace neighbourhood: The effect of spatial accessibility to healthcare services. Health and Place 30, 127-133.

Chaix, B., 2009. Geographic Life Environments and Coronary Heart Disease: A Literature Review, Theoretical Contributions, Methodological Updates, and a Research Agenda. Annu Rev Public Health.

Chaix, B., Kestens, Y., Bean, K., Leal, C., Karusisi, N., Meghiref, K., Burban, J., Fon Sing, M., Perchoux, C., Thomas, F., Merlo, J., Pannier, B., 2011. Cohort Profile: Residential and non-residential environments, individual activity spaces and cardiovascular risk factors and diseases—The RECORD Cohort Study. International Journal of Epidemiology.

Chaix, B., Kestens, Y., Perchoux, C., Karusisi, N., Merlo, J., Labadi, K., 2012. An interactive mapping tool to assess individual mobility patterns in neighborhood studies. Am J Prev Med 43, 440-450.

Chaix, B., Méline, J., Duncan, S., Merrien, C., Karusisi, N., Perchoux, C., Lewin, A., Labadi, K., Kestens, Y., 2013. GPS tracking in neighborhood and health studies: A step forward for environmental exposure assessment, a step backward for causal inference? Health & Place 21, 46-51.

Chaix, B., Merlo, J., Evans, D., Leal, C., Havard, S., 2009. Neighbourhoods in eco-epidemiologic research: delimiting personal exposure areas. A response to Riva, Gauvin, Apparicio and Brodeur. Soc Sci Med 69, 1306-1310.

Chaix, B., Simon, C., Charreire, H., Thomas, F., Kestens, Y., Karusisi, N., Vallée, J., Oppert, J.-M., Weber, C., Pannier, B., 2014. The environmental correlates of overall and neighborhood based recreational walking (a cross-sectional analysis of the RECORD Study). International journal of behavioral nutrition and physical activity 11, 20.

Charreire, H., Weber, C., Chaix, B., Salze, P., Casey, R., Banos, A., Badariotti, D., Kesse-Guyot, E., Hercberg, S., Simon, C., 2012. Identifying built environmental patterns using cluster analysis and GIS: Relationships with walking, cycling and body mass index in French adults. Int J Behav Nutr Phys Act 9, 59.

Colabianchi, N., Coulton, C., Hibbert, J.D., McClure, S., Ievers-Landis, C.E., Davis, E.M., 2014. Adolescent self-defined neighborhoods and activity spaces: Spatial overlap and relations to physical activity and obesity. Health & Place.

Coulton, C., Korbin, J., Chan, T., Su, M., 2001. Mapping Residents' Perceptions of Neighborhood Boundaries: A Methodological Note. American Journal of Community Psychology 29.

Crawford, T.W., Jilcott Pitts, S.B., McGuirt, J.T., Keyserling, T.C., Ammerman, A.S., 2014. Conceptualizing and comparing neighborhood and activity space measures for food environment research. Health and Place 30, 215-225.

Diez Roux, A.V., 2001. Investigating neighborhood and area effects on health. Am J Public Health 91, 1783-1789.

Feuillet, T., Charreire, H., Menai, M., Salze, P., Simon, C., Dugas, J., Hercberg, S., Andreeva, V.A., Enaux, C., Weber, C., 2015. Spatial heterogeneity of the relationships between environmental characteristics and active commuting: towards a locally varying social ecological model. International Journal of Health Geographics 14, 12.

Frank, L.D., Schmid, T.L., Sallis, J.F., Chapman, J., Saelens, B.E., 2005. Linking objectively measured physical activity with objectively measured urban form: findings from SMARTRAQ. American Journal of Preventive Medicine 28, 117-125.

Golledge, R.G., Stimson, R.J., 1997. Spatial Behavior. The Guilford Press, New York.

Guest, A.M., Lee, B.A., 1984. How urbanites define their neighborhoods. Population and Environment 7, 32-56.

