Université de Montréal & Université Pierre et Marie Curie

Accounting for residential and non-residential environments to measure contextual effects on health behavior: The case of recreational walking behavior

par

Camille Perchoux

Département de Médecine Sociale et Préventive, École de Santé Publique de l'Université de Montréal

École Doctorale 393 Pierre Louis de Santé Publique - Épidémiologie et Sciences de l'Information Biomédicale, Université Pierre et Marie Curie - Paris 06

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Cette thèse intitulée:

Accounting for residential and non-residential environments to measure contextual effects on health behavior: The case of recreational walking behavior

Présentée par :

Camille Perchoux

a été évaluée par un jury composé des personnes suivantes :

Maria Victoria ZUNZUNEGUI, Président rapporteur
Yan KESTENS, Directeur de thèse
Basile CHAIX, Co-directeur de thèse
Anthony GATRELL, Examinateur externe
Isabella ANNESI-MAESANO, Examinatrice
Pierre-Yves Boëlle, Examinateur
Sophie LAFOREST, Représentante du doyen de la FES

RESUME

Contexte : Les études portant sur les effets de l'environnement sur la santé ont essentiellement examiné les effets de l'environnement résidentiel. Cette approche a été critiquée pour son absence de prise en compte des environnements géographiques de vie non-résidentiels (c.-à-d. le travail, l'école, les lieux récréatifs et sociaux, etc.). Alors que la mobilité est un déterminant clé de l'exposition, peu d'études ont examiné les mobilités quotidiennes pour évaluer les effets du milieu sur la santé.

Objectifs : L'objectif général de cette thèse est d'évaluer si la prise en compte des lieux d'activité dans lesquels les individus se déplacent et sont régulièrement exposés permet de mieux estimer l'impact de l'environnement sur la pratique de la marche récréative. Les objectifs spécifiques de la thèse sont : i) identifier les différents types de comportement spatiaux des individus vivants en région Île-de-France et leurs déterminants sociodémographiques ; ii) évaluer si l'exposition à des facteurs environnementaux facilitant la marche diffère en fonction de la définition géographique de la zone d'exposition et varie en fonction du niveau socio-économique et de la localisation de la résidence dans la région Île-de-France ; iii) évaluer les caractéristiques environnementales, résidentielles et non-résidentielles, associées à la pratique de la marche récréative.

Méthodes : Trois études transversales ont été conduites sur la seconde vague de la Cohorte RECORD (Residential Environment and COronary heart Disease). Les lieux d'activité réguliers des participants, ainsi que la délimitation de leur quartier résidentiel perçu ont été collectés grâce à l'application VERITAS (Visualization and Evaluation of Regular Individual Travel destinations and Activity Spaces).

Résultats : La première étude a permis d'identifier une typologie des comportements de mobilité individuels caractérisés par : i) la taille de l'espace d'activité, ii) l'élongation de l'espace d'activité, iii) le centrage de l'espace d'activité sur le quartier de résidence, iv) le volume d'activités, et v) les types d'activités réalisées. Le statut socio-économique et la localisation de la résidence dans l'agglomération parisienne sont apparus comme de forts déterminants du comportement spatial. Les résultats de la deuxième étude montrent que l'exposition à des caractéristiques environnementales facilitant la marche diffère entre le quartier de résidence, le quartier résidentiel perçu, et l'espace d'activité. L'erreur de mesure liée à la seule prise en compte de mesures d'exposition résidentielle varie en fonction des groupes socio-économiques et des degrés d'urbanisation de la résidence dans la région Île-de-France. Dans la troisième étude, une densité de destinations élevée, la présence de lacs ou de voies d'eau et un niveau d'éducation élevé du quartier sont associés à une augmentation de la pratique de la marche récréative. Enfin, cette étude montre une forte influence des caractéristiques environnementales autour de la résidence et des lieux d'activité récréatifs sur la pratique de la marche récréative.

Conclusion : Cette thèse souligne l'importance de prendre en compte les environnements géographiques de vie résidentiels et non-résidentiels pour i) mieux approximer l'exposition environnementale réelle, ii) évaluer les effets de l'environnement sur les comportements de santé. Afin d'approfondir les mécanismes par lesquels l'environnement influence la pratique de l'activité physique, il apparait pertinent d'examiner conjointement *où les individus se déplacent,* mais également *ce que les individus font*, en termes de types d'activité et de contraintes liées aux activités réalisées. Identifier quels lieux d'activité ont le plus d'influence sur la pratique de l'activité physique contribue à cibler des contextes géographiques prioritaires pour les interventions en promotion de la santé.

Mots clés : Mobilités quotidiennes, Espace d'activité, Activité physique, Quartier résidentiel, Biais de mobilité sélective, Marche récréative

SUMMARY

Background: Previous studies on place effect on health focused on the residential neighborhood. This approach was criticized for not considering non-residential geographic life environments. While mobility is a key determinant of exposure, few studies accounted for daily mobility to evaluate environmental effects on health.

Purpose: The overarching aim of this dissertation is to estimate whether accounting for people's network of activity places and their resulting exposure allows improving the understanding of environmental influences on recreational walking behavior. The specific objectives are: i) to identify types of spatial behavior of individuals living in the Ile-de-France region and their socio-demographic correlates; ii) to assess whether the exposure to supportive walking environments differs depending on the geographic definition of the exposure area and varies by the socioeconomic status and the degree of urbanicity; iii) to evaluate which residential and non-residential neighborhood characteristics are associated with recreational walking.

Methods: Three cross sectional studies were conducted on the second wave of the RECORD Cohort Study (Residential Environment and CORonary heart Disease). Information on participants' regular activity places and perceived residential neighborhood were collected through the VERITAS application (Visualization and Evaluation of Regular Individual Travel destinations and Activity Spaces).

Result: In the first study, I identified a typology of individuals' patterns of mobility characterized by: i) the size of the activity space, ii) the elongation of the activity space, iii) the centering of the activity space on the residential neighborhood, iv) the volume of activity, and v) the type of activity performed. The individual-level socio-economic status and degree of urbanicity of the place of residence in the Ile-de-France region are strong determinants of individuals' spatial behavior. Results from the second study provide evidence that exposure to environmental characteristics supportive to walking highly differs between the residential neighborhood, the perceived residential neighborhood and the activity space. The measurement error resulting from the sole use of residential measures of exposure varies among SES groups and among categories of the degree of urbanicity of the residence. In the third empirical study a high density of destinations, the presence of a lake or waterway, and a high neighborhood education are associated with recreational walking. Finally, this study provides evidence of a strong influence of the environmental condition around the home and the recreational activity locations on the practice of recreational walking.

Conclusion: This dissertation strengthen the conceptual grounds and empirical evidence that accounting for both residential and non-residential geographical environments individual get exposed is required to i) better proxy the true environmental exposure, ii) estimate environmental influences on health behaviors. In order to investigate the mechanisms through which environmental exposure influence physical activity, it is relevant to examine *where people go*, and *what people actually do* in terms of type of activity and constraints related to the activity performed. Identifying which activity places is most influential on physical activity informs on the geographical contexts health promotion interventions should target.

Keywords: Daily mobility, Activity space, Physical activity, Residential trap, Selective daily mobility bias, Recreational walking

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LIST OF ABBREVIATIONS

AIC	Akaike Information Criterion
CIHR	Canadian Institutes of Health Research
CNIL	*Commission nationale de l'informatique et des libertés* National Commission for Data Protection and Liberties
GIS	Geographic Information System
IAU - IDF	*Institut d'Aménagement et d'Urbanisme d'Ile- de-France* Institute of Urban Planning of region Ile-de-France
ICC	Intraclass Correlation Coefficient
IGN	*Institut national de l'information géographique et forestière* National Geographic Institute
INSEE	*Institut National de la statistique et des études économiques* National Institute of Statistics and Economic Studies
INSERM	*Institut National de la Santé et de la Recherche Médicale* National Institute of Health and Medical Research
IPC	Centre d'Investigations Préventives et Cliniques
PRN	Perceived Residential Neighborhood
RECORD	Residential Environment and CORonary heart Disease
SES	Socio-economic Status
SRB	Street Residential Buffer
VERITAS	Visualization and Evaluation of Regular Individual Travel destinations and Activity Spaces
ZINB	Zero-inflated negative binomial regression

À mes parents,

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CHAPTER 1. INTRODUCTION

1.1 ENVIRONMENT AND DISEASE CAUSATION: Eras and paradigms

The environment has long been the subject of studies examining the causes of disease, albeit through different paradigms and via various causal pathways (Diez-Roux, 1998; Susser and Susser, 1996a, b) and indeed goes back to the Hippocratic tradition of medicine (Cummins et al., 2007). In the first half of the 19th century, the era of *Sanitary statistics,* with its miasma paradigm, related the environment to disease causation as “poisoning by foul emanations from soil, air and water” (Susser and Susser, 1996a, p. 669). In the late 19th century, leading figures of the *Infectious Disease Epidemiology* era such as Snow, Pasteur, Koch and Henle adopted the germ theory as a new paradigm which consisted in the search for the microbiological causes of disease in the environment.

The latter half of the 20th century witnessed a drastic decrease in the occurrence of infectious diseases and a rise in chronic disease (e.g. coronary heart disease, lung cancer), with which the *Chronic Disease* era had begun (Pearce, 1996; Susser and Susser, 1996a). Epidemiologists such as Doll, Hill and McKeown promoted a multicausal theory of disease causation, popularized through the metaphor of “the web of causation”, and developed new study designs and data analyses based on these theories. Yet, this period put greater emphasis on individuals than on the environment (Shareck, 2014). Indeed, modern epidemiology tended to shift the level of analysis from the population to the individual, using bottom-up epidemiological strategies that are conducive to risk individualization and decontextualization of risk behaviors, an approach that has been highly criticized for it tendency to result in victim-blaming (Pearce, 1996).

Concurrently, the 1990s saw an exponential increase in empirical studies investigating how the social and environmental characteristics of neighborhoods (i.e., residential area) contribute to the promotion, the maintenance, or the hindrance of health and related health behaviors (Berkman and Kawachi, 2000; Cummins et al., 2007; Diez Roux and Mair, 2010; Kawachi and Berkman, 2003; Kawachi and Subramanian, 2007). It should also be noted that this greater interest in neighborhood health effects is concomitant with a shift in focus from strict individual responsibility to environmental determinants that shape individual behavior (Diez Roux and Mair, 2010; King, 1994; King et al., 1995; Schmid et al., 1995; Troped et al., 2010). The notion of 'neighborhood' has been defined by Meegan and Mitchell as a "key living space through which people get access to material and social resources, across which they pass to reach other opportunities and which symbolizes aspects of the identity of those living there to themselves and to outsiders" (Meegan and Mitchell, 2001, p. 2172) cited in (Crawford et al., 2014). This definition stresses the potential of neighborhood studies to examine the pathways, either physical, social or cognitive and psychological, through which 'context' may have an influence on individual health. Neighborhood effects are also of great interest for studying inequalities in health. This stems from the fact the place of residence is strongly influenced by an individual's social position and represents a major location in people's every-day lives. As such, neighborhood characteristics are of utmost importance in the production of health inequalities (Diez Roux and Mair, 2010). Lastly, the use of multilevel analysis - suited to analyze individuals in their neighborhoods - and of new spatial analysis techniques have further contributed to the development of neighborhood and health studies (Diez-Roux, 1998; Diez Roux and Mair, 2010; Pickett and Pearl, 2001). However, defining and measuring neighborhood attributes has been, and continues to be, challenging (Schipperijn et al., 2013).

The twenty-first century saw a 'renewed interest in spatially oriented epidemiology' (Schipperijn et al., 2013). This *spatial turn* in health research has been mainly driven by the development of Geographical Information Systems (GIS) in conjunction with various geo-referenced databases. In the health field, GIS have facilitated the definition and the delineation of geographical areas such as neighborhoods (Richardson et al., 2013a; Schipperijn et al., 2013). They were also valuable for developing more sophisticated measures of neighborhood attributes including geographical accessibility to resources, density measures, etc (Diez Roux and Mair, 2010). These developments have, among other things, provided evidence that using different geographical definitions of the "neighborhood" can contribute to different results (Duncan et al., 2014; Haynes et al., 2008; Jones et al., 2010; Mitra and Buliung, 2012; Riva et al., 2008; Schipperijn et al., 2013; Schuurman et al., 2007; Tian et al., 2010). Therefore, the notion of space has become of utmost importance in epidemiology, raising the issue of neighborhood or geographic area definition when assessing environmental effects on health (Chaix et al., 2009). In this context, improved theoretical underpinnings and empirical evidence are required to assess environmental exposure in epidemiological studies.

Broadly, by relying on geographical and epidemiological concepts, this thesis examines the issue raised by Cummins in his question: "how can individual exposure to 'context' itself be better conceptualized?" (Cummins, 2007, p. 355), cited in (Crawford et al., 2014). More precisely, I question the notion of neighborhood as it is geographically defined in previous place and health research, and I advocate for a more comprehensive approach to the relationship between individuals, space and the resources it offers.

1.2 BACK TO THE FUTURE IN ENVIRONMENT AND HEALTH STUDIES: Moving beyond a residential-based perspective in exposure measurement toward the inclusion of multiple contexts

Many epidemiological studies examining neighborhood effects on health have focused exclusively on residential-based areas. They operationally defined the 'neighborhood' using fixed administrative units (i.e. census tract, postal code) or circular or street-network buffers centered on the residence as geographical area of interest (Chaix et al., 2009; Cummins et al., 2007; Diez Roux, 2001; Diez Roux and Mair, 2010; Rainham et al., 2010). Others have relied on the self-defined perceived residential neighborhood as an alternative to the somewhat arbitrary definition of the residential neighborhood due to its ability to provide information about individuals' preferences, perceptions and experiences of space (Coulton et al., 2001; Robinson and Oreskovic, 2013; Vallée et al., 2010; Vallée et al., 2011; Vallée and Chauvin, 2012; Vallée et al., 2014). Only few studies have considered other meaningful areas such as schools (An and Sturm, 2012; Babey et al., 2011; Gilliland et al., 2012; Kestens and Daniel, 2010; Lovasi et al., 2011; Van Hulst et al., 2012) or the workplace (Chum, 2013; Hoehner et al., 2013; Jeffery et al., 2006; Karusisi et al., 2014; Lewin et al., 2014; Moore et al., 2013). A recent literature review on the influence of geographic life environments on metabolic risk factors emphasised that 90% of the reviewed studies focused exclusively on the residential environment, 6% focused on non-residential environments and only 4% accounted for both residential and non residential environments (Leal and Chaix, 2011).

Defining exposure variables based solely on the residential area has been criticized through the concepts of 'local trap' (Cummins et al., 2007) and 'residential trap' (Chaix et al., 2009). Both concepts rely on the fact that the residential neighborhood may not be the exclusive geographical context of interest. Indeed, one major concern is that administrative units or home-centered buffers do not account for individuals' space-time behavior and for non-residential environments to evaluate place effects on health (Cummins, 2007; Cummins et al., 2007; Kwan, 2012b; Purcell and Brown, 2005). Researchers have argued in favor of a 'relational' view of place which constists, among other things, in the inclusion of multiple 'contexts' in space and time in the measurement of individual exposure (Cummins et al., 2007). In a similar vein, others advocate for a shift from a 'place-based' assessment of exposure to 'people-based' measures (i.e., replacing people in space and time), and the consideration of ego-centered definitions of contextual exposure (Kwan, 2009; Miller, 2007).

With the notion of spatial polygamy, authors have further emphasized that individuals have intimate relationships not only with their residential neighborhood, but often also with other places (Matthews and Yang, 2013). Most contextual studies have ignored locations outside the residential environment visited in everyday life such as the workplace, grocery stores, leisure and social environments. For instance, in an ethnographic study conducted in Boston (US), Matthews et al. (2005) have shown that 6% of daily activities are pursued in the residential census tract, 21% in adjacent census tracts and 73% take place in other parts of the city (Matthews et al., 2005) cited in (Zenk et al., 2011). Another study in the Paris metropolitan area has highlighted that individuals mainly pursue their domestic activities (i.e., food shopping and using services) within their residential neighborhood, and their social and leisure activities (i.e., going to a café or a restaurant, going for a walk or meeting friends) outside their neighborhood of residence (Vallée et al., 2010). A recent study from Basta et al. (2010) on the exposure to alcohol outlets among adolescents in Philadelphia (US), drew attention to the fact that adolescents cross an average of 8 census tracts in the course of their daily activities, and spend 71% of their outside-home-time outside of their census tract of residence. Furthermore, mobility, and thus exposure, vary from person to person, including less mobile groups (i.e., older, retired, children). However, Robinson et al. (2013) have shown that children spend 58% of their time within their residential neighborhood as defined by census tract (Robinson and Oreskovic, 2013). Similarly, Villanueva et al. (2012) found that children walk and bike only a small part of their residential neighborhood (i.e., circular or street-network buffers ranging from 800m to 1600m), suggesting that such traditional definitions of neighborhood do not accurately represent their 'true' neighborhood environment. As a consequence, the traditional notion of 'bounded' residential neighborhood might be obsolete (Cummins et al., 2007; Kearns and Parkinson, 2001) and the notion of neighborhood itself might not be as relevant anymore.

In short, defining the 'true' geographical context of exposure is challenging and failing to do so leads to 'spatial misclassification' (Duncan et al., 2014; Vallée and Shareck, 2014). This issue further is related to the 'Uncertain Geographic Context Problem' defined by Kwan as "the problem that findings about the effects of area-based contextual variables on individual behaviors or outcomes may be affected by how contextual units (e.g., neighborhoods) are geographically delineated and the extent to which these areal units deviate from the true geographic context" (Kwan, 2012a, p. 245; 2012b). In this thesis I argue that the space within which people move over the course of their daily activity should be considered, rather than only the places in which they live; this might provide a more accurate assessment of the geographic life environment to which they are exposed (Cummins et al., 2007; Zenk et al., 2011).

1.3 TWO MAJOR REASONS TO ACCOUNT FOR MOBILITY IN HEALTH STUDIES

There are two major reasons to account for individual daily mobility in studies examining place effects on health. Chaix et al. (2012) provide a useful framework depicting these reasons (Chaix et al., 2012b) (Figure 1).

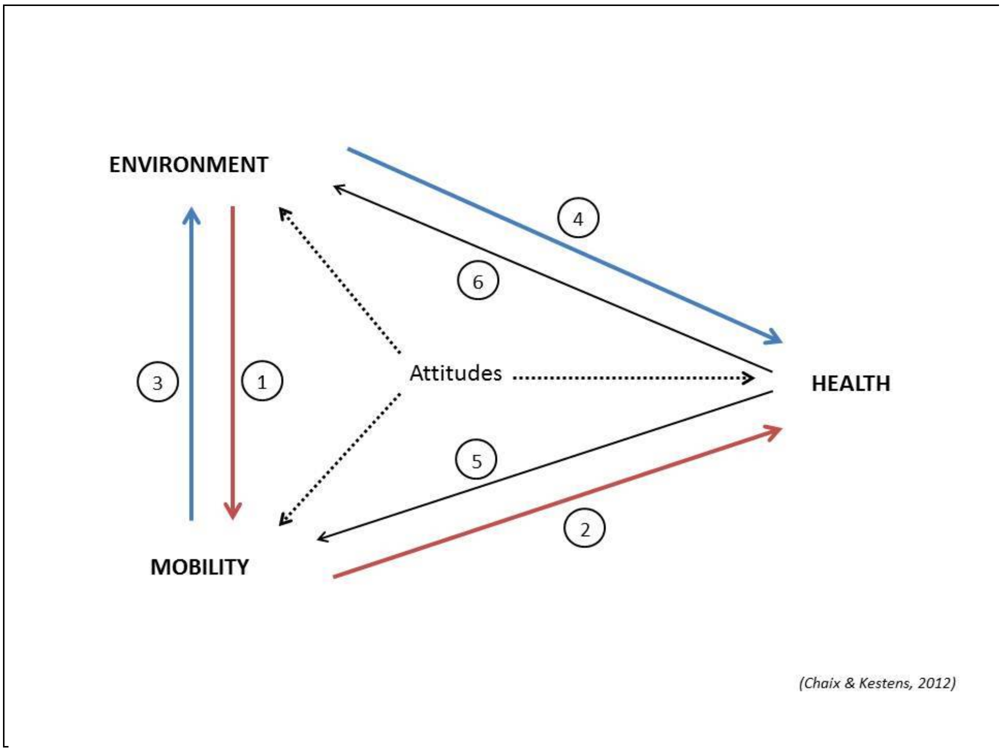

Figure 1. Chaix et al.'s (2012) theoretical illustration of the environment, mobility and health triad

Note: Conceptual framework from *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. American Journal of Preventive Medicine 43, 440-450.*

It is now widely recognized that the environment influences mobility and health (relations 1 and 4), and that through physical activity (for recreation and transportation purposes), mobility itself also influences health (relation 2) (Hamer and Chida, 2008; Ming Wen and Rissel, 2008). As emphasized before, individuals are not bound to their residential neighborhood and therefore, mobility is also a "vector of exposure to multiple geographic life environments" (Chaix et al., 2012b) (i.e. workplace, food and services activity places, social or recreational activity places) (relation 3). The relations that are of particular interest for our work are the two indirect pathways to health. Firstly, the environment may influence health by influencing mobility habits (Pathway 1-2) (Chaix et al., 2012b). For instance, greener living environments have indirectly been associated with individual-level health by providing opportunities for recreational physical activity and active commuting (Maas et al., 2008; Richardson et al., 2013b; Stronegger et al., 2010; Sugiyama et al., 2008). In such a case, active transportation and physical activity are mediating factors in the relationship between environment and health. Secondly, mobility influences health by "shaping the environments to which individuals are exposed" (Chaix et al., 2012b, p. 444) (Pathway 3-4). Environmental characteristics (i.e. greenness, aesthetic features, specific equipment, perceived barriers) influence individual daily mobility, which in turn influences levels of individual exposure to social and built environments, and thus health. As emphasized by Chaix et al., this last relation suggests that more attention needs to be paid to "contextual expology" defined as "a subdiscipline to better assess the spatiotemporal configuration of environmental exposures" (Chaix et al., 2012b, p. 440).

This dissertation provides new conceptual and methodological grounds to account for individuals' daily mobility patterns in health research. More precisely, this thesis provides evidence for the contributions made by accounting for environmental conditions around the activity locations visited on a regularly basis in the understanding of environmental effects on physical activity, and more specifically recreational walking.

1.4 ASSESSING INDIVIDUALS' SPATIAL BEHAVIORS IN HEALTH STUDIES: The concept of activity space

The recent developments in the technologies, the data collection, and the methods for analysis used to assess individuals' mobility, including travel surveys (Kestens et al., 2010; Lebel et al., 2012; Setton et al., 2011) and GPS receivers (Hurvitz and Moudon, 2012; Kerr et al., 2011; Rainham et al., 2008; Thierry et al., 2013; Zenk et al., 2011), have led to an increasing number of epidemiological studies accounting for mobility. Because daily mobility is a 'key determinant of exposure' (Chaix et al., 2012b), more attention is needed to evaluate characteristics of spatial behavior and their individual socio-demographic determinants. Also, identifying the more mobile populations will in turn provide insights for the individual profiles that are more susceptible to classification bias when only considering residential exposure. At the same time, further investigation is required to better evaluate the network of activity places to which individuals are exposed in the course of their day-to-day lives.

Some authors have argued that the concept of activity space might be helpful to grasp individual space-time patterns for health studies (Chaix et al., 2012b; Kwan, 2009; Miller, 2007). The concept of activity space has been defined by Golledge and Stimson as "the subset of all locations within which an individual has direct contact as a result of his or her day-to-day activities" (Golledge and Stimson, 1997). The activity space, in reflecting daily mobility, is an individual measure of spatial behavior (Sherman et al., 2005). Activity space has been examined in relation to self-rated health (Inagami et al., 2007), diet and obesity (Kestens et al., 2010; Lebel et al., 2012), cervical screening (Vallée et al., 2010), mental health (Vallée et al., 2011), air pollution (Setton et al., 2011), neighborhood deprivation (Shareck et al., 2014b), and physical activity (Villanueva et al., 2012; Zenk et al., 2011). However, little attention has been paid to the qualification and the quantification of individual space-time patterns in a health perspective. Yet, spatial behavior varies with age, gender and socio-economic status (SES) (Camarero and Oliva, 2008; Collia et al., 2003; Dijst, 1999a, b; Fobker and Grotz, 2006; Guest and Lee, 1984; Lord et al., 2009; Macintyre and Ellaway, 1998; Morency et al., 2011; Newbold et al., 2005; Páez et al., 2010; Paez et al., 2007; Schönfelder and Axhausen, 2002). Consequently, the nature and the quality of the visited place and the capacity for individuals to escape their residential neighborhood and reach different and better quality resources varies (Chaix et al., 2012b; Dijst, 1999a, b; Páez et al., 2010; Schönfelder and Axhausen, 2003; Shareck et al., 2014a; Shareck et al., 2014b).

1.5 ACCOUNTING FOR DAILY MOBILITY IN EXPOSURE ASSESSMENT

Focusing solely on the residential neighborhood might lead to an underestimation or overestimation of individual exposure (Chaix et al., 2005; Diez Roux, 2008). The nature of residential and non-residential exposures may indeed differ, thus daily mobility may act as a modifier of residential exposure by modulating their health effects (Basta et al., 2010; Inagami et al., 2007; Shareck et al., 2014b). However, how environmental exposure within and outside the residential neighborhood differs remains largely unknown. A recent study based on the tracking of participants with GPS receivers (N=41) in the Seattle area revealed that more than 90% of the built environment measures differed between residential and non-residential activity places (Hurvitz and Moudon, 2012). Another study based on a small sample of adolescents (N=55) found than exposure to alcohol outlets over the course of daily activities was significantly different from exposure within their census tract of residence (Basta et al., 2010).

Considering that people might experience different contextual exposure when they move or travel outside their residential neighborhood, daily mobility has been hypothesized as a vector to reduce inequalities in health. Indeed, individuals living in a deprived neighborhood may reach higher quality resources in the course of their daily activities. Or similarly, individuals living in a neighborhood not suitable for walking could experience more friendly-walking environments around non-residential activity locations (i.e., work, school, social or recreational activity places). Broadly, exposure to the geographic life environment could vary from individuals experiencing a good accessibility to resources, both within and outside their residential neighborhood to individuals suffering from a low exposure to healthy resources within their residential neighborhood and in the course of their daily activities (Vallée et al., 2014). The last category refers to the notion of double burden (Shareck et al., 2014b) and is of main interest for public health interventions. Therefore, further investigation on the variation of exposure between residential and activity space environments among individual socio-economic status groups is required.

1.6 BUT BEWARE OF THE SELECTIVE DAILY MOBILITY BIAS

Finally, accounting for daily mobility in place and health studies requires caution with regard to confounding related to the *selective daily mobility bias* (Chaix et al., 2012b; Chaix et al., 2013b). The selective daily mobility has been defined as "the fact that people who visit particular activity places during their daily lives have particular characteristics (e.g., socio-demographic, psychological, or cognitive characteristics; behavioral habits) that also influence their health status" (Chaix et al., 2012b, p. 441). Similar to concerns around residential selective migration (Frank et al., 2007; Oakes, 2004), not addressing the selective daily mobility bias might result in additional confounding. This would lead to an overestimation of the association between the built environment and health. However, as of yet, no studies examining place effects on health have attempted to address the selective daily mobility bias.

In this dissertation, I develop methodologies to examine the impact of the selective daily mobility bias on the assessment of the individual exposure to two built environment characteristics supportive of walking. I will further attempt to mitigate this selection bias in a case study on the environmental correlates of recreational walking.

1.7 DISSERTATION FORM

This manuscript begins with a scoping literature review on the current limitations associated with an exclusive focus on residential exposure, while examining and refining the concept of activity space through an interdisciplinary perspective (i.e., time geography, transportation research, environmental psychology and research on social networks). This literature review is presented in the article entitled "Conceptualization and measurement of environmental exposure in epidemiology: Accounting for activity space related to daily mobility" published in *Health and Place* in 2013 (Perchoux et al., 2013). A method section (Chapter 4) then presents the RECORD Cohort Study, the data collection process and variable definitions as used in the empirical analyses. Chapter 5 presents the results of my study and consists of three empirical papers. The first empirical study helped determine the main characteristics of individual spatial behaviors by performing a typology of mobility patterns related to socio-demographic determinants. By showing that mobility patterns indeed differ considerably between socio-demographic characteristics and location of the household residence in the Ile-de-France Region, this paper sets the foundations for the necessity to account for daily mobility in subsequent studies. It was published in 2014 in the journal *Social Science and Medicine* under the title "Assessing patterns of spatial behavior in health studies: their socio-demographic determinants and associations with transportation modes (the

RECORD Cohort Study)" (Perchoux et al., 2014). In a second empirical study, I looked at the differences in built environment exposures supportive of recreational walking when using traditional definitions of neighborhoods (residential-based areas) and the activity space. A manuscript entitled "Residential neighborhood, perceived neighborhood, and individual activity space: Quantifying differences in built environment exposure - The RECORD Cohort Study" was recently submitted to the *Journal of Urban Health*. Finally, a third empirical study examines the correlates of walking for recreational purposes both within and outside the residential neighborhood compared to a more classical analysis based on the residential neighborhood only. This study also examines the marginal contribution of environmental characteristics in each type of visited activity place (i.e. work place, social activity, recreational activity) on recreational walking. A manuscript entitled "Accounting for the multiple daily activity places of people in the study of the built environment correlates of recreational walking (the RECORD Cohort Study)" was recently submitted to the *American Journal of Preventive Medicine*. Finally, Chapter 6 includes a discussion of my thesis which provides an overview of the main findings and synthesis of the strengths and limitations of all of the main chapters and articles. It also suggests future directions and recommendations, as well as concluding remarks.

CHAPTER 2. LITERATURE REVIEW

2.1 ARTICLE 1: CONCEPTUALIZATION AND MEASUREMENT OF ENVIRONMENTAL EXPOSURE IN EPIDEMIOLOGY: Accounting for activity space related to daily mobility

Camille Perchoux, Basile Chaix, Steven Cummins, Yan Kestens

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Title: Conceptualization and measurement of environmental exposure in epidemiology: Accounting for activity space related to daily mobility

Author list: Camille Perchoux[a,b,c,d*], Basile Chaix[c,d], Steven Cummins[e], Yan Kestens[c,d]

[a] Department of Social and Preventive Medicine, Université de Montréal, Montreal, QC, Canada

[b] Montreal University Hospital Research Center, Pavillon Masson, Montreal QC, Canada

[c] Inserm, U707, Paris, France

[d] Université Pierre et Marie Curie-Paris6, UMR-S 707, Paris, France

[e] Department of geography, Queen Mary, University of London, England, United Kingdom

*Corresponding author

Camille Perchoux

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2.1.1 Abstract

A considerable body of literature has investigated how environmental exposures affect health through various pathways. These studies have generally adopted a common approach to define environmental exposures, focusing on the local residential environment, using census tracts or postcodes to delimit exposures. However, use of such administrative units may not be appropriate to evaluate contextual effects on health because they are generally not a 'true' representation of the environments to which individuals are exposed. Recent work has suggested that advances may be made if an activity-space approach is adopted. The present paper investigates how various disciplines may contribute to the refinement of the concept of activity space for use in health research. In particular we draw on seminal work in time geography, which provides a framework to describe individual behavior in space and time, and can help the conceptualization of activity space. In addition we review work in environmental psychology and social networks research, which provides insights on how people and places interact and offers new theories for improving the spatial definition of contextual exposures.

Keywords: Activity space, Daily mobility, Individual exposure, Neighborhood, Interdisciplinary theory

2.1.2 Introduction

A considerable body of literature in social science and population health research has investigated the field of contextual effects over the past two decades. Despite ongoing discussions on the best way to define geographic context (Bernard et al., 2007; Cummins, 2007; Daniel et al., 2008; Macintyre et al., 2002), ecologic and multilevel analysis have generally adopted a common approach based on the notion of "neighborhood". Most studies focus on the residential neighborhood and used local administrative units, such as census tracts, as spatial delimitations (Diez Roux, 2001). Such choices are primarily based on the availability of routine administrative data rather than on the theoretical underpinnings concerning the appropriate spatial scale at which environmental exposures are meant to affect individuals. Census tracts, block groups, or postal units provide a readily usable spatial delimitation for the assessment of social or built characteristics of local areas. Nevertheless, administrative units are probably ill-suited to represent the appropriate space to evaluate environmental effects on health, as they generally do not represent the potentially accessible environment of an individual nor the true experienced exposure (Lee et al., 2008). Prior research on environment-health relationships has observed a relatively marginal effect of neighborhood factors (Adams et al., 2009; Diez Roux, 2001; Oakes, 2004; Pickett and Pearl, 2001). However, a misspecification of contextual boundaries could explain the weakness of such observed associations (Spielman and Yoo, 2009). Until now, social and spatial epidemiology have not fully integrated individual space-time behavior, even if fixed residential spatial units may not be the most relevant way to account for environnemental exposure in epidemiologic research.

By reviewing the concept of space and mobility in the fields of epidemiology, geography, transportation research, and environmental psychology, the present article aims to help refine the conceptual and operational elements for environmental exposure assessment in epidemiological research. First, we question the relevance of routinely using administrative units. Second, the role of mobility is explored in relation to the current focus on residential exposure in aetiological studies. Given the transdisciplinary nature of research on mobility and exposure, the present article performs a scoping review in various disciplines in order to explore how notions of mobility and activity spaces may contribute to a refinement of contextual exposures in health research.

2.1.3 Measuring exposure: the limits of a static approach to neighborhood

The neighborhood: A static definition of context

Residential neighborhoods as fixed spatial units

Several literature reviews (Chaix, 2009; Cummins et al., 2007; Leal and Chaix, 2010; Riva et al., 2007; Schaefer-McDaniel et al., 2010a) have questioned the legitimacy of using fixed spatial units such as census tracts, census block groups, postal codes, voting precincts or administrative unit clusters as geographic boundaries to investigate social and physical influences. Relationships between neighborhood residential environments and various health behaviours and outcomes have traditionally been investigated using such an approach. This choice is justified, in part, by the homogeneity criterion (related both to the physical and socioeconomic environments) that is generally used to establish these spatial delimitations (Diez Roux, 2007), the availability of routine data describing such administrative units, and use of some statistical methods that require hierachical data such as multilevel modelling.

Such definitions of context have conceptual and methodological limitations for environmental exposure assessment in epidemiology. Whereas administrative or historically inherited delimitations of neighborhoods may have true sociological and collective meanings (Lebel et al., 2007), they are not necessarily representative of each individual's unique spatial experience. Due to individualized patterns of mobility around the residence, there is often a mismatch between the experienced or perceived residential neighborhood and its administrative definition. Perceptions of neighborhood limits will vary between individuals, even among those residing in the same building (Coulton et al., 2004; Coulton et al., 2001; Duncan and Aber, 1997; Schaefer-McDaniel et al., 2010b). Furthermore, the characteristics of a given unit are potentially less adequate in representing the exposure of individuals living near the boundaries of the unit than of individuals located near the center of the unit (Chaix et al., 2005). The currently rigid and uniform approach that nests individuals within fixed spatial units generates a common spatial definition of context and thus attributes similar levels of exposure to all individuals living in the same administrative territory (Leal and Chaix, 2010).

The heterogeneity of geographic units of analysis in research makes comparisons across studies difficult. For example, the mean number of inhabitants per geographic unit often varies from one study territory to the other (Diez Roux and Mair, 2010; Lee et al., 2008). Furthermore, multilevel studies usually analyze administrative units as independent and isolated areas (Chaix et al., 2005), as opposed to various types of spatial hierarchical models (Anselin, 2009). This practice ignores resources located in adjacent units (Coulton et al., 2001) that could potentially affect health (Morenoff, 2003). In other words, using administrative units imposes excessive simplifications and a fragmentation of space that leads to potential misestimation of interactions between space, its resources and individual spatial behavior (Diez Roux, 2008).

Shifting to an ego-centered definition of place

Geographic Information Systems (GIS) enable to circumvent the use of routine administratives units as proxies for neighborhoods. As recommended by several authors (Chaix et al., 2009; Lee et al., 2008; Miller, 2007a), an ego-centered definition of the residential "neighborhood" may reflect more accurately the local exposure area related to the personal experience of the residential space (Nemet and Bailey, 2000). An ego-centered neighborhood corresponds to a local area which is centered on an individual - typically his/her home - and whose boundaries are generally defined by a given distance threshold.

Different types of buffers have been used, such as circular or elliptic zones, and road network buffers (Oliver et al., 2007). Various distances have been experimented with, but authors have generally used a threshold distance that is easily walkable from home, so as to represent the distance people are willing to walk from home to reach basic utilitarian destinations – though there is limited empirical data to support the choice of buffer size. A number of authors have, for example, used half a mile radius circular buffers around each individual's home (Berke et al., 2007; Leal et al., 2011; Tilt et al., 2007). A study in Seattle, Washington, evaluated that most home and routine destinations were between 0.2 and 0.4 miles apart (Moudon et al., 2007). Some authors (Chaix et al., 2009) also emphasized the use of home centered buffers with fuzzy boundaries, which account for the often smooth transition between the inner and the outer neighborhood space. Similarly, person-focused exposure areas should be specific to the individual rather than universally applied to study participants, and may be defined as oriented rather than isotropic (i.e., distorted in a certain direction according to familiar places, street networks, shops, transport stations and obstacles such as railroads or rivers). Nonetheless, as emphasized by Leal et al. (2011), the choice of the spatial scale is intimately related to the study territory, type of contextual factors, and outcomes of interest and should be driven by these factors.

Yet, administrative and ego-centered neighborhoods are often exclusively home-centered and do not take into account that individuals move around and do not stay in one unique location over the course of their daily activities (Rainham et al., 2010).

From a static to a dynamic approach of exposure

The neighborhood: an incomplete unit of analysis

Defining the context of exposure using residential areas has been criticized from different perspectives including that of the "local trap" (Cummins, 2007) and the "residential trap" (Chaix, 2009). According to the concept of the local trap, the local scale is not the only meaningful unit of interest in environmental health research; as a result context should not be exclusively defined as a local area (Purcell and Brown, 2005a). The residential trap refers to the danger of reducing the influence of context solely to residential environments. Measuring exposure only at one's place of residence ignores non-residential locations visited during daily activities, such as the work place and school, and may thus misrepresent 'true' environmental exposures (Matthews, 2011a; Setton et al., 2011). Kwan et al. emphasized that households did not limit their use of contextual resources to their local neighborhood, but accessed facilities like shops or healthcare services in places other than the local areas (Kwan and Lee, 2004). The choice of where resources are accessed and used depends on their specific location but is also motivated by individual spatial trajectories, and life situation (Kwan, 1999). Moreover, some authors have shown that there are weak correlations between residential exposures and non-residential environments (Hurvitz and Moudon, 2012; Zenk et al., 2011). This entails that individuals have significantly different residential and non- residential exposures, and accounting for multiple place exposures would avoid individual exposure misclassification.

Most contextual studies in epidemiology have ignored exposure to activity spaces outside of the residential environment (Chaix, 2009). The amount of time spent at home and the fundamental importance of one's residence may be seen as a justification of the fact that contextual epidemiologic research has relied on residential neighborhood in order to assess environmental exposure. Moreover, limiting exposure to the residential neighborhood may be less misleading for specific groups such as young children (Inagami et al., 2007; Pearce et al., 2009) and older people, whose spatial patterns and mobility may be well represented by the local residential area. Such groups may also include marginalized populations or spatially segregated groups such as ethnic minorities (Bolt and van Kempen, 2010; Van Kempen, 2010). However, even for these groups and more particularly for more mobile groups, restricting the measurement of exposure to the residential neighborhood is a limitation.

The neighborhood: An inadequate approach to new space-time dynamics

The need to adapt our definition of areas for defining environmental exposure is strengthened by changing individual space-time behavior. Human activities are organized in space and time, and patterns of temporality and spatiality of activities have changed rapidly over time. Contemporary society has mostly transformed the regulation of individual space and time imposed by industrial societies. Janelle (1969) referred to this situation as 'space-time convergence', namely "a measure of change in the required effort to overcome distance", generally defined "as the average rate of decline in travel time between places over time" (Janelle, 2001, p. 15747).

Firstly, innovations in transportation have drastically reduced time-distance between places. This space-time convergence has also taken place at the local scale due to the democratization of public and private motorized transport such cars, buses, trains and trams. These innovations have significantly increased mobility, in terms of distance covered and a reduction in travel times. During the 20th and 21st centuries the individual time-budget for transportation has remained unchanged while the number of kilometers covered each day has dramatically increased (Zahavi and Talvitie, 1980). Shifting mobility patterns are also linked to developments in Information and Communication Technology (ICT) (Miller, 2007b). These innovations have meant that an increasing proportion of daily activities are no longer linked to a specific time or place, and the wide adoption of technologies such as the internet and smart phones has extended people's activities from physical to virtual environments (Yu and Shaw, 2008). Virtual space allows people to access many resources or engage in activities independently from any specific physical location.