Hurvitz, P.M., Moudon, A.V., 2012. Home Versus Nonhome Neighborhood: Quantifying Differences in Exposure to the Built Environment. American Journal of Preventive Medicine 42, 411-417.

Inagami, S., Cohen, D.A., Finch, B.K., 2007. Non-residential neighborhood exposures suppress neighborhood effects on self-rated health. Soc Sci Med 65, 1779-1791.

Karusisi, N., Thomas, F., Méline, J., Chaix, B., 2013. Spatial accessibility to specific sport facilities and corresponding sport practice: the RECORD Study. International journal of behavioral nutrition and physical activity 10, 48.

Kerr, J., 2013. Exposure Exposed. American Journal of Preventive Medicine 45, 524-525.

Kestens, Y., Chaix, B., Shareck, M., Vallée, J., 2016. Comments on Melis et al. The Effects of the Urban Built Environment on Mental Health: A Cohort Study in a Large Northern Italian City. Int. J. Environ. Res. Public Health, 2015, 12, 14898–14915. International journal of environmental research and public health 13, 250.

Kestens, Y., Lebel, A., Chaix, B., Clary, C., Daniel, M., Pampalon, R., Theriault, M., Subramanian, S.V., 2012. Association between Activity Space Exposure to Food Establishments and Individual Risk of Overweight. PLoS ONE 7, e41418.

Kestens, Y., Lebel, A., Daniel, M., Theriault, M., Pampalon, R., 2010. Using experienced activity spaces to measure foodscape exposure. Health Place 16, 1094-1103.

Leal, C., Chaix, B., 2011. The influence of geographic life environments on cardiometabolic risk factors: a systematic review, a methodological assessment and a research agenda. Obesity Reviews 12, 217-230.

Lipperman-Kreda, S., Morrison, C., Grube, J.W., Gaidus, A., 2015. Youth activity spaces and daily exposure to tobacco outlets. Health and Place 34, 30-33.

Mason, M.J., 2010. Attributing activity space as risky and safe: The social dimension to the meaning of place for urban adolescents. Health & Place 16, 926-933.

Matthews, S.A., 2011. Spatial Polygamy and the Heterogeneity of Place: Studying People and Place via Egocentric Methods, in: Burton, L.M., Matthews, S.A., Leung, M., Kemp, S.P., Takeuchi, D.T. (Eds.), Communities, Neighborhoods, and Health. Springer New York, pp. 35-55.

Matthews, S.A., Yang, T.-C., 2013. Spatial Polygamy and Contextual Exposures (SPACEs): Promoting Activity Space Approaches in Research on Place And Health. American Behavioral Scientist, 0002764213487345.

Mowen, A.J., Payne, L.L., Scott, D., 2005. Change and stability in park visitation constraints revisited. Leisure Sciences 27, 191-204.

Perchoux, C., Chaix, B., Cummins, S., Kestens, Y., 2013. Conceptualization and measurement of environmental exposure in epidemiology: Accounting for activity space related to daily mobility. Health & Place 21, 86-93.

Perchoux, C., Kestens, Y., Brondeel, R., Chaix, B., 2015. Accounting for the daily locations visited in the study of the built environment correlates of recreational walking (the RECORD Cohort Study). Preventive Medicine 81, 142-149.

Perchoux, C., Kestens, Y., Thomas, F., Van Hulst, A., Thierry, B., Chaix, B., 2014. Assessing patterns of spatial behavior in health studies: Their socio-demographic determinants and associations with transportation modes (the RECORD Cohort Study). Social Science and Medicine 119, 64-73.

Pickett, K., Pearl, M., 2001. Multilevel analyses of neighbourhood socio-economic context and health outcomes: a critical review. Journal of Epidemiology and Community Health 55, 111–122.

Riva, M., Gauvin, L., Barnett, T.A., 2007. Toward the next generation of research into small area effects on health: a synthesis of multilevel investigations published since July 1998. J Epidemiol Community Health 61, 853-861.