As a consequence, some have argued that the customary bounded residential neighborhood may be disappearing (Kearns and Parkinson, 2001), and that the traditional notion of neighborhood itself may not be as relevant anymore. Thus there is a need to account for change in space-time behaviors in epidemiological assessment of environmental exposures. Because people are increasingly mobile and experience numerous places in their daily lives, individualized measures of experienced activity spaces are required.

Considering individuals' specific interactions with space

Uniform spatial delimitations do not take into account individual heterogeneity in terms of lifestyle habits and related spatial patterns (Rainham et al., 2010; Saarloos et al., 2009). Different levels of mobility, access to resources and technologies, connections to social networks, and life stage have a considerable impact on the way people interact with environment. Consequently, the shape and the scale of personal exposure area may vary (Spielman and Yoo, 2009). Such an increasing individualization of spatial experience – also called "person-place convergence" (Kellerman, 1999) – requires more flexible measures of exposure centered on the individual (Cummins, 2007). As such, an individual's activity space may be a useful construct to describe spatial behavior and may help establish adequate assessments of environmental exposure.

2.1.4 Considering mobility in exposure assessment: relevance of the concept of activity space

A brief definition of activity space

The notion of "activity space", originally rooted in social sciences, has been defined as "the subset of all locations within which an individual has direct contact as a result of his or her day-to-day activities" (Golledge and Stimson, 1997, p. 279). The activity space, in reflecting daily mobility, is an individual measure of spatial behavior (Sherman et al., 2005b). Accordingly, the present paper focuses on daily mobility without losing sight of the fact that daily mobility is strongly influenced by residential location itself (activity spaces are likely to show variability in shape and size according to individual and residential environmental characteristics (Rainham et al., 2010)).

Activity spaces are defined in both space and time. Geographically, an activity space can be considered as a geometric indicator of observed or realized daily travel pattern travel (Schönfelder and Axhausen, 2003b). The structure of an activity space is often organized around three major spatial objects : 1) home and movement near the home 2) daily activity locations and movements around those locations and 3) movement and travel between the daily activity locations (Golledge and Stimson, 1997). As illustrated in Figure 1, activity spaces are generally multi-centered (Axhausen et al., 2002).

The temporal structure of an activity space is defined by the frequency, regularity, and duration at which locations are visited. Different ways to classify activities and mobility patterns have been used. "Fixed activities" which are spatially or temporally determined and cannot be easily rescheduled such as work are usually distinguished from "flexible activities" which are easy to reschedule and can occur in various locations or at different times such as sports (Hägerstrand, 1970). Activities have also been classified as habitual, planned or spontaneous (Gärling et al., 1998), a trichotomy that applies both to the temporal dimension and to the spatial dimension (Ramadier et al., 2005). Accordingly an activity may be fixed in the spatial dimension and flexible in time or reciprocally (Miranda-Moreno and Lee-Gosselin, 2008). Finally, Golledge and Stimson have identified 4 types of spatio-temporal patterns of activities (Golledge and Stimson, 1997). The "regularly scheduled activities" occur at a specific and pre-planned time, like work commonly starting in the morning, ending in the evening, 5 days per week. "Trips to purchase needed items consumed regularly" tend to be spaced over time without being fixed, "trips to undertake times-contagious activities" refer to activities with an increase in the probability of participation again soon which gradually decrease over time and finally "trips to activities that occur randomly in time". Accordingly, the structure of activity space is related to the location of activities but also to the types and frequencies of these activities within a specific time period.

Space time pattern analyses are particularly relevant to qualify and quantify individual spatial behavior in relation with the accessibility to resources. Activity space studies would allow identifying spatial exclusion of low mobility people trapped in low resource residential neighborhoods (Schönfelder and Axhausen, 2003b), or detecting mobile people travelling exclusively across low resource environments (Chaix et al., 2012b). Moreover, as mobility may be seen as a key determinant of environmental exposure, activity space studies allow taking into account the full range of environments people get exposed to during their day to day activities.

Few studies investigating contextual influences on health have considered individual activity spaces and related exposures (Inagami et al., 2007; Kestens et al., 2010; Setton et al., 2011). Some authors have indirectly assessed activity spaces by asking study participants whether their daily activities were inside or outside their perceived residential neighborhood and found significant influence of activity space (Vallée et al., 2010; Vallée et al., 2011). Others have taken into account the location and the environmental characteristics of the residential neighborhood and non-residential activity destinations. One of the only studies considering both residential and non-residential activity locations looked at the place of work, place of worship, location of medical care, location of grocery store, and other areas where individuals might spend time (Inagami et al., 2007) in relation to self-rated health. In that study, considering exposure to socioeconomic disadvantage in non-residential neighborhoods increased the magnitude of the association between area characteristics and self-rated health.

Refining the concept of activity space in an interdisciplinary perspective

Despite its relevance for assessing environmental exposure, the notion of activity space is almost absent from epidemiological studies and needs to be further explored. Therefore, we examine how various disciplines may contribute to enrich and refine the concept of activity space for health research.

Space-time geography: examining space-time patterns

Notions of activity space are historically rooted in space-time geography (Hägerstrand, 1970) which provides a relevant framework to analyze human daily activity travel patterns. Participating in fixed and flexible activities implies dealing with constraints like time budget and resources for physical movements and interactions (Miller, 2007b). Hägerstrand identifies three types of constraints. The "capability constraints" are determined by physiological reasons (place to eat, sleep, etc.) and physical capabilities, available resources (transportation modes, rate of speed etc.), and topological reasons that limit our universe of possibilities. The "coupling constraints" refer to the feasibility to have, in a specific space and time, the conjunction of the required individuals and entities to pursue and realize a project. At last, the "authority constraints" embrace access restrictions determined by the rules and regulations of the society. Those constraints limit movements' freedom of an individual and define a space time pattern of mobility (ie. "space time path") that can be experienced by that person during his/her day to day activities (Kwan and Weber, 2007). Consequently, in health studies, those space-time constraints should be taken into account to assess the urban opportunities/resources that an individual can reach and the environmental hazards to which he/she is exposed from specific activity locations. In their study, Kestens et al. (2010) have suggested that the use of kernel density estimations to derive local densities of food stores at each visited location might allow to account for time-budget and other individual constraints in exposure assessment (Kestens et al., 2010).

The spatial and the temporal dimensions are connected through the concept of "space-time path" which describes a person's movement from one location to another. There are two kinds of space-time paths: the potential path area and the actual path area. The potential path area is defined “as an area containing all feasible routes and urban opportunities given the space time constraints defined by the fixed activities” (Kwan, 1999, p. 213). On the opposite, the actual path area represents all the places to which an individual effectively goes in his/her daily activities. In the same vein, daily mobility patterns can be represented in 2D by space-time prisms (Hägerstrand, 1970; Lenntorp, 1976; Pred, 1977) and visualized in 3D through space-time aquariums (Kwan, 1999; Kwan and Lee, 2004). However, these two concepts are not further discussed here as the present article is focused on the measurement of mobility rather than on its visualization.

Transportation research and urban-planning research: structuring the activity space

Transportation research and urban planning have widely developed and enriched Hägerstrand’s legacy. Both have investigated mobility in terms of “accessibility”, which can be defined as ‘‘the ease and convenience of access to spatially distributed opportunities with a choice of travel’’ (Dong et al., 2006, p. 164). One traditional measure of accessibility was grounded on the trip-based model which examines one trip at a time with no considerations for trip chaining and scheduling (Dong et al., 2006). However, the emergence of the activity based approach (ABA) in transportation research (Ben-Akiva and Bowman, 1998) has highlighted the link between travel and activities to establish a comprehensive framework of travel behavior. The ABA takes into account the schedule of activities in space and time, the trip chain, and the interdependency of spatial, temporal, transportation, and personal constraints which impact travel-activity behavior, and finally the full set of activities in which an individual engages in a day (Dong et al., 2006; McNally, 2000). The ABA, by describing the spatial and temporal behavior in more detail, contributes to structuring the concept of activity space.

The organizing concept of a Personal Network of Usual Places, rooted in the field of transportation research, has been proposed as a useful tool to apprehend individual activity spaces (Flamm and Kaufmann, 2006). The network of usual places includes all the places an individual visits regularly and the roads he/she usually takes to join those anchor points. In order to describe the space-time patterns of mobility in relation to activities, the authors emphasize four significant components: the “daily life centers” are where individuals spend a great amount of time and which are considered as important for some symbolic or practical reasons (home, work, etc.); the “clusters of minor activities locations” (banks, restaurants, daily shopping, etc.), usually close to the daily centers; the “circulation corridors” i.e. the familiar routes between usual places; and finally, the “transport interfaces” regularly used such as underground station or car parks.

Activity spaces can also be defined in terms of stability, flexibility, variability and periodicity. According to the utility maximization theory, travel behavior consists mainly of routines resulting from the human will to perform activities as efficiently as possible (Schlich and Axhausen, 2003). However, human spontaneity and the complexity of external factors acting on our daily travels induce intrapersonal variability in daily travel patterns. One obvious distinction in spatial behaviors is between weekdays and weekends (Schönfelder, 2001). In a study in Switzerland, Srivastava (2003) identified that larger variations in size of activity spaces arise when comparing weekdays and weekends. During weekdays, activities tended to cluster around daily life centers like school, workplace or home. For instance, full time workers had a very stable and repeating activity space during weekdays but a different and more variable activity space during the weekend. On the opposite, part-time workers had a larger activity space during weekdays while weekends were relatively stable in terms of experienced space. Finally, no difference between weekdays and weekends activity spaces was observed among retired people (Srivastava and Schoenfelder, 2003).

Transportation research provides a framework to explore individual mobility. This approach contributes to the definition of the notion of activity space through the emphasis on its structuring elements such as daily life centers, clusters of activity places, circulation corridors, and transport interfaces that may be useful to take into account for improved environmental exposure estimates.

Environmental psychology: sense of belonging and perception of space

Activity spaces can be considered as composed of sub-regions to which the individuals are differently exposed. Environmental psychology emphasizes the concept of "territorial belonging" (Gubert, 2000) to establish a hierarchical distinction of those sub-regions. The concept of territorial belonging is anchored in the relationship between place and identity and embraces the concept of "place identity" referring to "a pot-pourri of memories, conceptions, interpretations, ideas and related feelings about specific physical setting" (Proshansky et al., 1983, p. 60). The present article emphasizes the fact that different places contribute to shape the identity of individuals (Twigger-Ross and Uzzell, 1996) and that individuals have distinct cognitive and emotional ties with their different activity places.

Human mobility and the size and shape of the activity space play a role in the relationship between place and identity. The increased mobility observed in recent decades may not reduce people's feeling of territorial belonging , but rather might reinforce the sense of belonging (Gustafson, 2009). Many socio-demographic factors such as sex, age, or social class are related to mobility in terms of frequency, distance and duration and to the sense of territorial belonging. Different forms of mobility have different implications on the scale of territorial belonging (feeling of belongingness for one's neighborhood, village, city, region, or nation) (Lewicka, 2010). Van der Land even emphasizes that "mobility might in fact be conducive to forming ties with a place" [(Van der Land, 1998) cited by Gustafson (2009)]. The influence of daily mobility on local belonging is unclear. Some authors emphasize that longer commutes may reduce time spent at home, attenuate sense of belonging, and limit community life (Putnam, 2000), whereas others argue the opposite (Case, 1996).

The notion of "perceptual regions" (Reginster and Edwards, 2001) examines experienced space through key concepts of locations and activities. Perceptual regions are based on three interacting elements: "a sense of belonging to a space, associated with a hierarchical structure; a set of environmental qualities; and a collection of activities" (Reginster and Edwards, 2001, p. 7). Each location is associated with a set of qualities and activities. The subjective representation of those qualities determines the sense of belonging to each place. This model considers that both the knowledge of the environment and the related sense of belonging are elaborated by experiencing a place many times. Spatial behavior translates into a hierarchy of perceived spatial regions: the vista space, the local displacement space and the enlarged displacement space. The perceptual region is a hierarchical structure of interlocked spaces whereof the related sense of belonging decreases with growing distance from activity center. In terms of exposure assessment, this concept suggests i) a hierarchy between activity locations according to their related sense of territorial belonging and ii) a gradient in the intensity of exposure decreasing with increasing distance from the core locations of the activity space. In other words, activity space exposure may be conceived as a network of places with a varying intensity of exposure.

Social sciences: the spatial dimension of social-activity travel

According to Hägerstrand (Hägerstrand, 1970), the study of the spatial distribution of activities is more related to people and their interactions than to the activity locations themselves. Social research has paid relatively little attention to the geographic dimension of social networks (Daraganova et al., 2011; van den Berg et al., 2009). However, some work has analyzed social networks as a source of explanation of the social activity-travel behavior (Carrasco et al., 2008). It seems particularly important to consider social networks when investigating spatial behavior because "social structures facilitate and constrain opportunities, behavior and cognitions" (Tindall and Wellman, 2001, p. 256). In addition, space-time convergence has participated to enlarge the social network geography (Larsen et al., 2006).

Spatial dimensions of social networks have been shown to relate to the "arrangement of support systems, place attachment and physical social interactions" (Sharmeen et al., 2010, p. 3). This spatial dimension of networks has been measured by Carrasco et al. (Carrasco and Miller, 2008; Carrasco et al., 2008) by defining, as performed in geography, an activity space in terms of anchor points (home, institutions, and public space) characterized by recurrence and distance. Income was a strong correlate of the spatial dimension of a social network. People with a high income tended to have a wider social network, with more frequent interactions and greater distances between network members. On the opposite, people with a low income were involved in a lower number of socializing activities, which took place in a more restricted spatial territory (Carrasco et al., 2008). Furthermore, age was also highly correlated with the spatial scope and the frequency of social activities. Such differences may generate inequity and social exclusion. Carrasco and Miller suggest a homophily effect (McPherson et al., 2001) by which individuals have a high activity frequency with people of the same age class. Other household characteristics like household size, having children at home, being in couple, and distance between social network members are significant determinants of the social activity space defined by Carrasco et al. as “a set of potential locations to perform social activities” (Carrasco et al., 2008, p. 5).

Transportation research has also investigated activity spaces in relation to social networks, for example analyzing how activity space size relates to social network geography. In essence, the main fixed location of the person’s social network geography is one’s residence, while the other locations where people meet are considered as dynamic elements, which shape the activity space. Some authors have hypothesized that the size of one’s activity space is proportional to one’s social network geography (Axhausen, 2005). And because both openness towards others or things and spatial knowledge are influenced by age and position in one’s life course, activity space and the social network geography may be correlated within a given generation. However, this hypothesis has not been empirically demonstrated yet.

Incorporating activity space in place and health research

Place and health researchers have started to question whether and how to integrate the perceived activity space or the objectively experienced environment in their studies. The perceived activity space can be approximated by asking individuals to draw so-called mental maps (Lynch, 1960). Urban sociology and environmental psychology acknowledge that maps drawn by residents provide meaningful information to analyze the neighborhood construct (Coulton et al., 2001). However, even if perceived or subjective measures of the experienced neighborhood are important in place and health research, they do not really allow to infer the effectively experienced neighborhood (Diez Roux and Mair, 2010) or activity space. People have a tendency, consciously or not, to represent their environment as they would like it to be (Chaix et al., 2009).

Several methods have been developed to analyze space time activity data. Point based location data and GPS data have been used to derive indicators of spatial behavior and of the activity space. The most common approaches to reflect activity spaces are the standard deviational ellipse (Sherman et al., 2005c; Yuill, 1971), the convex envelope (Buliung and Kanaroglou, 2006a), the kernel density estimation (Schönfelder and Axhausen, 2003b) and the daily/potential path area. A review of the set of approaches to assess activity spaces is available in Chaix et al. (2012). However, few studies in public health have used sophisticated representations of the activity space. Kestens et al. (2010) have determined and evaluated measures of exposure to foodscapes using individual activity spaces derived from a mobility survey in Montreal, Canada. All activity locations including home were used as an anchor point for deriving exposure to a variety of food stores. Using local densities of food stores as exposure estimates, the authors attempted to represent the potential accessibility to food stores from actually visited locations, indirectly combining actual and potential activity spaces. Such activity space exposure measures have furthermore been associated with obesity (Kestens et al., 2012; Lebel et al., 2012). Setton et al. (2011) relied on a similar activity space model to estimate the bias in air pollution exposure estimates when considering only residential and omitting non-residential exposure. In this study, exposure was further weighted by the time spent at each location. The authors found that considering only the place of residence underestimated the true activity space exposure by 16% in Vancouver and by 7% in Southern California.

Various methods are currently being developed to measure individuals' activity spaces. Such methods include web based interactive mapping questionnaires allowing to collect detailed information on individuals' activity locations and related frequencies of visit and on the exact shape of their perceived neighborhood (Chaix et al., 2012b), as well as wearable global positioning system (GPS) units (Hurvitz and Moudon, 2012; Rodríguez et al., 2012; Troped et al., 2010; Zenk et al., 2011). These developments in the collection of detailed activity locations generate new needs in terms of operationalization of the activity space and associated environmental exposures.

Finally, space-time analysis in health studies could improve our ability to capture and investigate the multiple places people get exposed to in order to develop effective health interventions. First, participants could be grouped by types of mobility behaviors to assess whether space-time patterns are related to different health or demographic profiles. Researchers could also examine whether indicators of spatial behavior modify the observed relationships between residential environmental factors and health. Second, in order to better understand how geographic life environments influence health behavior and health it is important to identify i) the type of environments that matter (e.g. residential vs. non-residential environments), ii) the type of characteristics of these environments that matter (i.e. physical, socio-demographic, services, social networks, sense of belonging, etc.), and iii) the spatial scale at which these characteristics matter for a specific outcome. Therefore, the consideration of exposure to multiple places may be helpful to determine environmental targets and inform policy interventions. However, knowledge on mobility from one specific setting might be hardly generalizable to another, because of the structural, cultural, political, economic, ethnical and demographical characteristics of the setting that shape individual space time-behavior, which in turn determine individual exposure. At last, accounting for individual space-time behavior would allow evaluating the benefits of specific interventions by examining whether people have changed their mobility behavior to reach healthier resources. In a quasi-experimental intervention study, Almanza et al. (2012) have used GPS to examine the frequenting of green spaces of two groups of participants, living or not in a smart growth community (Almanza et al., 2012b).

2.1.5 Conclusion

In this paper, we have investigated how notions of mobility and activity space can improve our capacity to integrate space in the measurement of exposure to environmental factors. Our assessment of the literature covered four disciplines in which notions of activity space were used.

It appears that time geography and transportation research offer interesting theoretical and analytical frameworks to investigate individual mobility in space and time, with related notions of daily activities and trip chains. In this literature, daily mobility is also examined in terms of personal and environmental constraints which contribute to shape the activity space. Environmental psychology further adds the relevant notion of territorial belonging. The gradual sense of belonging developed by an individual for his/her experienced space allows us to define three zones referring to different levels of exposure ranging from proximal to distal effects. This hierarchical classification of sub-regions of the activity space is mostly dependent on the activity locations, the trip frequencies and attachment to each place. Finally, social sciences have investigated social activity spaces to explain individuals' spatial behavior based on the idea that social structures act on behavior, opportunities and cognition.

Some recent studies in public health have adopted the notion of activity space and related concepts, essentially from time geography and transportation research. However, this practice has yet remained marginal in spite of the improved capacity of the notion of activity space to help us capture the "true" exposure to environmental factors. This paper paves the way for related empirical developments, both for refined data collection of people's mobility and the measurement of activity spaces adapted to health research.

Issues related to the analytical techniques and the measurement of relationships between multi-place environmental exposures, individual spatial behavior, and health were not covered here.