Scott, D., Munson, W., 1994. Perceived Constraints to Park Usage. Journal of Park and Recreation Administration.

Setton, E., Marshall, J.D., Brauer, M., Lundquist, K.R., Hystad, P., Keller, P., Cloutier-Fisher, D., 2011. The impact of daily mobility on exposure to traffic-related air pollution and health effect estimates. J Expo Sci Environ Epidemiol 21, 42-48.

Shareck, M., Frohlich, K.L., Kestens, Y., 2014a. Considering daily mobility for a more comprehensive understanding of contextual effects on social inequalities in health: A conceptual proposal. Health and Place 29, 154-160.

Shareck, M., Kestens, Y., Frohlich, K.L., 2014b. Moving beyond the residential neighborhood to explore social inequalities in exposure to area-level disadvantage: Results from the Interdisciplinary Study on Inequalities in Smoking. Social Science & Medicine 108, 106-114.

Sugiyama, T., Neuhaus, M., Cole, R., Giles-Corti, B., Owen, N., 2012. Destination and Route Attributes Associated with Adults' Walking: A Review. Med Sci Sports Exer 44, 1275-1286.

Thierry, B., Chaix, B., Kestens, Y., 2013. Detecting activity locations from raw GPS data: a novel kernel-based algorithm. International Journal of Health Geographics 12, 14.

Troped, P.J., Wilson, J.S., Matthews, C.E., Cromley, E.K., Melly, S.J., 2010. The Built Environment and Location-Based Physical Activity. American Journal of Preventive Medicine 38, 429-438.

Vallée, J., Le Roux, G., Chaix, B., Kestens, Y., Chauvin, P., 2014. The 'constant size neighbourhood trap'in accessibility and health studies. Urban studies, 0042098014528393.

Vallée, J., Shareck, M., 2014. RE:"EXAMINATION OF HOW NEIGHBORHOOD DEFINITION INFLUENCES MEASUREMENTS OF YOUTHS'ACCESS TO TOBACCO RETAILERS: A METHODOLOGICAL NOTE ON SPATIAL MISCLASSIFICATION". American journal of epidemiology, kwt436.

Villanueva, K., Knuiman, M., Nathan, A., Giles-Corti, B., Christian, H., Foster, S., Bull, F., 2014. The impact of neighborhood walkability on walking: Does it differ across adult life stage and does neighborhood buffer size matter? Health and Place 25, 43-46.

Zenk, S.N., Schulz, A.J., Matthews, S.A., Odoms-Young, A., Wilbur, J., Wegrzyn, L., Gibbs, K., Braunschweig, C., Stokes, C., 2011. Activity space environment and dietary and physical activity behaviors: A pilot study. Health & Place 17, 1150-1161.

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Variables	Street-network residential buffer		Perceived residential neighborhood		Full activity space		Truncated activity space	
	Mean (SD)	JT Test *p value*	Mean (SD)	JT Test *p value*	Mean (SD)	JT Test *p value*	Mean (SD)	JT Test *p value*
PROPORTION OF GREEN SPACES[a]								
All	0.071 (0.076)		0.080 (0.113)		0.080 (0.061)		0.071 (0.053)	
By urbanicity								
Center	0.058 (0.037)		0.076 (0.082)		0.071 (0.042)		0.064 (0.035)	
Inner suburbs	0.070 (0.077)	0.009*	0.083 (0.083)	<.001*	0.081 (0.062)	<.001*	0.070 (0.054)	0.04*
Outer suburbs	0.084 (0.097)		0.077 (0.129)		0.089 (0.071)		0.078 (0.065)	
DENSITY OF DESTINATIONS[b]								
All	360.1 (399.4)		461.1 (503.3)		481.2 (382.2)		441.1 (407.1)	
By urbanicity								
Center	907.8 (375.0)		1035.4 (502.5)		886.2 (344.5)		868.1 (868.1)	
Inner suburbs	211.2 (144.9)	<.001*	321.8 (322.0)	<.001*	394.8 (279.5)	<.001*	341.4 (295.8)	<.001*
Outer suburbs	82.0 (82.1)		141.4 (230.5)		235.9 (236.8)		197.0 (265.4)	

*$p < 0.05$; SD: standard deviation.