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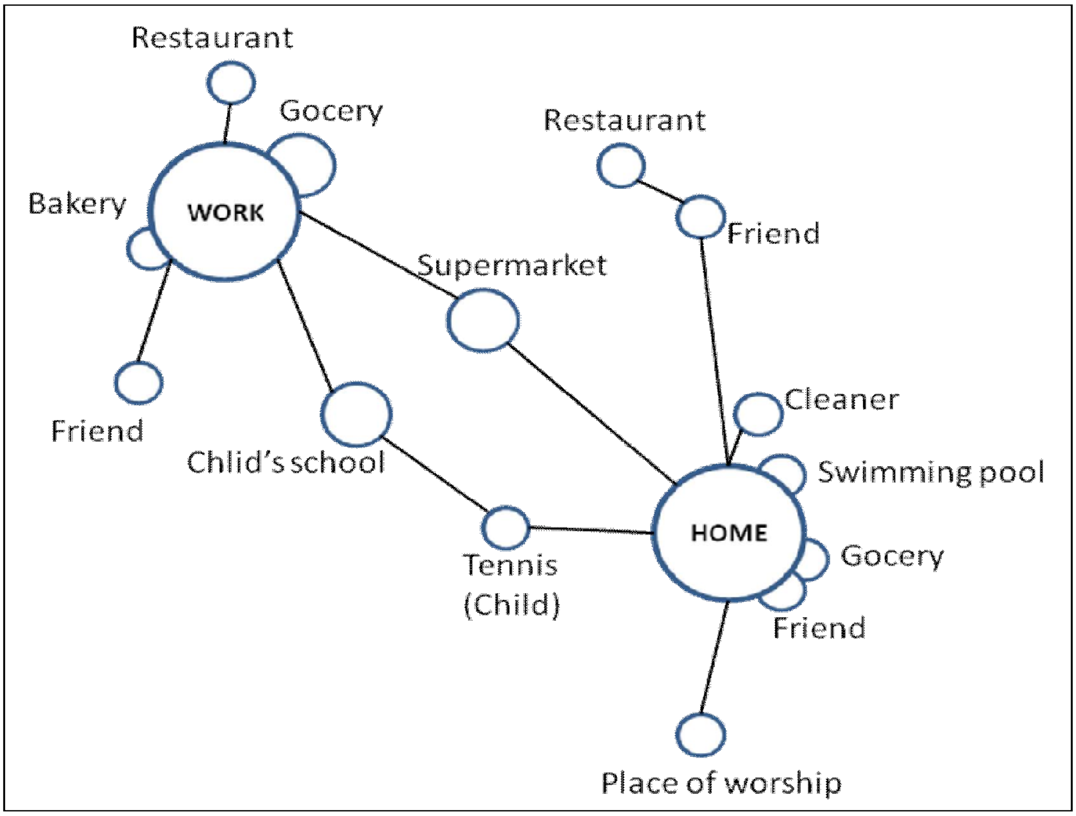
2.1.7 Tables and figures

Figure 1. Schematic activity space representation with nodes and links (inspired from Flamm and Kaufmann 2006)



Note: Links represent routes an individual usually takes between fixed geographical points. Places visited on a recurring basis are symbolized by nodes of various sizes depending on the frequency, the regularity and the duration of the visit.

2.2 AN EMPIRICAL CASE STUDY: Recreational walking behavior

2.2.1 Definition of physical activity and recreational walking

Physical activity has been defined by the World Health Organization as "any bodily movement produced by skeletal muscles that requires energy expenditure" (World Health Organization). Typical guidelines for health benefits recommend to accumulate 30 minutes of moderate-intensity physical activity at least five days a week for adults (Pate et al., 1995). This recommendation aims to balance the energy input (feeding behavior) and the energy expenditure (physical activity). The impact of physical activity on population health and prevention of major chronic diseases is well-established (Franco et al., 2005; Kohl, 2001; Powell et al., 1987; Sesso et al., 2000). Three major types of the practice of physical activity have been identified: physical activity related to professional activities, physical activity practiced at home or in the daily life including active transportation, and physical activity resulting from exercise or recreational activities (Oppert, 2005). In this thesis, I focus on the most common form of physical activity: walking (Eyler et al., 2003; Lovasi et al., 2012; Owen et al., 2004).

Walking behavior has been highly targeted by public health to promote active lifestyle (Sugiyama, 2012). It is usually divided into walking for utilitarian (i.e. transportation) or recreational purposes (Ewing et al., 2003; Giles-Corti et al., 2005; Lee and Moudon, 2006; McCormack et al., 2008; Owen et al., 2004; Saelens and Handy, 2008; Saelens et al., 2003). Recent literature suggests investigating these two types of walking separately since findings suggest different associations between environmental characteristics and types of walking (Ewing et al., 2003; Giles-Corti et al., 2014; Giles-Corti et al., 2005; Owen et al., 2004; Pikora et al., 2006; Saelens and Handy, 2008; Sugiyama et al., 2012). The present manuscript focuses on recreational walking.

2.2.2 Prevalence and patterns of recreational walking

In the literature, recreational walking has also been referred to as walking for exercise (Ball et al., 2001; Humpel et al., 2004a; Siegel et al., 1995; Suminski et al., 2005), walking for pleasure (Humpel et al., 2004a) and leisure walking (Cerin and Leslie, 2008; Ewing et al., 2003; Hirsch et al., 2014). While no strict definitions were found, recreational walking usually embraces walking for leisure, pleasure, or exercise, as well as walking for social reasons: e.g. walking during a work break or walking a dog. More broadly, recreational physical activity has been defined as "a considered behavior, undertaken for health, fitness or pleasure, rather than out of necessity" (Giles-Corti et al., 2014, p. 187).

From a public health perspective, recreational walking has been pointed out as a major health determinant since it is one of the most popular forms of physical activity (Giles-Corti et al., 2014). Moreover, walking for exercise has been more strongly associated with cardiovascular disease than transportation walking due in part to the faster pace and the regularity at which it is undertaken (Lovasi and Goldsmith, 2014). Prevalence of recreational walking varies according to the geographic region, but also tends to vary with age. Reported prevalence among adults was similar in Melbourne, Australia (78.8%) (Cleland et al., 2008), and Calgary, Canada (76.1%) (McCormack et al., 2012). A recent study in Belgium among older Flemish adults (≥ 65 years old) reported a prevalence of 53% (Van Cauwenberg et al., 2012). Another study in Perth, Australia distinguished between regular recreational walking (43.5%) and irregular/occasional recreational walking (27.7%) among adults (McCormack et al., 2008). Variations in time spent walking for recreational purposes have also been found. The mean time of recreational walking per week has been found to range from 60 minutes to more than 330 minutes (Cerin et al., 2013; Chaix et al., 2014b; Christian et al., 2011; De Greef et al., 2011; Humpel et al., 2004a; Inoue et al., 2010b; McCormack et al., 2008; Troped et al., 2003; Van Dyck et al., 2013).

Whereas some have argued that walking for recreation mainly occurs around the residence (Humpel et al., 2004b), others have observed that almost half of the median walking time was performed outside the residential neighborhood defined as an area up to 15 min walk from the residence (Cerin et al., 2013; Giles-Corti et al., 2006). More broadly, it has been shown that, among adults, more than a half of physical activity takes place outside the residential neighborhood (Cummins et al., 2007; Troped et al., 2010), while findings are mixed among children (Dunton et al., 2013; Jones et al., 2010; Robinson and Oreskovic, 2013; Villanueva et al., 2012).

2.2.3 Correlates of recreational walking

Research on recreational walking exclusively is relatively new and, despite the increasing number of publications in the last few years, most studies are exploratory in nature (Saelens and Handy, 2008).

Individual-level socio-demographic factors such as age (Humpel et al., 2004a; Van Dyck et al., 2013), sex (Chaix et al., 2014b), individual level of education (Ball et al., 2007; Cerin et al., 2013; Van Dyck et al., 2013), SES (Cerin and Leslie, 2008; Chaix et al., 2014b) and owning a dog (Cutt et al., 2007; Cutt et al., 2008a; Cutt et al., 2008b; Suminski et al., 2005) have been associated with walking for recreational purposes. Some psychological factors such as perceived barriers, enjoyment, self-efficacy and social support (Ball et al., 2007; De Greef et al., 2011; Troped et al., 2003) have also been related to recreational walking. Age, sex and SES were also identified as factors which may interact with built environment characteristics (Cerin and Leslie, 2008; Cerin et al., 2013; Humpel et al., 2004a; Van Cauwenberg et al., 2012). Finally, lack of time - because of work responsibilities for instance – and motivation, have been pointed out as important correlates of low levels of leisure-time physical activity, and more specifically, of recreational walking (Dishman and Sallis, 1994; Droomers et al., 1998; Lakka et al., 1996; McCormack et al., 2008; Owen and Bauman, 1992; Sallis and Owen, 1999; Siegel et al., 1995).

Findings regarding the environmental correlates of recreational walking have been inconsistent (Owen et al., 2004; Saelens and Handy, 2008; Sugiyama et al., 2012). Land mix use has sometimes been associated with recreational walking (Bourdeaudhuij et al., 2005; Van Dyck et al., 2013), sometimes not (Handy et al., 2006). Neighborhood educational level (Chaix et al., 2014b; Leslie et al., 2010) and residential density (Coogan et al., 2009; Van Dyck et al., 2010) have also been positively associated with recreational walking. Some studies have reported a positive association with presence, access and/or the quality of utilitarian and recreational destinations (Chaix et al., 2014b; Charreire et al., 2012; Coogan et al., 2009; De Greef et al., 2011; McCormack et al., 2008; Nagel et al., 2008; Van Cauwenberg et al., 2012), while others have found no (Ball et al., 2007; Bourdeaudhuij et al., 2005; Cerin et al., 2008; Foster et al., 2009; Handy et al., 2006; Inoue et al., 2010a; Lee and Moudon, 2006), or even negative associations (Duncan and Mummery, 2005; Heinrich et al., 2007; Maas et al., 2008). Several studies have suggested positive associations with neighborhood greenness and public open spaces (attractiveness, size and proximity) (Chaix et al., 2014b; Charreire et al., 2012; Giles-Corti et al., 2005; Sugiyama, 2012; Sugiyama et al., 2010). However, the positive association was non-systematic (Giles-Corti and Donovan, 2002; McCormack et al., 2008; Zlot and Schmid, 2005), as shown in a literature review which found positive associations in only 44% of the studies reviewed (Sugiyama et al., 2012). In a recent longitudinal study, living near a park or within walking distance was not associated with the initiation of recreational walking, but helped participants to maintain their walking behavior (Sugiyama et al., 2013). A literature review exposed that 30% of the studies found a positive association with street connectivity (Sugiyama et al., 2012). According to the same literature review, associations were found with the presence of walking facilities (sidewalks, walking trails) in only 20% of the studies, (Ball et al., 2001; Bourdeaudhuij et al., 2005; Lee and Moudon, 2006; Van Dyck et al., 2013), and 30% of the studies reported association with aesthetics and pleasant environmental features (Ball et al., 2001; Ball et al., 2007; Cleland et al., 2008; Giles-Corti and Donovan, 2002; Inoue et al., 2010b; Lee and Moudon, 2006; Van Dyck et al., 2013). Finally, perceived and objective safety from crime was, to a certain extent, reported to be positively associated with recreational walking (Alfonzo et al., 2008; Ball et al., 2007; Giles-Corti and Donovan, 2002; Hovell et al., 1989; Suminski et al., 2005; Van Dyck et al., 2013).

In summary, the links between built environment factors and recreational walking remain poorly understood, in part due to a relative low number of studies, inconsistencies in built environment measurements (objective vs. perceived), and unclear and sometimes contradictory results (Owen et al., 2004; Saelens and Handy, 2008).

2.2.4 Addressing Limitations of Past Research

Such inconsistencies in associations between built environment factors and the practice and duration of recreational walking may indicate that non-environmental factors may be at play (Sugiyama et al., 2012). However, the spatial definition at which environmental factors have been examined is quite exclusively residential-based (Lovasi et al., 2012; Saelens and Handy, 2008), and could have resulted in a spatial misspecification of exposure measures (Boruff et al., 2012; Zenk et al., 2011). The reliance on census tracts to define exposure areas has been highly criticized for not representing the area in which a person walks (Boruff et al., 2012; Oliver et al., 2007; Zenk et al., 2011). Home centered buffers ranging from 200m to 1600m have often been used to reflect a 5- to 20-minute walk from the residence (Villanueva et al., 2014). Despite these various distance radii, the one kilometer buffer appears to be the most commonly used (Lovasi et al., 2012; Troped et al., 2010). Calls have been made to use street-network buffers instead of circular buffers arguing that recreational walking behavior is influenced by the street network and the immediate landscape along the walking road (Eyler et al., 2003; Oliver et al., 2007). Additionally, recommendations have been made to account for 'multiple neighborhoods' such as work, school and regular activity locations alongside to the residential neighborhood, to improve the definition of exposure areas in walkability studies (Lovasi et al., 2012;

Troped et al., 2010). In the same vein, researchers have examined daily mobility using GPS receivers to assess movement beyond the residential neighborhood. However, most studies focused on physical activity as a whole, examining moderate-to-vigorous physical activity in relation to built environment characteristics (Cooper et al., 2010; Koohsari et al., 2013; Maddison et al., 2010; Troped et al., 2010; Zenk et al., 2011). One recent study has looked at built environment and recreational walking using both traditional buffering techniques centered on the residence (circular and street network buffers) and new areas representing where residents actually spend time (Boruff et al., 2012). The authors consistently found better goodness of fit when using buffers based on actual spatial behavior.

In order to better inform public health stakeholders and to provide stronger evidence on the places and populations that should be targeted by future public health interventions, it is essential to explore individuals' daily mobility in the assessment of environmental effects on recreational walking.

CHAPTER 3. SUMMARY AND OBJECTIVES

3.1 SUMMARY AND GENERAL OBJECTIVE

Despite ongoing discussion about the best way to define geographic context (Bernard et al., 2007; Cummins et al., 2007; Daniel et al., 2008; Macintyre et al., 2002), researchers have too often considered exclusively the residential neighborhood as the only place for which environmental influences are being assessed. Moreover, past studies on neighborhood and health have often measured environmental exposure using local administrative units (i.e. census tracts) (Diez Roux, 2001) while more recent studies have relied on geographic information systems to assess environmental factors in neighborhoods of various sizes and shapes (Chaix et al., 2009; Leal and Chaix, 2011; Oliver et al., 2007). Authors have argued that spatial definitions focused on the residential neighborhood are probably ill-suited to evaluate environmental effects on health. In fact, such spatial definitions only partially account for individuals' space-time behavior, and thereby the "true" experienced exposure is misspecified (Chaix et al., 2009; Cummins, 2007; Lee et al., 2008).

However, recent calls have been made for the examination of the benefits of an activity space approach as a way to overcome such limitations (Chaix et al., 2012b; Chaix et al., 2009; Cummins, 2007; Kwan, 2009; Matthews, 2011; Rainham et al., 2010). By accounting for people-place interactions, the notion of activity space might be helpful to capture both residential and non-residential environmental exposures and to better estimate their effect on health.

Recreational walking will serve as a case study for the consideration of individuals' space-time patterns to assess environmental exposure. Inequalities in walking arise across socio-demographic status (Frank et al., 2008), and according to differences in exposure to environmental attributes (Owen et al., 2004). Researchers still aim to identify contextual factors associated with active living, but the scale and the spatial shapes for which these contexts affect health behavior still need to be identified.

The overarching aim of this dissertation is to estimate whether accounting for people's network of activity places and thereby extending exposure measures beyond the residential neighborhood allows to improve the understanding of environmental influences on walking behavior.

3.2 SPECIFIC OBJECTIVES

The specific objectives of this thesis are the following:

1 - To identify types of spatial behavior of individuals living in the Paris metropolitan area and their socio-demographic correlates.

2 – To assess whether exposure to supportive walking environments differs between the residential neighborhood, perceived residential neighborhood and the activity space by socioeconomic status and degree of urbanicity.

3 – To evaluate which residential and non-residential neighborhood characteristics are associated with recreational walking.

3.2.1 To identify types of spatial behavior of individuals living in the Paris metropolitan area and their socio-demographic correlates

Summary: Over the past decades, studies on geographic life environment and health have relied on administrative units and home-centered buffers to estimate environmental exposure. However, most people are mobile and are exposed to environments outside their residential neighborhood. Furthermore, investigating daily mobility may also shed light on the determinants and circumstances of active transport and transportation-related physical activity. Because little literature has attempted to examine daily mobility from a health perspective, I sought to develop

innovative spatial behavior metrics to establish a typology of mobility patterns, and assess their associated individual socio-demographic characteristics.

Hypothesis: It is hypothesized that daily mobility cannot be reduced to one variable such as the number of trips. It is a multidimensional construct organized around a reduced number of conceptual factors that can be identified from a larger number of raw variables. It is further hypothesized that age, socio-economic status and location of the residence within the Paris Ile-de-France region are significant correlates of individuals' mobility patterns.

3.2.2 To assess whether exposure to hypothesized supportive walking environments differs between the residential neighborhood, perceived residential neighborhood and activity space by socio-economic status and degree of urbanicity

Summary: Measuring health related exposure calls into question which environments or exposure areas are relevant to consider. Defining relevant areas of exposure for health research remains a challenge. Alternatives to the traditional definitions of residential neighborhoods (i.e., administrative units and buffer around home) have been proposed in the literature, including i) self-reported residential neighborhoods and ii) accounting for regular activity places. However, few empirical studies have evaluated the benefits of such approaches. Therefore this specific objective has two major components. First, to evaluate whether exposure to two built environment characteristics conducive to walking varied between three spatial definitions of context, i.e. the street-network residential buffer, the self-reported perceived residential neighborhoods, and the activity space. Second, to assess links between exposure levels in these distinct areas and i) household income and ii) degree of urbanicity of the residence. A sub-objective was to further examine the impact of the selective daily mobility on the assessment of environmental exposures.

Hypothesis: It is hypothesized that environmental exposure to built environment characteristics conducive to walking will be significantly different in all three types of areas. It is further hypothesized that differences in exposure measures will be lower among high-income households and among central city dwellers. Broadly, these hypotheses suggest that the magnitude of measurement error related to the sole use of residential neighborhoods varies by socioeconomic status and degree of urbanicity of the residence.

3.2.3 To evaluate which residential and non-residential neighborhood characteristics are associated with recreational walking

Summary: This third specific objective examines the environmental correlates of recreational walking. If the results of objective 2 are consistent, the next logical step consists in exploring whether and how the differences in environmental exposure between the residential neighborhood and the activity space result in variations in the association with recreational walking. Therefore, the aim is to estimate the built environmental factors conducive to walking in the residential neighborhood, and the variations in these associations and changes in model fit when further considering exposure to non-residential activity places. The contribution of the environmental condition around specific types of activity locations (work, services, recreational activity places, social activity places) in addition to the residential neighborhood are also examined separately.

Hypothesis: Associations between residential based environmental correlates are changed when accounting for non-residential environments. It is also hypothesized that accounting for both residential and non-residential environment will increase the statistical model robustness. It is further hypothesized that all types of visited activity location do not equally improve the understanding of built environment influence on recreational walking.

CHAPTER 4. METHODS

4.1 DESIGN

This research was conducted in the context of a 2010 CIHR funded Theory and Methods grant (TOO - # 213338) on 'Extending Concepts and Measures of People-Place Interactions to Tackle Spatial Determinants of Chronic Health Outcomes'. It involved the French RECORD Cohort Study (Residential Environment and CORonary Heart Disease). The RECORD Cohort Study was established in 2007-2008 to investigate the influence of geographic life environments on territorial and social disparities in health (Chaix et al., 2012a; Chaix et al., 2011; Karusisi et al., 2012; Karusisi et al., 2013; Leal et al., 2011; Lewin et al., 2014). This cohort is a longitudinal study that includes 7290 participants at baseline recruited between March 2007 and February 2008. The French National Health Insurance System for Salaried Workers offers every 5 years a free medical examination to all working and retired employee and to their family members. The RECORD Cohort Study recruited without sampling people who were getting these two-hour medical check-ups within four health centers (Centre d'Investigations Préventives et Cliniques) located in the Ile-de-France region (i.e., Paris, Argenteuil, Trappe and Mantes-la-Jolie) (Figure 1). Some occupational categories could not be recruited because they are not insured by the National Health Insurance System for Salaried Workers; it includes: shopkeepers, craftsmen, farmers, salaried farm workers and self-employed occupations (lawyers, architects, etc.). The eligible candidates had: i) to be between 30 and 79 years old, ii) to be able to complete the study questionnaire, and iii) to live in one of the 10 (out of 20) administrative divisions of Paris or in one of 111 other municipalities of the metropolitan area (Chaix et al., 2011). When the visitors of the IPC centers satisfied these three criteria, they were asked to join the RECORD Cohort Study.

The administrative territories included in the sample were selected *a priori* to represent contrasted socio-economic backgrounds and both peri-urban and urban areas (Chaix et al., 2011). Based on a list of postal codes of the residence from the people who came to the IPC Centers before 2006 (before the beginning of the study), a pre-selection of the municipalities included in the sample was performed to ensure insofar as possible that various socio-economic territories were represented. At least 15000 postal codes of inhabitants from the 1999 Census were selected, as they accounted for the largest share of participants at the IPC Centers in 2006. During this selection, postal codes of lowest median income municipalities were over-represented.

The sample includes both more advantaged municipalities such as Versailles or Neuilly-sur-Seine, and more deprived municipalities like Sarcelles or Mantes-la-Jolie. The sample also includes municipalities of various degree of urbanicity, ranging from densely urbanized municipalities to less urbanized municipalities. In sum, 1915 neighborhoods located in 112 municipalities were selected. This guarantees a large diversity of social and territorial situations in the sample, which is of utmost importance to study the influence of context on health and related health behaviors (Karusisi, 2013; Leal Lefèvre, 2011).