[a] Surface of green spaces per km^2

[b] Number of destinations per km^2

Table II. Differences in environmental exposures between the street-network residential buffer, the perceived residential neighborhood, and the activity space by urbanicity, using paired sample T-tests (n=4383)

Variables	Perceived residential neighborhood – Street-network residential buffer		Truncated activity space – Street-network residential buffer		Truncated activity space – Perceived residential neighborhood		Full – truncated activity space	
	Diff.	95% CI	Diff.	95% CI	Diff.	95% CI	Diff.	95% CI
PROPORTION OF GREEN SPACES[a]								
All	0.009*	(0.006 ; 0.012)	-0.000	(-0.001 ; 0.001)	-.009*	(-0.012 ; -0.006)	0.010*	(0.009; 0.011)
By urbanicity								
Center	0.018*	(0.014 ; 0.022)	0.005*	(0.003 ; 0.007)	-0.013*	(-0.017 ; -0.0081)	0.007*	(0.006; 0.009)
Inner suburbs	0.013*	(0.008 ; 0.017)	-0.000	(-0.002 ; 0.002)	-0.013*	(-0.018 ; -0.008)	0.011*	(0.009; 0.012)
Outer suburbs	-0.006	(-0.013 ; 0.001)	-0.005*	(-0.008 ; -0.001)	0.002	(-0.005 ; 0.008)	0.010*	(0.008; 0.012)
JT test*	<.001*		<.001*		<.001*		0.014*	
DENSITY OF DESTINATIONS[b]								
All	101.0*	(93.0 ; 109.0)	81.0*	(72.7 ; 89.4)	-20.0*	(-31.6 ; -8.4)	40.1*	(36.1; 44.1)
By urbanicity								

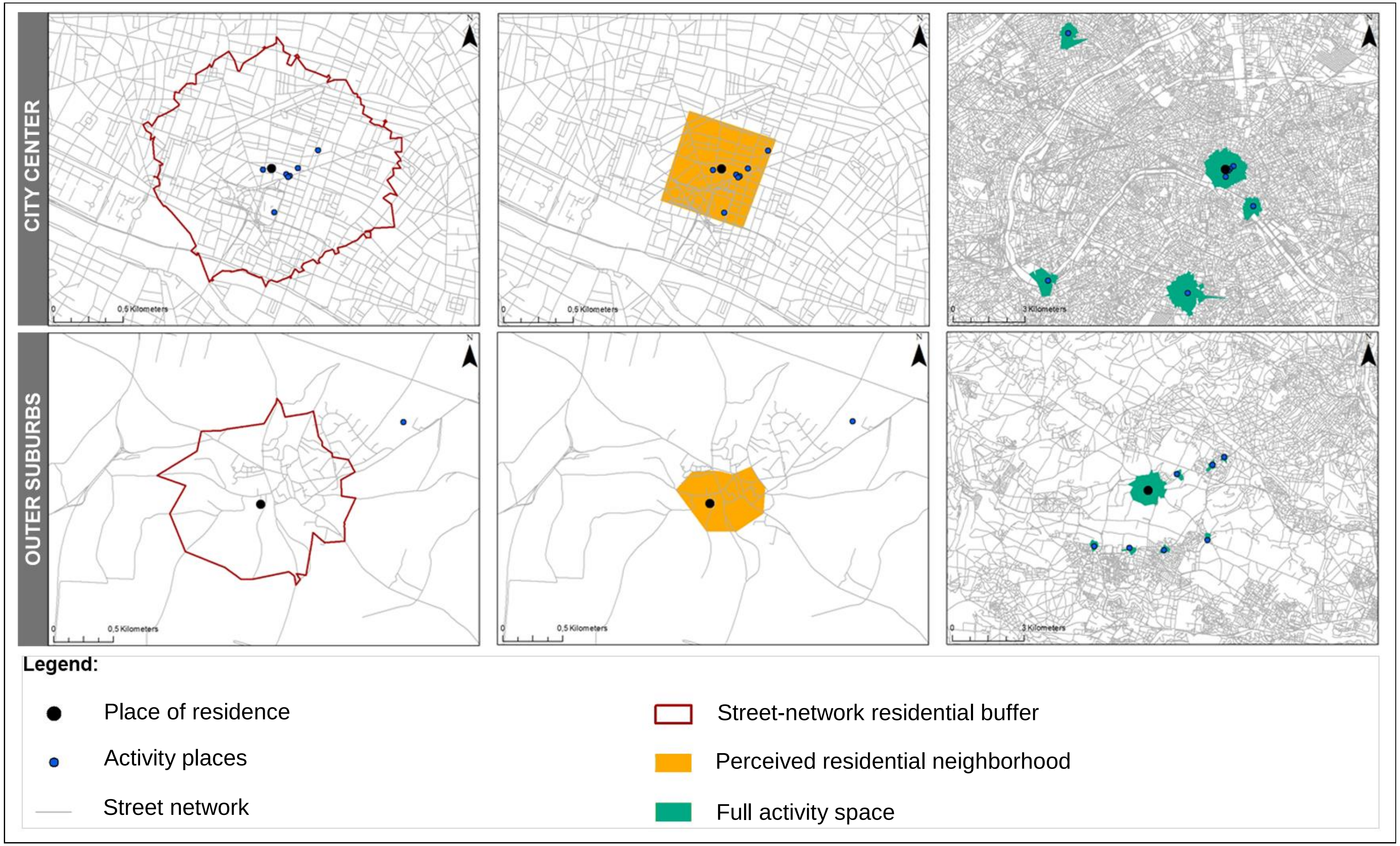
Center	127.5*	(108.0 ; 147.0)	-39.8*	(-55.5; -24.0)	-167.3*	(-191.8 ; -142.8)	18.1*	(10.2; 26.0)
Inner suburbs	110.6*	(99.2 ; 122.0)	130.2*	(118.0 ; 142.4)	19.7*	(2.6 ; 36.7)	53.4*	(47.4; 59.4)
Outer suburbs	59.4*	(48.4 ; 70.3)	115.0*	(100.6; 129.5)	55.7*	(37.8 ; 73.5)	38.8*	(32.0; 45.6)
JT test*	<.001*		<.001*		<.001*		<.001*	

*p<0.05; CI: confidence interval.

[a] Surface of green spaces per km^2

[b] Number of destinations per km^2

Figure I. Graphical representation of the street-network residential buffer, perceived residential neighborhood, and activity space of two participants of the RECORD Cohort residing respectively in the city center and in the outer suburb



Appendix I. Separate analyses of variance for the relationship between each individual/environmental characteristic and the size of the different exposure areas in km² (n=4383[a])

	Street-network residential buffer	Perceived residential neighborhood	Full activity space	Truncated activity space - Green spaces	Truncated activity space - Destinations
INDIVIDUAL CHARACTERISTICS					
Age, mean (SD)					
30 – 44	1.724 (0.257)	1.094 (2.054)	4.188 (1.369)	3.988 (1.299)	3.347 (1.179)
45 – 59	1.717 (0.263)	1.519 (9.037)	4.100 (1.407)	3.901 (1.344)	3.267 (1.224)
60 – 85	1.721 (0.274)	1.333 (3.248)	3.180 (1.237)	2.978 (1.146)	2.235 (0.969)
p value	0.713	0.194	<0.001	<0.001	<0.001
Sex, mean (SD)					
Female	1.714 (0.271)	1.096 (2.230)	3.724 (1.438)	3.568 (1.386)	2.899 (1.239)
Male	1.723 (0.261)	1.479 (7.650)	3.935 (1.401)	3.712 (1.330)	3.048 (1.239)
p value	0.116	<0.001	0.257	0.065	1.00
Income[a], mean (SD)					
High	1.761 (0.253)	1.348 (7.144)	4.035 (1.418)	3.784 (1.348)	3.101 (1.273)
Medium	1.726 (0.265)	1.390 (7.615)	3.929 (1.447)	3.703 (1.372)	3.048 (1.258)
Low	1.677 (0.268)	1.299 (3.701)	3.652 (1.367)	3.528 (1.325)	2.871 (1.186)
p value	<0.001	0.929	<0.001	<0.001	<0.001
Location of the residence, mean (SD)					