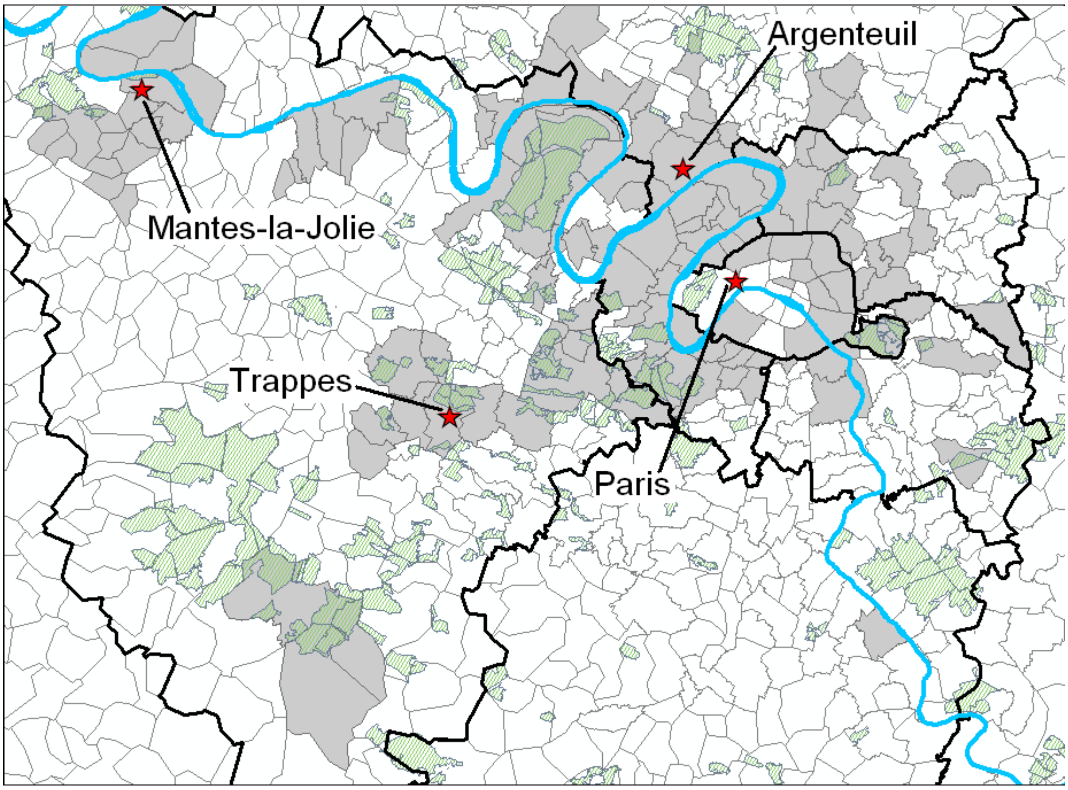


Figure 1. Location of the 112 municipalities selected in the RECORD Cohort Study and the 4 health care centers where participants had a check-up

Since February 2011, study participants have been invited to a second two-hour long health check-up at the Centre IPC for the second wave of the RECORD Cohort Study. The second wave also comprises new inclusions. Among the 6240 participants of the second wave (17/10/2014), 62,5 % were previously surveyed in the first wave (ongoing survey). The current project uses data collected during this second wave.

4.2 PARTICIPANTS

With ongoing recruitments, the sample sizes of the empirical analyses differ. The analyses presented in Article 2 were performed with 2062 respondents, (mean age 51, 31% female); while Articles 3 and 4 encompass 4383 and 4365 respondents respectively (mean age 53, 33% female for both Articles).

4.3 PROCEDURES

Ethic approval was obtained from the CNIL (Commission Nationale de l'Informatique et des Libertés). For both waves of data collection, participants attended a two-hour long general check-up. During the clinic visit, an assessment of medical, biological and clinical factors was conducted. Biological and clinical data included: a biological check-up[1], blood pressure measurements, an electrocardiogram, spirometry, a dental exam, a visiotest and anthropometric measures (including weight, height and waist circumference). Socio-demographic, behavioral, psychological and contextual surveys were also submitted to the participants.

In addition, a survey specific to the RECORD Cohort Study was submitted to the participants and included information on their socio-economic status; their perception of their weight and related behaviors (i.e., diet, weighing themselves etc.); their sleep; their physical activity (recreational walking and sports activities frequencies and durations) and their sedentary behaviors; their eating behaviors; a possible selective migration; the perception of their residential neighborhood; and the perception of their mobility behavior.

For the second wave of the study, the participants' regular destinations were assessed through the VERITAS application ('Visualization and Evaluation of Regular Individual Travel destinations and Activity Spaces') (Chaix et al., 2012b) (see Appendix II). The VERITAS application is a "web-based computer tool that integrates Google Maps interactive mapping functionalities" (Chaix et al., 2012b, p.

[1] The biological check-up was achieved after 12 hours of fasting and included: a complete blood count, urea, creatinine, glycaemia, potassium, cholestero levell, triglycerides, aspartate aminotransferase (ASAT), gamma glutamyl transferase (GT), albuminuria, glycosuria, hematuria, etc..

441). Survey technicians, together with the participants, searched for, visualized, and geocoded participants' self-reported activity locations. They also delineated areas such as perceived/experienced neighborhoods. In order to limit the recall bias, participants were guided through a spatio-cognitive process that ease recall of activities (Chaix et al., 2012b).The VERITAS application has two major components to avoid this bias: a series of survey questions, and electronic maps through which geographical information is collected. Participants were asked to map a number of regular destinations, with the help of a survey technician. The 6240 participants who completed a second wave on the 17 October 2014 have a total of 90670 geocoded activity places. Participants were asked to draw the limits of their perceived neighborhood. Additional information was collected for each reported location, such as the frequency of visit, degree of attachment to the residential neighborhood and the work environment, or more specific information relating to the specific activity they are documenting (ie. indoor or outdoor workplace, type of sport) (Chaix et al., 2012b). The median time of completion of the VERITAS survey among the first 2500 participants was 19 minutes (Chaix et al., 2012b).

All the investigators of the study had a specific training in explaining the study to the participants. All participants had to sign a consent form to enter the study (Appendix I).

4.4 MEASURES

4.4.1 Dependent variable

Recreational walking behavior data: Participants were asked to report the number of hours and minutes they had walked over the previous seven days for leisure or exercise. Participants further distinguished walking time inside and outside the residential neighborhood, relying on their subjective perception of their neighborhood. The main outcome was the overall time of recreational walking, created by summing up the time reported inside and outside the residential neighborhood.

4.4.2 Environmental variables

Variables related to supportive walking environments have been identified in a review of the literature (McCormack and Shiell, 2011; Owen et al., 2004; Saelens and Handy, 2008; Sugiyama et al., 2012), and through discussions with team members. Environmental variables were computed using road network buffers centered on each participant's activity locations. Appendix III presents the sources of each environmental data and the related measurement approaches. Different domains have been taken into account: the socio-demographic environment, the physical environment, and the services environment. The ***socio-demographic domain*** is measured through neighborhood education (proportion of residents with University education). The ***physical domain*** accounts for the density of green space (proportion of surface covered by green spaces), the presence of a lake or waterway, and the density of street intersections (number per km^2). The ***service domain*** is measured with the density of destinations (number per km^2) and included administrations, public/private shops, health services, and entertainment facilities.

4.4.3 Individual variables

Demographic and SES characteristics of the participants include the following.

Participants' sex and date of birth (age) were directly assessed from the socio-demographic survey.

Household structure was coded as living alone or living in a couple, regardless of living with children.

Having children under the age of fourteen was coded as a binary variable (yes vs. no).

French citizenship or not was defined as binary variable (French vs. other).

Education was defined by the highest level of completion. Participants were asked "What is the highest degree that you obtained?" and could choose among 10 options ranking from "No diploma" to "Master degree or Ph.D". Four educational categories were then created: low (no education or a level less than the bachelor), middle low (having a bachelor degree or a two years university degree), middle high (3 or 4 years university degree) and high (having a master degree and more).

Household income per consumption unit was defined as the net household income divided by the number of consumption units. Participants were asked to sum up all incomes of the household members including alimony and family allowance, housing assistance and other pension, and to identify their corresponding household income category. They could choose among 10 options ranking from "less than 500€" to "more than 7 000€". Income per consumption unit was divided into tertiles. Based on each sample, the cut points differs: in Article 2 (N=2062; tertiles: 1125 and 1750 Euros/month) and in Article 3 (N= 4383; tertiles 1,222 and 2,125 Euros/month).

Occupation status was derived from the question "What is your current situation?", and participants could choose from 12 options. Five occupational status variables were created: stable job (having a permanent contract), precarious job (fixed-term contract, paid traineeship or apprentice, youth employment or other supported employment program), unemployed (being unemployed for more or less than 6 months, unpaid traineeship, house-wife or house husband), retired and other.

Parental education was derived from the questions "What is the level of schooling attained by your father?" and "What is the level of schooling attained by your mother?". Parental education was coded in three classes as low (no education and primary education), middle (secondary education) and high (tertiary education).

Self-reported financial strain was derived from the question "In your adult life, have you ever had difficulties to pay your rent, electricity or water charges, or to afford food?". The variable was coded in three categories: never, rarely and frequently.

Owner score (0-3) was derived from respondents' answers to the following questions "Do you - or someone in your household - own one home housing that you are renting out?", "Do you - or someone in your household – own a business or a company?" and "Do you - or someone in your household – have savings or financial investments up to 25 000€?". Owner score was categorized as low (0), middle (1) and high (2-3).

Degree of urbanicity defines the degree to which the participants' home is in an urbanized part of the Paris Metropolitan Area. The variable distinguishes three areas: within the Paris city limits, the inner suburbs, the outer suburbs (Figure 2).

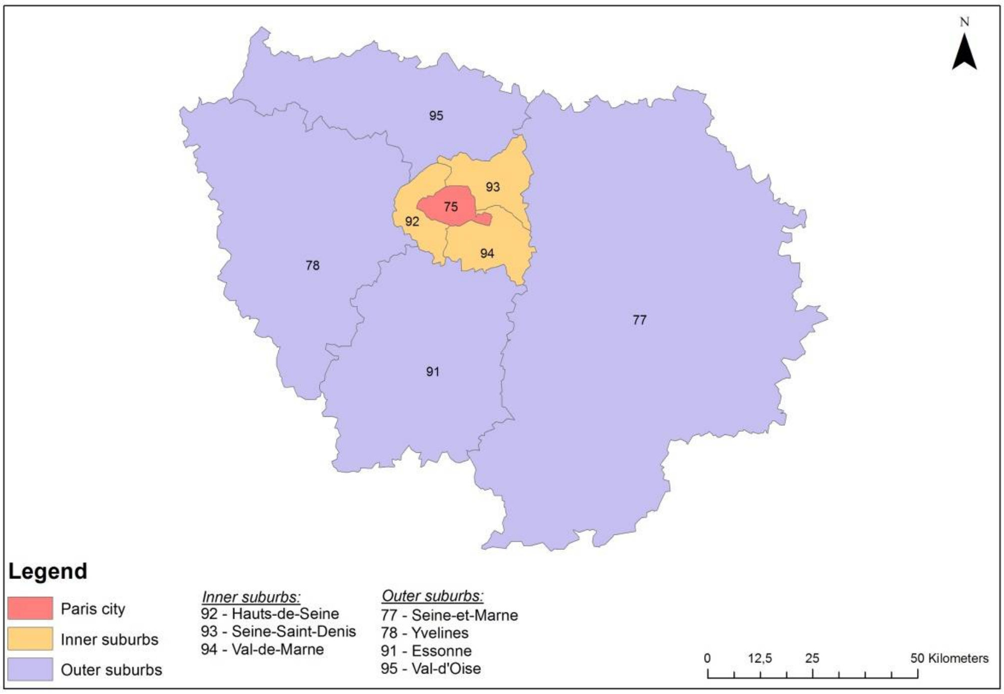


Figure 2. Paris city and suburbs

Self-reported mobility behavior is measured in terms of frequency within the last seven days for: walking more than five minutes at a time, biking more than five minutes at a time, using the bus/tram, using the subway and using one's own motorized vehicle.

Individual perceptions of mobility (as positive or negative) was expressed using three binary variables (agree/disagree): Systematic use of the nearest shop, willingness to travel out of the residential neighborhood to access new types of activity/shop, renunciation of traveling out of the residential neighborhood because of a lack of time. The three dichotomous variables correspond to three separate items of the questionnaire: "When I have to shop, I systematically use the closest shops from home", "Going out of my neighborhood allows me to practice activities and access to services that do not exist in my neighborhood", and "Going out of my neighborhood to shop is a waste of time". Each survey question offered a choice of four possible answers: 'fully agree', 'somewhat agree', 'somewhat disagree', and 'fully disagree'. The first two options and the last two options were combined to determine dichotomous variables.

Activity space information was collected through the VERITAS Application. The questionnaire recorded the geographic location of the place of residence, and a series of other possible destinations which participants mentioned visiting at least once per week (See Appendix II). These destinations included: locations where the participant may spend at least one night per week, workplaces (up to 3 sites), groceries, outdoor markets, bakeries, fruit and vegetable shops, fish shops, cheese dairies, specific food stores, tobacco stores, transportation stations used from home (bus, underground, tramline and train), sports facilities (the participant is also invited to specify the type of sport), entertainment facilities, places for cultural activities (music lesson, art lesson, drama, photography lesson, etc.) places for community or spiritual activities, places where participants take relatives (children, mother, father or someone else), places where participants visits people. Figure 3 shows the activity locations of 4386 participants from the RECORD Cohort Study. No particular recall period, such as "over the past 6 months," was specified. Information on banks, post offices, and hairdressers were also collected regardless of the frequency because these activities are generally undertaken less regularly than once per week. In addition, using a polygon-drawing functionality, participants were asked to draw the perceived boundaries of their residential neighborhood. Lastly, participants were asked to indicate their degree of attachment to the place of residence and the workplace on a scale from 0 to 6.

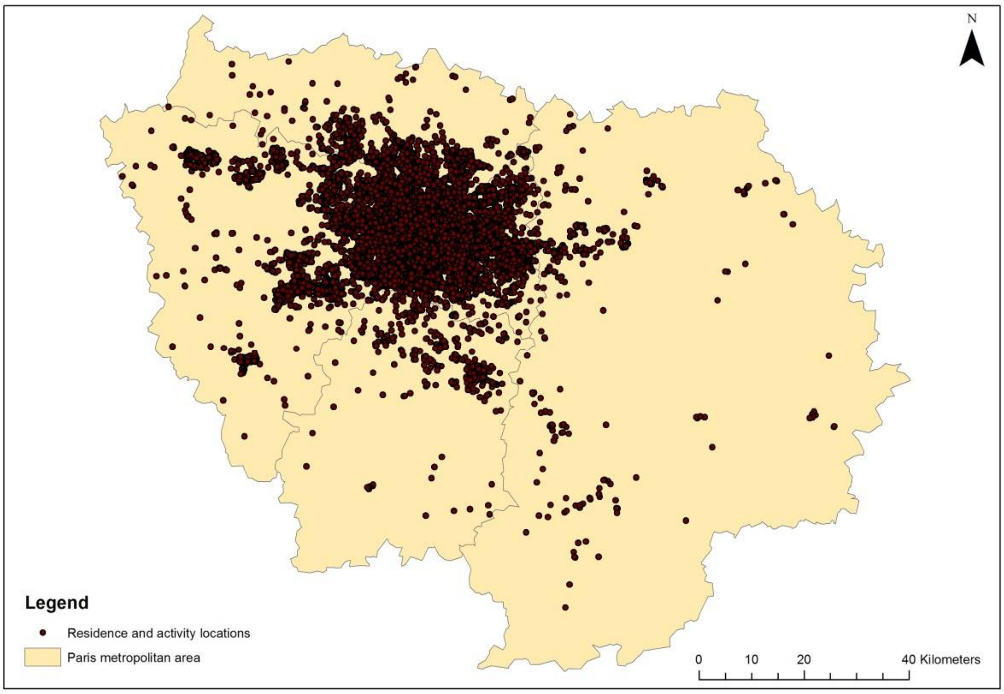


Figure 3. Residence and regular activity locations of 4386 participants from the RECORD Cohort Study

4.4.4 Creating residential and activity space exposure areas

In this dissertation, two definitions of the residential neighborhood were of interest: i) the perceived residential neighborhood, and ii) the commonly used street-network buffer around participants' home. The perceived residential neighborhood was directly assessed from the self-drawn neighborhood in the VERITAS application. Additionally, street-network buffer zones of 1000m were created around participants' home to proxy their residential neighborhood (Figure 4). The 1000m distance correspond to a 10-to-15 minute walk from home and "typically represents the 'walkable' distance to local destinations" (Villanueva et al., 2014, p. 43). This threshold distance has previously been used in place and health research studies (Brondeel et al., 2014; Chaix et al., 2014b; Frank et al., 2005; Karusisi et al., 2013; Lewin et al., 2014; Oliver et al., 2007; Troped et al., 2010; Villanueva et al., 2014).

Additionally, street-network buffers of various sizes were created around non-residential activity locations, depending on the type of activity performed. Larger buffer sizes were applied to major activity locations where individuals are likely to spend more time and have more opportunity to explore the surrounding space (Chaix et al., 2012b). I computed street-network buffers of 1000m of radius around the workplace, of 200m of radius around the food and non-food services, and of 500m of radius for both recreational and social activities. Table 1 presents the classification of activity places and corresponding buffer size.

Table 1. Types of activity places geolocated in VERITAS and related buffer seize for environmental data extraction

Activity location	Size of the road network buffer
Domain : Residence	
Place of residence	1000m
Another address where the participant may spend at least one night per week	1000m
Domain: Work	
Workplace	1000m
Domain: Groceries and services	
Grocery	200m
Outdoor market	200m
Bakery	200m
Fruits and vegetables shop	200m
Fish shop	200m
Cheese dairy	200m
Specific food store	200m
Bank	200m
Post office	200m

Hair dresser	200m
Domain: Transport	
Transportation station used from home	200m
Domain: Recreational activities	
Sports facilities	500m
Places of cultural activity	500m
Place for community or spiritual activities	500m
Domain: Social activities	
Places of social activities (bar, restaurant, cinema…)	500m
Place where participants take relatives	500m
Places where participants visits people	500m

Various definitions of the activity spaces were of interest in this thesis. Broadly, the activity space was operationally defined by dissolving residential and nonresidential buffers into one new buffer to suppress the overlap between them (Figure 4).

In Article 3, two definitions of the activity space were used to examine the influence of the selective daily mobility bias on exposure estimates: i) the full activity space, encompassing all the activity locations visited by the participant, and ii) the truncated activity space, excluding the activity locations that theoretically relate to the exposure of interest, in this case exposure to green spaces and exposure to destinations. Figure 5, schematically represents the full and the truncated activity space.

In article 4, portions of the activity space by type of activity (i.e., work, food and non-food services, recreational activities and social activities) were also of interest to evaluate the specific contribution of each type of activity space on recreational walking. To operationally define these specific portions of the activity space, I determined four additional exposure areas by separately adding to the residential buffer either the work space, or the food and non-food service space, or the recreational space, or the social space (separate addition of each of these spaces to the residential neighborhood).

All street network buffers were created using Network Analyst in ArcGIS 10.1. Python scripts were used to program the buffer creation and the extraction of environmental variables.

Figure 4. Representation of the residential neighborhood and the activity space of one participant living in the inner suburbs from the RECORD Cohort Study

1) *Full activity space* 2) *Truncated activity space*

Figure 5. Representation of the full and truncated activity space

4.5 ANALYSES

4.5.1 Objective 1

In Article 2, a three-step procedure was followed to assess the individual patterns of spatial behavior and their socio-demographic determinants. I first computed 24 indicators to qualify and quantity individual mobility patterns. Among these indicators, some were previously used in geography and transportation research, and some were new. The indicators related to three main categories: i) lifestyle indicators related to the number of places visited and to the type of places visited (i.e. work, food and non-food services, social activities, and recreational activities) ii) geometric indicators of the activity space that reflect the shape and the scale of the activity space, and iii) indicators on the relative importance of the residential neighborhood in the overall activity space. I then conducted a principal component analysis on the 24 indicators using a varimax rotation. Based on eigenvalues greater than 1, I selected a five-component solution. Finally, I used multilevel linear modeling with random effects at the municipality level to assess whether each identified components of spatial behavior was associated with individual demographics, socioeconomic status, perception of mobility, and the degree of urbanicity. The random effect of the models allowed to account for the within-neighborhood correlation in each outcome, with participants nested within municipal administrative neighborhoods. Variables independently associated with each outcome were retained in the final models, with systematic adjustment for age and sex. The Intraclass Correlation Coefficient (ICC) indicates the proportion of total residual variability at the municipality level and the Akaike Information Criterion (AIC) indicates model fit.

4.5.2 Objective 2

In Article 3, two elements were of interest: i) the differences in exposure measures when considering the street-network residential buffer, the perceived residential neighborhoods, and the activity space, and ii) the differences in exposure levels by individual-level socioeconomic status and the degree of urbanicity of the residence. Two environmental exposures previously reported in literature reviews as walking-friendly characteristics were of interest in this study: the density of destinations and the density of green spaces (Owen et al., 2004; Saelens and Handy, 2008; Sugiyama et al., 2012). I used *densities* rather than *counts* to standardize the environmental exposure on the size of the different exposure areas. I first used paired sample t-tests to assess the differences in built environment exposure measurements between the distinct exposure areas. Then, I performed Jonckheere-Terpstra tests to assess trends in exposure between ordered classes of socio-economic status and degree of urbanicity.

4.5.3 Objective 3

In Article 4, I used zero-inflated negative binomial (ZINB) regressions to assess the associations between the individual and environmental variables and i) being a recreational walker, and ii) time spent in recreational walking. The ZINB regressions were used due to the increased zeros and the over-dispersion of the outcome. The zero-inflation part models the probability of not reporting any recreational walking, and consists in a logistic regression, interpreted with odds ratios. The count part analyses the time of recreational walking, with a negative binomial regression. Coefficients can be interpreted as rate ratios. Model building involved multiple steps.

Several models were built in Article 4. The first model included all socio-demographic variables (Model A). I then added residential-based contextual variables in the model adjusted for individual covariates (Model B). Model C to F tested the marginal contribution of specific portions of the activity space in addition to the residential space. The residential environmental variables were successively replaced by environmental variables separately including, in addition to the residential space, the work space (model C), the service space (model D), the recreational space (model E), and the social space (model F). Finally, model G estimated relationships between environmental variables taking into account all of these activity locations simultaneously and recreational walking. Only the environmental variable associated with the outcome were retained in the models. I reported the AIC for each model to compare the fit of the data. The AIC lower values indicate better fit.

CHAPTER 5. RESULTS

5.1 ARTICLE 2: ASSESSING PATTERNS OF SPATIAL BEHAVIOR IN HEALTH STUDIES: THEIR SOCIO-DEMOGRAPHIC DETERMINANTS AND ASSOCIATIONS WITH TRANSPORTATION MODES (THE RECORD COHORT STUDY)

Camille Perchoux, Yan Kestens, Frédérique Thomas, Andréa Van Hulst, Benoit Thierry, Basile Chaix

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Title: Assessing patterns of spatial behavior in health studies: their socio-demographic determinants and associations with transportation modes (the Record Cohort Study)

Authors names and affiliations Camille Perchoux[1*], Yan Kestens[2], Frédérique Thomas[3], Andréa Van Hulst[4], Benoit Thierry[5], Basile Chaix[6]

[1]Université de Montréal, Montreal University Hospital Research Centre, Sorbonne Universités, UPMC Université Paris 06, INSERM UMR_S 1136

[2]Unversité de Montréal, Montreal University Hospital Research Center

[3]Centre d'Investigations Préventives et Cliniques

[4]Université de Montréal, Centre de recherche du CHU Sainte Justine

[5]Montreal University Hospital Research Centre

[6]INSERM UMR_S1136, Sorbonne Universités, UPMC Université Paris 06

***Corresponding author information:** Camille Perchoux,

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5.1.1 Abstract

Prior epidemiological studies have mainly focused on local residential neighborhoods to assess environmental exposures. However, individual spatial behavior may modify residential neighborhood influences, with weaker health effects expected for mobile populations. By examining individual patterns of daily mobility and associated socio-demographic profiles and transportation modes, this article seeks to develop innovative methods to account for daily mobility in health studies. We used data from the RECORD Cohort Study collected in 2011-2012 in the Paris metropolitan area, France. A sample of 2062 individuals was investigated. Participants' perceived residential neighborhood boundaries and regular activity locations were geocoded using the VERITAS application. Twenty-four indicators were created to qualify individual space-time patterns, using spatial analysis methods and a geographic information system. Three domains of indicators were considered: lifestyle indicators, indicators related to the geometry of the activity space, and indicators related to the importance of the residential neighborhood in the overall activity space. Principal component analysis was used to identify main dimensions of spatial behavior. Multilevel linear regression was used to determine which individual characteristics were associated with each spatial behavior dimension. The factor analysis generated five dimensions of spatial behavior: importance of the residential neighborhood in the activity space, volume of activities, and size, eccentricity, and specialization of the activity space. Age, socioeconomic status, and location of the household in the region were the main predictors of daily mobility patterns. Activity spaces of small sizes centered on the residential neighborhood and implying a large volume of activities were associated with walking and/or biking as a transportation mode. Examination of patterns of spatial behavior by individual socio-demographic characteristics and in relation to transportation modes is useful to identify populations with specific mobility/accessibility needs and has implications for investigating transportation-related physical activity and assessing environmental exposures and their effects on health.

Keywords: Paris (France), spatial behavior, mobility, socioeconomic status, spatial analysis, principal component analysis.

5.1.2 Introduction

Over the past decades, research on geographic life environments and health has first relied on residential administrative area subdivisions to estimate environmental exposure. Later ego-centered areas of exposure have been used, through circular (Berke et al., 2007; Seliske et al., 2009) or street network (Karusisi et al., 2013; Leal and Chaix, 2011) buffers of various sizes centered on individual residences. As a distinct issue than the so-called Modifiable Area Unit Problem related to the influence of the territory subdivisions used on the estimated statistics and associations (Mobley and Andrews, 2008; Openshaw, 1983), numerous critics were formulated against the traditional assessment of environmental exposures in neighborhood and health studies (Chaix et al., 2009). Scholars have pointed to the local trap (i.e., exclusive focus on local environments) (Cummins, 2007), to the residential trap (i.e., exclusive focus on residential neighborhoods) (Chaix et al., 2009), or to the uncertain geographic context problem (or difficulties to identify the truly relevant contexts) (Kwan, 2012a, b), all of which have potential for exposure misclassification.

Most people are highly mobile (Matthews, 2008), which underlines the need for innovative research strategies that can account for individual space-time behaviors in health studies (Lee et al., 2008; Perchoux et al., 2013). Concepts of spatial polygamy (Matthews, 2011b; Matthews and Yang, 2013b), network of usual places (Flamm and Kaufmann, 2006), and, more largely, activity space (Golledge and Stimson, 1997) are increasingly used. They guide our thinking on how environmental effects may act beyond the residential neighborhood. Furthermore, investigating individual spatial behavior may also shed light on the determinants and circumstances of active transport and transportation physical activity.

Daily mobility is increasingly accounted for in the assessment of neighborhood effects on health in emerging social/spatial epidemiology and health geography (Chaix et al., 2012c; Inagami et al., 2007; Kestens et al., 2012; Kestens et al., 2010; Mason, 2010; Setton et al., 2011; Vallée et al., 2010; Vallée et al., 2011;

Vallée and Chauvin, 2012; Zenk et al., 2011). For instance, Inagami and colleagues examined associations between non-residential exposures and self-rated health (Inagami et al., 2007) and reported that non-residential exposures may confound and suppress residential neighborhood effects on health. Setton et al. observed that using solely residence-based exposures underestimated the true exposure to air pollution and biased towards the null the effect of air pollution on health (Setton et al., 2011). In their assessment of residential and non-residential foodscape exposure, Kestens et al. reported that activity space exposure significantly differed from the traditional residential exposure and that these differences varied according to age and socioeconomic status (Kestens et al., 2010). Vallée et al. found an interaction between the self-reported activity space and the residential density of health services on health seeking behaviors; woman living in a low health services density neighborhood were more likely to delay medical screening if their self-reported activity space was centered on their residential neighborhood (Vallée and Chauvin, 2012).

Time geography and transportation research have provided relevant frameworks and analytic tools to study spatial behavior. Various geographic measures of activity space have been proposed, including the standard deviational ellipse (Arcury et al., 2005; Rai et al., 2007; Schönfelder and Axhausen, 2003a; Sherman et al., 2005a; Yuill, 1971), the convex hull (Buliung and Kanaroglou, 2006b; Buliung et al., 2008), the daily or shortest path area connecting the locations visited (Schönfelder and Axhausen, 2003a, 2004b) and kernel density surfaces (Kestens et al., 2010; Schönfelder and Axhausen, 2003a, 2004a). These studies that have examined the association between individual socio-demographic characteristics and activity space metrics have shown that age (Fobker and Grotz, 2006; Lord et al., 2009), being a female (Lord et al., 2009), being a part-time worker (Dijst, 1999a, b), and having a residential location near the city center (Schönfelder and Axhausen, 2002) were associated with limited activity spaces in terms of extent and number of activity locations (Dijst, 1999a, b; Lord et al., 2009; Schönfelder and Axhausen, 2003a).

Given the limited work on these questions, the present study seeks to refine the description of daily mobility patterns by proposing a set of spatial indicators based on individual-level data of networks of usual places. We further use these spatial indicators to establish a typology of mobility patterns, and evaluate which individual socio-demographic characteristics and active and motorized transportation modes were associated. Such analyses are potentially important for health research because daily mobility patterns need to be accounted for to improve our assessment of environmental influences.

The following hypotheses were tested in the present study: i) spatial behavior (or daily mobility habits) cannot be reduced to one variable (such as the number of trips) or one unique dimension but needs to be captured using a larger set of indicators, ii) spatial behavior is a multidimensional construct organized around a reduced number of conceptual axes that can be identified from a larger number of raw variables, iii) age, socioeconomic status, and location of the household within the region are related to daily mobility patterns, and iv) active modes of transportation are more often used when activity spaces are smaller and overlap the residential neighborhood.

5.1.3 Materials and methods

Population

This study relies on data of the second wave of the RECORD Study (Residential Environment and CORonary heart Disease). Some 2,312 adult participants were surveyed between February 2011 and March 2012. Among those, 1,029 participants had already been enrolled in the RECORD Study in the first wave (2007-2008) and 1,033 were new recruits. All participants were recruited without *a priori* sampling during a 2-hour preventive medical checkup conducted by the Centre d'Investigations Préventives et Cliniques (IPC) in four centers of the Paris Ile-de-

France region. The entire data collection protocol was approved by the French Data Protection Authority. For further details on the recruitment procedure and RECORD Study, see (Chaix et al., 2011a; Chaix et al., 2011d).

Measures

Individual variables

As explanatory variables, the following individual characteristics were considered in our analysis: sex, age, citizenship (French or other), marital status (living alone or living in a couple), education (4 categories: no education and primary education, lower secondary education, higher secondary education and lower tertiary education, and upper tertiary education), tertiles of household income per consumption units (1125 and 1750 Euros/month), employment status (4 categories: stable job, unstable and precarious job, unemployed, and other), a score of material ownership (low, middle, or high), and the location of the household in the Paris Ile-de-France region (Paris, inner suburbs, and outer suburbs).

Individual perceptions of mobility and spatial behavior were measured using a self-administered questionnaire with the following items: systematic use of the nearest shops, traveling out of one's residential neighborhood perceived as a way to access new types of activities and shops, and traveling out of one's residential neighborhood considered as a waste of time, with possible answers fully agree, somewhat agree, somewhat disagree, and fully disagree, recoded into dichotomous agree / disagree.

Regarding their transportation mode, the participants also reported the usual number of days per week i) they walked at least 5 minutes at a time, ii) they cycled at least 5 minutes at a time, iii) they used public transports, and iv) they used a car.

Measures of spatial behavior

Participants were surveyed on their regular activity places and residential neighborhood using the VERITAS application (Visualization and Evaluation of Route Itineraries, Travel Destinations, and Activity Spaces) (Chaix et al., 2012c). The VERITAS application is web based interactive mapping questionnaire administered during a face-to-face meeting with the participants. As described in details elsewhere (Chaix et al., 2012c), the application allows participants to draw the perceived boundaries of their residential neighborhood on an electronic map, and precisely locate their regular activity locations. Information on frequencies of visit was further collected. The following activity places were surveyed: 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 took relatives, and where they visited people. For most activity types, the participants were invited to report the destinations they visited at least once a week, without specific recall period. As exceptions to the once-a-week minimum frequency, participants were asked to geolocate workplaces where they spent at least one third of their working time; supermarkets they visited at least once a month; and regardless of frequency of use, their bank, post office, and hair salon/barber.

Using this spatial information, we defined three categories of indicators to qualify and quantify mobility patterns: i) lifestyle indicators related to the number of places visited and to the specialization of the activity space (the type of places visited), ii) geometric indicators of the activity space that reflect the shape and the scale of the activity space, and iii) indicators on the importance of the residential neighborhood in the overall activity space that proxy the proportion of time spent in the immediate vicinity of the residence rather than elsewhere. Regarding the geometry of the activity space, a geographic information system was used to derive convex hulls (Figure 1a), standard deviational ellipses (Figure 1b), and shortest paths between the residence and all activity locations (Figure 1c). Street network distances between the residence and activity locations were computed with street network data from the National Geographic Institute for activity places located in the Ile-de-France region. Indicators related to the residential neighborhood were computed with both the perceived residential neighborhood (PRN) and a 500m street network buffer centered on participant's residence. The measurement approach, definition, and bibliographic references are provided for all 24 indicators in Table 1.

Statistical analysis

In order to identify the main dimensions of spatial behavior, we first conducted a principal component analysis (PCA) on the 24 indicators, using a varimax rotation. A five-factor solution was selected based on Eigenvalues greater than 1. Then, the association between each of the five identified components of spatial behavior and individual demographics, socioeconomic status, perception of mobility, and location of the household in the region were estimated through multilevel linear modeling with random effects at the municipality level. Only the variables that were independently associated with each outcome were retained in the final models, with systematic adjustment for age and sex. We report the Intraclass Correlation Coefficient (ICC) – the proportion of the total residual variability that is at the municipality level and the Akaike Information Criterion (AIC) for the null models and the final models.

Finally, we assessed the relationship between each of the five spatial behavior dimensions and the number of days the participants used each transportation mode. PCA factor scores were divided in tertiles and average by transportation mode were computed. Trends were tested using the Jonckheere-Terpstra nonparametric trend test. All analyses were conducted with SAS, version 9.2.

5.1.4 Results

Description of the study sample

In the initial sample, 352 participants reported at least one activity place outside the Ile-de-France region, of which 66 reported at least one activity place outside the crown of counties bordering the Paris Ile-de-France region, including 19 who reported a regular activity location outside the country. These participants include 19 persons who located their primary residence outside the Paris Ile-de-France region and 162 participants who reported going regularly to a secondary home. As the general objective of this study was to describe the local spatial mobility patterns of individuals living in the Paris Ile-de-France region, we only retained participants residing in Ile-de-France and we excluded participants reporting at least one regular activity location outside the Paris Ile-de-France region and the crown of counties bordering the region. We also excluded participants with secondary homes (within or outside Ile-de-France), considering that commuting from principal to secondary homes was not part of local daily mobility and because participants often declared activity locations nearby their secondary home. Finally, one participant for whom no activity location at all was reported was excluded. The final sample thus comprises 2,062 individuals and 22,799 reported activity places with a mean of 11 activity places per individual (range: 2-52). The mean age of the participants was 51 years (range: 33-84). The final sample was predominantly male (69%), French (83%), and with a stable employment (50%). Table 2 presents the characteristics of these participants.

Principal component analysis

Results of the PCA are shown in Table 3. The five components that were retained explained 90% of the variance.

Component 1 explained 35% of the variation. Variables with highest factor loadings were the percentage of visits made in the PRN, the proportion of the overall activity/perceived space covered by the PRN, and the proportion of the activity space covered by the PRN. This component thus captures the proportion of activity pursued in the PRN and the importance of the residential neighborhood in the overall activity space. We labeled this component: “Centering of the activity space on the residential neighborhood.”

Component 2 - explaining 20% of the variance - was mainly characterized by the surface and the perimeter of the convex hull and by the maximum distance between the residence and an activity place. This component was labeled “Size of the activity space”.

The number of activity places and the number of visits made per week to places loaded strongly on component 3 which explained 16% of the variation. This component was identified as the “Volume of activities.”

Component 4 explained 10% of the variation in spatial behavior. This component captured the opposition between people who had a high share of their activities devoted to visiting local food stores and other services located in their residential neighborhood and people who, on the opposite, were more involved in recreational and social activities at more distant places from their residence. This component was labeled “Specialization of the activity space.”

Finally, component 5 explained 9% of the variation in spatial behavior. The shape of the activity space (Gravelius compactness coefficient and major to minor axis ratio) loaded heavily on this component, which expresses the stretching of the activity space and was thus labeled: “Elongation of the activity space.”

Multilevel analysis

Table 4 presents the results of the five multilevel linear regressions. ‘Living alone’ and ‘considering that traveling out of the residential neighborhood is a waste of time’ were not associated with any of the outcomes.

Component 1, or the degree of centering of the activity space on the residential neighborhood was associated with age, employment status, financial strain, systematic use of the nearest shop, willingness to travel out of the residential neighborhood, and the location of the household in the region. The activity space of older participants was more centered on their residential neighborhood. Individuals with an unstable employment status or without job tended to cluster their activity locations to a larger extent in their residential neighborhood. Individuals reporting financial strain had an activity space that was less centered on their residential neighborhood. Individuals who expressed the general willingness to use the nearest shops from their home were more likely to have activities clustered in their residential neighborhood. In contrast, individuals who consider that going outside their neighborhood provides access to other types of activities, had an activity space that was less centered on their neighborhood. Finally, an urban-suburban effect was noted: people living far from the city center had, to a greater extent, their activity places located outside their residential neighborhood.

Regarding the second dimension, males had a larger activity space than females, whereas unemployed participants or participants with a precarious job (compared to employed participants), a lower ownership score, and the systematic use of nearby shops were associated with a smaller activity space. Outer suburb residents were more likely to have a much larger activity space than residents of the city of Paris.

The “volume of activities” was lower among males, older people, non-French citizens, low educated individuals, unemployed participants, and participants with a precarious job. However, people reporting financial strain engaged in a higher volume of activities. Finally, living in the inner or outer suburbs was associated with a lower volume of activities than residing in the city of Paris.

Age, individual education, employment status, financial strain, systematic use of nearby shops, and location within the region were associated with the specialization of the activity space. Older participants had their activities more specialized towards the use of services (rather than other activities) nearby their residence. Similarly, people without a stable employment status and residents of the inner suburbs (compared to those of central Paris) had their activities in proportion more devoted to local food or other services and less to social and recreational activities.

Finally, individuals with a lower income had a more compact activity space. In contrast, participants with a permanent job had more elongated activity spaces than the unemployed or individuals with a precarious employment status.

In the null models, the ICC varied between 2.6% and 12.0%. The ICC was much lower in most cases after accounting for individual and contextual variables, which was to a large extent attributable to the difference in mobility behavior explained by living in Paris, in the inner suburb, or in the outer suburb.

Description of the use of transportation modes according to spatial behavior

In descriptive analyses (Table 5), we found that walking and cycling were more common among participants whose activity space was centered on their residential neighborhood and who reported a higher volume of activity locations. Participants used public transportation more often when their activity space was more elongated, based on a higher volume of activity locations, and less specialized in food and other services. Finally, a larger and more elongated activity space, not centered on the residential neighborhood, and based on a lower volume of activities was associated with a higher average number of days of car use.

5.1.5 Discussion

Our work suggests that individuals' daily exposures are not bounded by their residential neighborhood. The main findings of the study are the following: i) spatial behavior is a multidimensional construct; ii) five structuring dimensions of spatial behavior were identified: the size of the activity space, the elongation of the activity space, the centering of the activity space on the residential neighborhood, the volume of activities, and the specialization of the activity space; iii) age, socioeconomic status, and the location of the household in the region were strong determinants of individual spatial behavior; and iv) the use of active transportation modes correlated strongly with small activity spaces comprising a high volume of activity places mainly located within the residential neighborhood.

The primary strength of the study is the large sample size and rich information on participants' activity places over a relatively large study territory that allowed the identification of diverse patterns of spatial behavior. Second, the combination of information on the PRN delimited by the participants themselves with a wide range of indicators obtained with a GIS from the activity locations of participants allowed us to characterize more accurately individual space-time behavior than in previous studies (Dijst, 1999b; Lord et al., 2009; Schönfelder and Axhausen, 2002). A third strength of the study is that the combination of PCA with regression analyses allowed to identify both patterns of spatial behavior and how these related to socio-demographic profiles. The fact that each of the five identified components of spatial behavior contributed to explain variations in the corresponding indicators confirms that spatial behavior is a multidimensional construct that cannot be reduced to a unique dimension.