City center	1.921 (0.159)	1.468 (4.022)	3.980 (1.438)	3.803 (1.375)	3.222 (1.272)
Inner suburbs	1.699 (0.224)	1.130 (2.859)	3.890 (1.408)	3.689 (1.341)	3.027 (1.225)
Outer suburbs	1.561 (0.285)	1.615 (10.937)	3.706 (1.400)	3.487 (1.324)	2.735 (1.190)
p value	<0.001	0.0878	<0.001	<0.001	<0.001
ENVIRONMENTAL EXPOSURE					
Proportion of green spaces, mean (SD)					
High	1.667 (0.264)	2.274 (8.852)	4.011 (1.418)	3.729 (1.334)	-
Mediun	1.782 (0.235)	1.280 (6.417)	4.018 (1.437)	3.858 (1.387)	-
Low	1.710 (0.279)	0.502 (1.103)	3.561 (1.346)	3.406 (1.293)	-
p value	<0.001	<0.001	<0.001	<0.001	-
Density of destinations, mean (SD)					
High	1.897 (0.168)	1.257 (4.401)	4.225 (1.476)	-	3.487 (1.302)
Mediun	1.703 (0.221)	1.071 (1.697)	3.879 (1.404)	-	3.035 (1.549)
Low	1.560 (0.275)	1.736 (10.053)	3.492 (1.269)	-	2.473 (1.041)
p value	<0.001	0.0147	<0.001	-	<0.001

[a] n = 4323 when stratifying by household income; SD: standard deviation

Appendix II. Means and standard deviations of environmental exposures in the street-network residential buffer, the perceived residential neighborhood, and in the activity spaces by household income (n=4323)

Variables	Street-network residential buffer		Perceived residential neighborhood		Full activity space		Truncated activity space	
	Mean (SD)	JT Test *p value*	Mean (SD)	JT Test *p value*	Mean (SD)	JT Test *p value*	Mean (SD)	JT Test *p value*
PROPORTION OF GREEN SPACES								
All	0.071 (0.076)		0.080 (0.113)		0.080 (0.061)		0.071 (0.053)	
By household income[a]								
High	0.070 (0.077)		0.078 (0.114)		0.081 (0.057)		0.069 (0.049)	
Medium	0.071 (0.075)	0.647	0.082 (0.115)	0.334	0.082 (0.063)	0.001*	0.072 (0.054)	0.443
Low	0.071 (0.075)		0.077 (0.110)		0.076 (0.060)		0.070 (0.055)	
DENSITY OF DESTINATIONS								
All	360.1 (399.4)		461.1 (503.3)		481.2 (382.2)		441.1 (407.1)	
By household income [a]								
High	447.3 (440.4)		573.7 (538.5)		567.4 (405.4)		526.1 (436.5)	
Medium	352.7 (387.6)	<.001*	451.4 (498.4)	<.001*	480.6 (374.9)	<.001*	440.9 (396.9)	<.001*
Low	286.8 (356.3)		368.2 (455.9)		402.4 (352.3)		363.4 (375.3)	

*$p < 0.05$; SD: standard deviation
[a] n = 4323 when stratifying by household income