However, there were limitations to our study. The main limitation is that the data on regular mobility were self-reported. Moreover, this exploratory study did not consider environmental factors in the multilevel linear regressions as independent variables to explain variations in the five identified dimensions of spatial behavior. Despite this limitation, the expected importance of the suburbia effect (Schönfelder and Axhausen, 2002) was accounted for in the present study by taking into account the location of the household in the Paris Ile-de-France region, which partly reflects differences in the accessibility to services and in the urban morphology. However, this methodological choice implies that effects of age, sex, and socioeconomic status were adjusted on the location of the household in the region, and should therefore be interpreted as direct effects net of the influence of these socio-demographic variables on the location in the region.

Finally, the present study did not account for the temporal dimension of spatial behavior, for which only minimal information was collected with VERITAS (frequency of visit). The RECORD GPS and MultiSensor Studies, based on a subsample of the participants wearing GPS for 7 days, are currently undergoing to overcome these limitations (Chaix et al., 2013a; Chaix et al., 2013b; Thierry et al., 2013).

Measuring the activity space

In order to focus on regular daily mobility, we excluded people regularly travelling (at least once a week) to a secondary residence, considering that a trip from the main residence to the secondary residence and travel patterns around the secondary residence are not part of daily mobility, which is often considered as centered on a daily basis on the main residence (Kaufmann, 1997). However, it must be kept in mind that this methodological choice likely results in the underestimation of the size of effective regular activity space of high socioeconomic status participants.

In order to describe spatial behavior, we relied on existing procedures to characterize the activity space, transforming point patterns into geographical forms. Despite their interest, the standard deviational ellipse and the convex hull are not ideal to represent the activity space. Both of them capture large areas free of visited locations (Rai et al., 2007; Schönfelder and Axhausen, 2002) that may not be familiar to the participants. Therefore, these polygons are likely to be very rough approximations of the ‘true’ experienced space. For example, the standard deviational ellipse will tend to encompass the residence and the workplace that may be very distant from each other and a large portion of space between these locations that the individual never specifically visits (Schönfelder and Axhausen, 2002). In our analysis, the use of multiple geographical methods to represent the activity space likely mitigated the limitations of these specific indicators. Previous studies have suggested that the notion of “network of activity places” could more accurately reflect activity spaces (Chaix et al., 2012c; Flamm and Kaufmann, 2006).

Our study did not develop indicators allowing to assess the polycentric or monocentric nature of the activity space (Flamm and Kaufmann, 2006; Perchoux et al., 2013; Schönfelder and Axhausen, 2004b; Vallée and Chauvin, 2012). It has been shown that individuals often tend to cluster their activities in a small number of subcenters due to the spatial distribution of resources (Schönfelder and Axhausen, 2004b) and to the utility maximization theory (Schlich and Axhausen, 2003). However, a critical challenge is to conceptually define clusters of activities – or daily activity centers – from the set of activity locations of each individual (Flamm and Kaufmann, 2006), and to empirically distinguish between the different subclusters of activity locations. Defining such indicators will need assumptions on the minimum number of activity places required for a subcluster and on a distance threshold above which activity places cannot be agglomerated, without losing sight of scale issues.

Spatial behavior by age and sex

Investigating associations between socio-demographic variables and spatial behavior is important to assess the extent to which bias in residential measures of environmental exposures are stratified. These findings show age being strongly associated with spatial behavior. Older participants had a more residential-centered activity space, and overall fewer activity locations, which were more specialized toward food and services than towards recreational and social activities. The decrease in activity space size with increasing age has been reported before (Lord et al., 2009). Other studies have reported that the frequency and distance covered in daily commutes is lower for older adults (Fobker and Grotz, 2006) and that older commuters have shorter trip durations (Newsome et al., 1998). The worsening of health status, the incidence of functional limitations, the resulting lack of autonomy and independence, and the greater social isolation might contribute to such a reduction in the overall mobility of elderly people.

In our study, gender was associated with the size of the activity space and the volume of activities, in line with studies showing that women have smaller commuting distances than men (Madden, 1981; Singell and Lillydahl, 1986) and an activity space more centered on their residential neighborhood (Lord et al., 2009). Such patterns have been attributed to the *household responsibility hypothesis* (i.e., to the unequal repartition of housekeeping and childcare responsibilities) (Turner and Niemeier, 1997). However, other studies did not report any association between gender and characteristics of the activity space (Newsome et al., 1998; Smith and Sylvestre, 2001).

Spatial behavior by socioeconomic status

Our findings suggest that employment status and individual education were strong predictors of spatial behavior. Unemployment and precarious employment status were associated with a higher degree of clustering of the activity locations in the PRN, and with a smaller and more compact activity space. Participants with a precarious job position or unemployed engaged in fewer activities which were more specialized towards food and other services (i.e., they engaged in less recreational activities). This was similar for education, where less educated participants were more likely to restrict their activity locations to their residential neighborhood and less likely to commute longer distances. It is difficult to conclude from the present findings whether low socioeconomic status people are more restricted in their mobility and consequently confined to their residential neighborhood or whether the residential-centering of their activity space is merely a matter of personal preferences (Ross et al., 2000). However, because preferences related to mobility were taken into account in the models, we believe the observed socioeconomic effects are rather attributable to constraints and to a lack of opportunities to travel far from one's neighborhood.

Unexpectedly, participants reporting financial strain had an activity space less centered on their residential neighborhood and engaged in a higher volume of activities, mostly related to food stores and other services. The higher volume of the activities related to food and other services may be related to the fact that such participants are unable pay for recreational activities and that they may be less socially integrated. A potential explanation for the activity space less centered on their residential neighborhood is that participants reporting financial strain may have a lower spatial accessibility to food stores in their residential neighborhood and may travel longer distances to reach cheaper stores.

Spatial behavior by location within the region

As in numerous studies, centrality was a strong predictor of spatial behavior. Living in the suburbs was associated with more activity destinations outside the residential neighborhood. With increasing distance from the city of Paris, individuals had a more extended activity space and reported a lower number of destinations. A comparable *suburbia effect* – more extended activity spaces – was observed in two German cities (Schönfelder and Axhausen, 2002). The urban morphology of suburbs - with lower street connectivity and lower density of stores and destinations - forces suburbanites to travel further distances to reach destinations. Buliung et al. described an urban/suburban behavioral dichotomy in space-time patterns, emphasizing that suburban households have larger and more dispersed activity spaces and travel more kilometers than their urban counterparts (Buliung and Kanaroglou, 2006c).

Additionally, in our study, the activity locations of the suburbanites were less specialized towards food stores and other services. A possible explanation may be the lower availability of and spatial accessibility to a variety of specialized retail stores (i.e. bakery, butcher, fish market, etc.) in the suburbs and the resulting propensity of participants to perform their food shopping in centralized larger supermarkets offering a variety of amenities.

Correlations between patterns of spatial behavior and use of transportation modes

Use of active transportation (walking and cycling) was associated with both having a higher share of one's activity space in one's residential neighborhood and engaging in more activities. These finding are coherent with previous literature indicating that non-motorized travels are highly localized around an origin point, i.e., the residence (Frank et al., 2003; Sallis et al., 2004). In contrast, larger scales (i.e., large and elongated activity spaces) require personal or public motorized transportation modes, which is consistent with previous studies reporting a greater car use among suburban dwellers (Dieleman et al., 2002).

5.1.6 Conclusion

These results are important for studies on health and place for three reasons. First, individuals are mobile and mobility patterns differs, which means exposure to environmental conditions needs to account for participants' daily mobility. Second, identifying mobility patterns sheds light on possible specific needs. For example, some individuals may be trapped in their low resource residential neighborhood or may be constantly traveling across low resource environments. Third and finally, the information on spatial behavior that we were able to derive may causally influence or be associated with certain health behavior, for example transportation physical activity or purchasing of foods.

This work is in line with an increasing number of health studies accounting for mobility behavior. The development of technologies, data collection, and analysis methods including use of origin-destination surveys (Kestens et al., 2010; Lebel et al., 2012; Setton et al., 2011) or GPS tracking (Hurvitz and Moudon, 2012; Kerr et al., 2011; Rainham et al., 2008; Thierry et al., 2013; Zenk et al., 2011) allows researchers to improve the assessment of multiple environmental exposures (Chaix et al., 2013b). These novel data and associated analytic strategies may lead to reconsider the importance of environmental effects on health, with a potential underrepresentation when using residential environment only (Chaix et al., 2013a; Chum, 2013). Overall, more accurate measures of environmental exposures and their effects on health will provide better evidence for public health policies and interventions promoting healthy behaviors including active living.

5.1.7 References

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5.1.8 Tables and figures

Table 1. Spatial and behavioral indicators considered for the typology of spatial behavior

Indicators	**Measurement approach**	**References**
Indicators related to the lifestyle		
Number of activity places	Count of activity places	(Buliung et al., 2008; Dijst, 1999b; Lord et al., 2009; Schönfelder and Axhausen, 2002, 2003a, 2004a, b)
Number of visits to places per week	Number of activity places per individual multiplied by the frequency of visit per week to each location, excluding the residence	(Buliung et al., 2008; Schönfelder and Axhausen, 2002; Schönfelder and Axhausen, 2003b; Schönfelder and Axhausen, 2004a, b)
Number of activity types	6 types of activities considered: 1-Residential; 2-Work; 3-Food and other services; 4-Transport station/stop; 5-Recreational activity; 6- Social activity	(Buliung et al., 2008; Rai et al., 2007; Schönfelder and Axhausen, 2004b)
Individual quotient of food stores and services	Comparison of the proportion of food and other services for each participant to the proportion of other activities	(Pumain and Saint-Julien, 1997)
Individual quotient of recreational activities	Comparison of the proportion of recreational activities for each participant to the proportion of other activities	(Pumain and Saint-Julien, 1997)
Individual quotient of social activities	Comparison of the proportion of social activities for each participant to the proportion of other activities	(Pumain and Saint-Julien, 1997)
Indicators related to the geometry of the activity space		
Perimeter of the convex hull ***(Figure 1a)***	GIS processing: perimeter of the smallest polygon containing all the activity locations of the participant (unit: km)	
Surface of the convex hull ***(Figure 1a)***	GIS processing: surface of the smallest polygon containing all the activity locations of	(Buliung et al., 2008; Sherman et al., 2005a)

	the participant (unit: km^2)	
Major to minor axis ratio ***(Figure 1b)***	GIS processing: ratio of the axes of a standard deviational ellipse weighted by the annual frequency of visits to places	(Lord et al., 2009; Newsome et al., 1998; Schönfelder and Axhausen, 2004a)
Gravelius compactness coefficient	GIS processing: activity space represented by a Convex Hull. $K = P / (2\sqrt{\pi A})$ (where P = perimeter and A = surface)	(Bendjoudi and Hubert, 2002; Gravelius, 1914)
Index of eccentricity	GIS Processing: ratio of the distance between the residence and the centroid of the standard deviational ellipse to the length of major axis	(Lord et al., 2009)
Density of activity locations in the standard deviational ellipse	GIS processing: ratio of the number of activity places to the surface of the standard deviational ellipse	
Minimal road network distance from the residence to an activity place ***(Figue 1c)***	GIS processing: minimal distance from the residence to an activity place using the road network	(Arcury et al., 2005)
Maximal road network distance from the residence to an activity place ***(Figue 1c)***	GIS processing: maximal distance from the residence to an activity place using the road network. For activity locations outside Ile-de-France, the distance was approximated with the Euclidian distance.	
Median road network distance from the residence to all activity places	GIS processing: median distance from home to all activity places using the road network	
Indicators related to the importance of the residential neighborhood		
Degree of attachment to the PRN	Scale 0-6; 6=high attachment	
Percentage of visits to places in the residential neighborhood	GIS processing: count of visits to places within the 500 m road network buffer centered on the residence divided by the total number of visits to places	

Number of activity locations in the PRN	Count of activity locations in the PRN	
Percentage of visits in the PRN	GIS processing: count of visits to places in the PRN divided by the total number of visits to places	
Surface of the PRN	GIS processing: unit: km²	
Proportion of the overall activity/perceived space covered by the PRN[a]	GIS processing: percentage of the activity/perceived space (resulting from the merge of the PRN with the activity space convex hull) covered by the PRN	
Proportion of the activity space covered by the PRN[a]	GIS processing: percentage of the activity space convex hull covered by the PRN	
(figue 1d)		
Gravelius compactness coefficient for the PRN	GIS processing: Gravelius compactness coefficient calculated for the PRN	(Bendjoudi and Hubert, 2002; Gravelius, 1914)
Index of eccentricity for the PRN	Shortest distance from the residence to the PRN boundary divided by the radius of a circle of the same area than the PRN	

PRN, Perceived residential neighborhood.

[a] Both the numerator and the denominator can differ between these two indicators. The two indicators are exactly similar for the participants for whom the PRN is entirely comprised within the activity space convex hull. However, they differ when at least part of the PRN is out of the activity space convex hull.

Table 2. Selected characteristics of the RECORD participants included in the present study (n=2062)

Variable	Category	Value
Sex (%)	Female	31
Age (mean, years)	_	51
Citizenship (%)	French	83
Individual education (%)	High	23
	Middle-High	18
	Middle-Low	28
	Low	31
Household income per consumption unit (%)	High (>1750 € per month)	33
	Medium (1125–1750 € per month)	33
	Low (<1125 € per months)	34
Employment status (%)	Stable	50
	Unstable	13
	Unemployed	15
	Other	22
Location in the region (%)	Center	27
	Inner suburbs	46
	Outer suburbs	27

Table 3. Factor analysis of indicators of spatial behavior, VERITAS-RECORD data (n=2062)

	Centering of the activity space on the residential neighborhood	Size of the activity space	Volume of activities	Specialization of the activity space	Elongation of the activity space
% of variation explained	35%	20%	16%	10%	9%
Surface of the convex hull	-	0.78*	-	-	-
Perimeter of the convex hull	-	0.92*	-	-	-
Gravelius compactness coefficient	-	-	-	-	0.82*
Major to minor axis ratio	-	-	-	-	0.74
Number of activity places	-	-	0.83*	-	-
Number of visits to places per week	-	-	0.80*	-	-
Number of activity types	-	-	0.60	-0.49	-
Index of eccentricity	-	-	-	-0.47	-
Number of activity locations in the PRN	0.50	-	0.71	-	-
Percentage of visits to places in the PRN	0.67	-	-	0.43	-
Proportion of the activity space covered by the PRN	0.88*	-	-	-	-
Proportion of the overall activity/perceived space covered by the PRN	0.88*	-	-	-	-

Percentage of visits to places in the residential neighborhood	0.39	-	-	0.48	-
Maximal road network distance from home to an activity place	-	0.88*	-	-0.40	0.37
Median road network distance from home to activity places	-	0.36	-	-0.49	-
Individual quotient of food stores and services	-	-	-	0.72	-
Individual quotient of recreational activities	-	-	-	-0.36	-
Individual quotient of social activities	-	-	-	-0.37	-

Loading factors higher than 0.75 are flagged with a '*'. Values lower than 0.3 are not reported.

Table 4. Associations between individual socio-demographic characteristics and the different components of spatial behavior (n=2062)

	Centering of the activity space on the residential neighborhood	Size of the activity space	Volume of activities	Specialization of the activity space	Elongation of the activity space
	β (95% CI)	**β (95% CI)**	**β (95% CI)**	**β (95% CI)**	**β (95% CI)**
Male (vs. female)	0.01 (-0.07, 0.10)	0.09 (0.00, 0.18)	-0.10 (-0.18, -0.02)	-0.01 (-0.09, 0.07)	0.07 (-0.01, 0.16)
Age (1 year increase)	0.01 (0.00, 0.01)	0.00 (-0.01, 0.00)	-0.01 (-0.01, 0.00)	0.01 (0.00, 0.01)	0.00 (-0.01, 0.00)
French citizenship (vs. other)	-	-	-0.12 (-0.23, -0.02)	-	-
Individual education (vs. high)					
Middle-High	-	-	0.03 (-0.09, 0.15)	0.07 (-0.4, 0.19)	-
Middle-Low	-	-	-0.10 (-0.21, 0.01)	0.11 (0.00, 0.21)	-
Low	-	-	-0.36 (-0.46, -0.25)	0.25 (0.14 0.35)	-
Employment Status (vs. stable)					
Unstable	0.27 (0.14, 0.39)	-0.11 (-0.24, 0.02)	-0.06 (-0.18, 0.06)	0.25 (0.13, 0.37)	-0.25 (-0.37, -0.12)
Unemployed	0.44 (0.32, 0.55)	-0.18 (-0.31, -0.06)	-0.23 (-0.34, -0.12)	0.55 (0.44, 0.66)	-0.26 (-0.38, -0.14)
Other	0.39 (0.26, 0.51)	-0.22 (-0.35, -0.09)	-0.25 (-0.37, -0.13)	0.43 (0.32, 0.55)	-0.21 (-0.34, -0.09)

Income (vs. high)					
Medium	-	-	-	-	-0.13 (-0.23, -0.04)
Low	-	-	-	-	-0.07 (-0.18, 0.03)
Financial strain					
(vs. not)					
Rarely	-0.04 (-0.14, 0.05)	-	0.03 (-0.06, 0.12)	0.04 (-0.05, 0.13)	-
Frequently	-0.11 (-0.21, -0.02)	-	0.10 (0.00, 0.20)	0.11 (0.2, 0.20)	-
Ownership score					
(vs. high)					
Middle	-	-0.13 (-0.25, -0.01)	-		-
Low	-	-0.14 (-0.25, -0.03)	-	-	-
Systematic use of the nearest shop	0.20 (0.11, 0.29)	-0.16 (-0.25, -0.06)	-	0.10 (0.01, 0.19)	0.15 (0.05, 0.24)
Willingness to travel out of the neighborhood to access new types of activity	-0.19 (-0.28, -0.09)	-	-	-	-
Location in the region (vs. center)					

Inner suburbs	-0.49 (-0.62, -0.37)	0.05 (-0.09, 0.20)	-0.51 (-0.61, -0.41)	-0.23 (-0.35, -0.12)	-
Outer suburbs	-0.61 (-0.75, -0.48)	0.48 (0.33, 0.64)	-0.87 (-0.98, -0.76)	-0.30 (-0.43, -0.18)	-
Null model ICC	0.075	0.069	0.120	0.026	0.029
Full model ICC	0.017	0.025	0.004	0.014	0.043
Null model AIC	5593.7	5757.0	5478.4	5417.1	5461.8
Full model AIC	5435.7	5706.3	5277.3	5196.3	5425.6

AIC, Akaike Information Criterion; CI, confidence interval; ICC, intraclass correlation coefficient (proportion of the total variance explained by the variance between the municipality units).

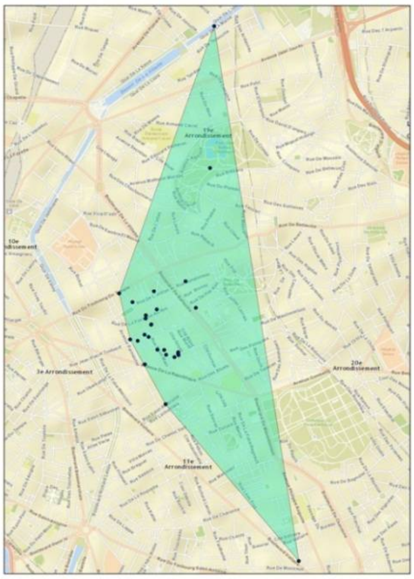
Table 5. Average weekly number of days (standard deviations) of use of transportation modes according to the components of spatial behavior divided in three categories (n=2062)

	Walk		Bicycle		Public transport		Car	
	M (SD)	JT test p value	M (SD)	JT test p value	M (SD)	JT test p value	M (SD)	JT test p value
Centering of the activity space on the residential neighborhood								
High	6.0 (2.0)		0.7 (1.7)		2.0 (1.8)		1.1 (1.3)	
Medium	5.4 (2.4)	<.001	0.5 (1.4)	0.001	2.2 (2.0)	0.229	1.6 (1.4)	<.001
Low	5.0 (2.6)		0.4 (1.4)		2.0 (2.1)		1.9 (1.5)	
Size of the activity space								
High	5.2 (2.4)		0.5 (1.4)		2.2 (2.0)		1.8 (1.4)	
Medium	5.7 (2.2)	0.042	0.5 (1.5)	0.636	1.9 (1.9)	0.540	1.5 (1.5)	<.001
Low	5.4 (2.4)		0.6 (1.6)		2.1 (2.0)		1.3 (1.4)	
Volume of activities								
High	6.1 (1.8)		0.7 (1.6)		2.9 (1.9)		1.1 (1.2)	
Medium	5.5 (2.3)	<.001	0.5 (1.6)	<.001	2.1 (2.0)	<.001	1.6 (1.5)	<.001
Low	4.6 (2.7)		0.4 (1.4)		1.2 (1.8)		1.9 (1.5)	
Specialization of the activity space								

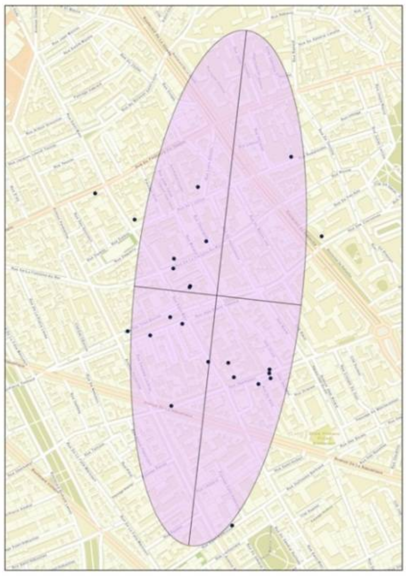
High	5.3 (2.4)		0.4 (1.3)		1.7 (1.9)		1.4 (1.4)	
Medium	5.6 (2.3)	0.818	0.6 (1.6)	0.325	2.2 (2.0)	<.001	1.5 (1.4)	0.022
Low	5.4 (2.4)		0.6 (1.6)		2.3 (2.0)		1.6 (1.4)	
Elongation of the activity space								
High	5.4 (2.3)		0.5 (0.5)		2.3 (1.9)		1.4 (1.3)	
Medium	5.4 (2.4)	0.568	0.5 (1.4)	0.118	2.1 (2.0)	<.001	1.5 (1.5)	0.003
Low	5.5 (2.4)		0.7 (1.7)		1.8 (2.0)		1.7 (1.5)	

JT test, Jonckheere-Terpstra test

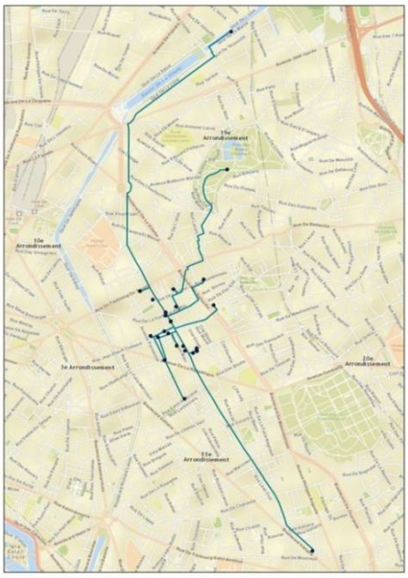
Figure 1. Examples of indicators of spatial behavior



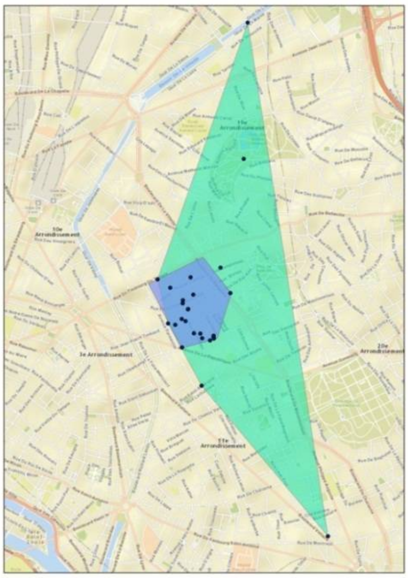
a) Perimeter and surface of the convex hull



b) Major to minor axis ratio of the ellipse



c) Road network distance from home to activity places



d) Proportion of the activity space covered by the perceived residential neighborhood

Legend

- Activity place
- Convex hull
- Shortest path
- Standard deviational ellipse
- Perceived residential neighborhood

5.2 ARTICLE 3: RESIDENTIAL NEIGHBORHOOD, PERCEIVED NEIGHBORHOOD, AND INDIVIDUAL ACTIVITY SPACE: QUANTIFYING DIFFERENCES IN BUILT ENVIRONMENT EXPOSURE - THE RECORD COHORT STUDY

Camille Perchoux, Basile Chaix, Ruben Brondeel, Yan Kestens

Title: Residential neighborhood, perceived neighborhood, and individual activity space: Quantifying differences in built environment exposure - The RECORD Cohort Study

Authors names and affiliations: Camille Perchoux, M.Sc [a,b,c,d*]; Basile Chaix, Ph.D [a, b]; Ruben Brondeel, M.Sc [a,b, e], Yan Kestens, Ph.D [c,d]

[a] Sorbonne Universités, UPMC Université Paris 06, UMR_S 1136, Institut Pierre Louis d'Epidémiologie et de Santé Publique, 75012, Paris, France

[b] INSERM, UMR_S 1136, Institut Pierre Louis d'Epidémiologie et de Santé Publique, F-75012, Paris, France

[c] Département de médecine sociale et préventive, Université de Montréal, Montreal (QC), Canada

[d] Centre de Recherche du Centre Hospitalier Universitaire de Montréal (CRCHUM), Montreal (QC), Canada

[e] Ecole des Hautes Etudes en Santé Publique (EHESP), 35043, Rennes, France

***Corresponding author information:** Camille Perchoux

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5.2.1 Abstract

Background: Neighborhood effects on health have been widely investigated; yet the definition of neighborhoods is usually not based on knowledge of the 'true' personal exposure area.

Purpose: This study analyses how disparities in environmental exposure according to household income and urbanicity degree vary when using three distinct definitions of exposure areas: a home-centered network-buffer, the perceived residential neighborhood, and the activity space encompassing activity locations.

Methods: Point-based activity places and perceived neighborhood delimitations were collected between 2011 and 2013 in the Paris region using the VERITAS software among 4,383 participants of the RECORD Cohort Study. Exposures to the density of destinations and density of green spaces were compared for the three spatial definitions of the exposure area, overall and stratified by household income and urbanicity degree of the residence. Using paired sample t-tests (95% CI) and Jonckheere-Terpstra tests, differences in exposure measures and gradients were tested. Data were analyzed in 2013.

Results: Densities of destinations and green spaces were highest in the perceived neighborhood, while density of destinations was higher in the activity space than in the home-centered buffer. Density of destinations increased with household income and with urbanicity degree. Differences in exposure between the different types of exposure areas varied by income and urbanicity degree.

Conclusions: Environmental exposure levels and gradients vary depending on the spatial definition of the exposure area. Future studies of environment-health relationships will have to compare classical ego-centered neighborhoods, perceived neighborhoods, and activity space definitions of exposure areas.

Keywords: Environmental exposure, Activity space, Perceived residential neighborhood, Daily mobility bias.

5.2.2 Introduction

The previous decades have witnessed a renewed focus on the effect of environmental factors on health behavior and health. Yet, such advances call into question which environments or exposure areas are relevant to consider to measure health related exposures.

Alternatives to the relatively arbitrary definitions of residential neighborhoods (administrative neighborhoods, buffer areas) have been proposed in the literature, such as collecting data to take into account the perceived or experienced neighborhoods (Chaix et al., 2009; Vallée and Shareck, 2014). Other scholars have proposed to also take into account the non-residential environmental exposures related to people's daily mobility patterns using an activity space definition of exposure area (Chaix et al., 2012c; Chaix et al., 2013a; Matthews and Yang, 2013b; Perchoux et al., 2013; Rainham et al., 2010).

Considering the participant's perceived residential neighborhood (**Table 1**) has been suggested as an interesting method to assess neighborhood environmental exposures (Chaix et al., 2009; Chappell et al., 2006). Its size and shape have been shown to vary according to socio-demographic characteristics (Coulton et al., 2001). Also, substantial variations in the exposure to environmental characteristics (park availability, commercial physical activity facilities, restaurants, and food stores) were observed between the residential and the perceived neighborhood (Colabianchi et al., 2014). However, to our knowledge, no study has examined how built environment characteristics differ between the perceived residential neighborhood and the broader activity space.

Not taking individuals' daily mobility into account can lead to a misrepresentation of the real exposure (Matthews, 2011b; Matthews and Yang, 2013b; Perchoux et al., 2013; 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; Mason, 2010; Setton et al., 2011; Zenk et al., 2011). The few studies that attempted to move beyond the residential neighborhood have used the concept of activity space (**Table 1**) to operationalize the personal area of exposure.

Despite the growing use of the concept of activity space (Hurvitz and Moudon, 2012; Inagami et al., 2007; Kestens et al., 2010; Setton et al., 2011; Shareck et al., 2014b; Vallée et al., 2010; Vallée and Chauvin, 2012; Zenk et al., 2011), few studies were able to report how much residential and non-residential environments differ.

Mobility has been hypothesized as a vector to reduce social inequities in the access to resources and possibly health: people living in a deprived neighborhood can compensate by reaching less deprived neighborhoods in the course of their daily activities. However, even after accounting for the exposure to low socioeconomic status in non-residential environments, Inagami et al. observed a worse self-rated health among individuals living in a residential neighborhood with a very low socioeconomic status (Inagami et al., 2007). Other studies have observed a double burden on individuals living in deprived neighborhoods and being confined in deprived non-residential neighborhood (Shareck et al., 2014b).

However, accounting for the non-residential places individuals regularly visit requires caution. Concerns about circularity – or confounding related to the selective daily mobility bias (**Table 1**) – have been raised (Chaix et al., 2012c; Chaix et al., 2013b; Kerr, 2013; Kestens et al., 2012). To overcome this potential source of confounding, Chaix et al. (2012) suggested to, either exclude the activity places visited related to the behavior of interest (as, for example, it would be nonsense to consider the accessibility to sport activity locations from the places specifically visited to practice sports) or only retain the spatial anchor points that correspond to constrained activities (**Table 1**) (Chaix et al., 2012c).

Objectives

First, we evaluated whether and how exposure measurements of two built environment characteristics conducive to walking (Chaix et al., 2014b; Sugiyama et al., 2012a) – density of destinations and green spaces – varied when considering different definitions of the exposure area [street-network residential buffer (SRB), self-reported perceived residential neighborhoods (PRN), and activity space]. Second, we assessed differences in exposure levels by individual-level socioeconomic status and degree of urbanicity of the residence; and examined whether such disparities in exposure differed when different exposure areas were used. A secondary objective was to examine whether exposure measures and gradients differed when two definitions of the activity space were used, one accounting for all the destinations reported (full activity space) and one attempting to address the daily mobility bias (truncated activity space).

5.2.3 Methods

Population

The study relies on the second wave of the RECORD Cohort Study (Chaix et al., 2011d). Overall, 4,383 participants were surveyed without *a priori* sampling between February 2011 and October 2013 during preventive health checkups conducted by the Centre d'Investigations Préventives et Cliniques (IPC) in Paris (Chaix et al., 2010b; Chaix et al., 2011a; Chaix et al., 2011b; Havard et al., 2011; Leal et al., 2011). 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. 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.

Individual variables

individual-level variables were considered in our analyses: the household income per consumption unit (tertiles: 1,222 and 2,125 Euros/month), and the location of the residence in the Paris Ile-de-France region as a proxy of urbanicity degree (City center, inner suburbs, and outer suburbs).

Geospatial data

Self-reported activity places were geocoded using the VERITAS application (Chaix et al., 2012c). Using this interactive mapping tool, participants were asked to draw the boundaries of their perceived neighborhood and to report the geographic location of the activity places listed in **Table 2**.

Spatial definition of exposure areas

The SRB was defined as a 1000 meter street network buffer around each participant's home (Chaix et al., 2014b). The PRN was drawn by the participant or the survey technician on the map of the VERITAS application.

Two definitions of the activity space were used: a full activity space; and a truncated activity space. The full activity space took into consideration all the regular activity places reported. In an attempt to limit the daily mobility bias, the activity places that theoretically relate to the exposure of interest were removed to create the truncated activity space. To measure the accessibility to green spaces, the reported sport activity destinations were excluded. To measure the accessibility to services and destinations, we only retained relatively constrained and fixed destinations and excluded all other destinations that were mainly related to the use of services, i.e., to the exposure itself (**Table 1**); i.e. the residence, the workplace, the bank and the place where participants take relatives. **Figure 1** presents a comparison of the areas of exposure. For each of the two definitions of the activity space, street network buffers were constructed around each reported activity location. The size of the street network buffer varied in function of the type of activity conducted (**Table 2**).

Environmental data

Two environmental variables that have been related to walkability were extracted for each exposure area definition: density of green spaces (proportion of surface covered with green spaces) and density of destinations (number per km²). Green spaces were assessed from a 2008 geographic layer of the Institute of Urban Planning of the Ile-de-France Region (IAU-IDF). 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.

Statistical analyses

Analyses of variance were used to examine variations in the size of the SRB, PRN, and full and truncated activity spaces in relation to age, sex, income, urbanicity degree of residence, and densities of green spaces and destinations.

Paired sample t-tests were used to assess differences in exposure measures between the different definitions of the exposure area. Jonckheere-Terpstra (JT) tests were performed to assess trends in exposure between ordered classes. All analyses were conducted with SAS version 9.2 in 2013.

5.2.4 Results

Description of the study sample

From the original sample we excluded: 55 participants living and 996 participants regularly traveling outside the Ile-de-France region and 108 participants regularly visiting a secondary home. 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 the Paris City, 46% in the inner suburbs, and 27% in the outer suburbs of the Paris Ile-de-France region.

The participants reported a median number of 13 distinct activity locations (range: 2-42). The median surface area was 1.8 km^2 (range: 0.5-2.9) for the SRB, 0.5 km^2 (range: 0.0-277.5) for the PRN, 3.8 km^2 (range: 1.1-11.4) for the full activity space, 3.7 km^2 (range: 1.0-10.8) for the green space-truncated activity space, and 3.1 km^2 (range: 0.5-10.0) for the destinations-truncated activity space. Unadjusted relationships between individual/environmental characteristics and the size of the different exposure areas are reported in Supplemental material Table S1. The size of the activity space decreased with increasing age. Men reported a larger PRN than women. The size of both the SRB and the activity spaces increased with household income and urbanicity degree (possibly simply due to the higher connectivity of higher income and urbanicity environments). Regarding relationships between density of green spaces and the size of the exposure area, a particularly strong relationship was documented for the PRN (suggesting that participants may extend their perceived neighborhood so as to encompass green spaces). Opposite patterns of relationship were documented for the association between density of services and area size (depending on the exposure area considered).

Differences in environmental exposure by neighborhood definition

Averages of environmental characteristics by exposure areas are presented in **Table 3**. **Table 4** shows differences in environmental exposures between the different types of exposure areas.

Overall, there was little evidence of association between household income and density of green spaces in the exposure areas (**Table 3**). On the opposite, the density of green spaces in the exposure area was larger in the outer suburbs than in the city center, except when the PRN was considered. Regardless of the exposure area examined, the density of services in the exposure area increased with household income and urbanicity degree.

Street-network residential buffer vs. perceived residential neighborhood

The mean density of green spaces was higher in the PRN (0.080) than in the SRB (0.071). This difference between the two exposure areas increased from the outer suburbs to the city center (**Table 4**).

Again, the density of destinations was greater in the PRN than in the SRB. The observed difference of exposure between these areas by household income revealed an increasing trend from the low-income group (81.4) to the high-income group (126.4) ($p<0.001$). The same trend in the difference was observed from the outer suburbs to the city center ($p<0.001$) **(Table 4)**.

Street-network residential buffer vs. truncated activity space

Regarding the density of green spaces, no overall differences were found between the SRB and the truncated activity space. However, differences between exposure areas became apparent when calculated by urbanicity degree of the residence ($p<0.001$). Participants living in the center had higher exposure to green spaces in their truncated activity space than in their SRB, while the contrary was true for suburbanites.

Overall, the truncated activity space contained a higher density of destinations than the SRB. However, while individuals living in the city center had a higher density of destinations in their SRB (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 SRB (**Fig. 2**).

Perceived residential neighborhood vs. truncated activity space

The densities of green spaces and destinations were lower in the truncated activity space than in the PRN.

Differences in exposure to green spaces according to the exposure area considered varied by urbanicity degree of the residence, with a lower exposure to green spaces in the truncated activity space than in the PRN for residents of the city center or inner suburbs (-0.013) as opposed to those of outer suburbs.

The differences in the accessibility to destinations varied both by household income and urbanicity degree. A strong trend ($p<0.001$) in the difference between the PRN and the truncated activity space showed that urban individuals had a higher exposure to destinations in their PRN, whereas suburbanites had a higher exposure to destinations in their truncated activity space.

Full Activity Space vs. Truncated Activity Space

Overall exposure estimates were higher in the full than in the truncated activity space.

The density of green spaces increased with household income when considering the full activity space ($p>0.001$) but not when considering the truncated activity space (**Fig. 2**, as also reflected in the differences in exposure in **Table 4**). The 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 the gradient due to a larger difference in accessibility between the two versions of the activity space for the residents of outer suburbs.

For both the truncated and the full activity space, the accessibility to destinations increased from low to high household income ($p<0.001$). Stratification by urbanicity degree of the residence shows accessibility to a larger density of destinations when considering the full rather than the truncated activity space, with more pronounced differences for suburban rather than urban residents ($p<0.001$).

5.2.5 Discussion

This study defined and compared measures of environmental exposure to built environment features conducive to walking using four definitions of the exposure area: a classical street network-buffer centered on the residence, the self-reported perceived neighborhood, and a full and truncated versions of the activity space.

Similarly to previous studies (Colabianchi et al., 2014; Smith et al., 2010) the median SRB size was three times larger than the median PRN size. The size of the activity space defined from the geocoded activity locations (between 3 and 4 km^2) was smaller than expected (Zenk et al., 2011). The small size of the activity space in our study might be due to a high clustering of activity locations around major destinations (e.g. home, work) (Flamm and Kaufmann, 2006). In line with other studies, age (Fobker and Grotz, 2006; Lord et al., 2009) and location of the residence in the region (Buliung and Kanaroglou, 2006c; Schönfelder and Axhausen, 2002) were associated with the size of as the activity space. Notwithstanding the standardization of the environmental variables for the size of the exposure area, both green space and destination densities were associated with the size of the activity space.

Overall estimates of environmental exposure differed according to the definition of the exposure area. First, exposure to destinations and green spaces were higher in the PRN than in the SRB, as reported before (Colabianchi et al., 2014). This observation combined with the smaller size of the PRN confirm the anisotropic character of the PRN which eliminates low density areas where individuals do not go, compared to the isotropic shape of the ORN (Chaix et al., 2009).

Second, measures of environmental exposure that account for daily mobility (full and truncated activity spaces) differed from those based on the SRB and PRN. The exposure to destinations was higher in the activity space than in the SRB, in accordance with other studies on the food environment (Basta et al., 2010; Hurvitz and Moudon, 2012; Kestens et al., 2010). However, densities of green spaces and destinations (standardized on area size) were both greater in the PRN than in the activity space (we found no previous literature to compare with our finding).

Third, in most cases, differences in exposure between definitions of exposure areas showed variations by household income and urbanicity degree. Our findings indicate a greater exposure mismatch between types of exposure areas among high-income than among low-income participants for density of destinations, which was attributable to the particularly high accessibility to services of high-income residents in their PRN. Regarding urbanicity degree, the difference in exposure levels between the different exposure areas was attributable: first, to the fact that residents of the city center access to a notably larger density of green spaces and destinations in their oriented PRN than in their isotropic SRB (they probably define their PRN according to these resources); and second, to the fact that, while participants living in the city center have higher densities of destinations in their residential neighborhood (both their PRN and SRB), participants from the inner and the outer suburbs have access to much higher densities of destinations near their non-residential activity locations (as reflected in the activity space measures).

Finally, exposure levels were different in the two representations of the activity space (full and truncated). No trend was observed for the accessibility to green spaces by household income in the truncated activity space while a trend was present with the full activity space. A potential explanation is that people of different socioeconomic background in fact have a comparable accessibility to green spaces from their daily activity locations, but that high-income participants are more likely to regularly visit parks than low-income participants. Therefore, as previously emphasized (Chaix et al., 2012c; Chaix et al., 2013b), our expectation is that correlating the accessibility to green spaces assessed in the full activity space with, e.g., walking may generate bias, while our exposure measures in truncated activity spaces may be useful to mitigate the so-called daily mobility bias.

Strengths and limitations

The definitions of the activity space included the residential neighborhood. This 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 to exclude to mitigate the selective daily mobility bias. 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.

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 (Chaix et al., 2012c). Our study is also one of the first to address concerns related to the selective daily mobility bias.

5.2.6 Conclusion

While more and more studies are currently collecting real-time exposure data through GPS receivers eventually combined with environmental sensors, our study strengthens the theoretical ground for assessing multiple-place exposure by underlining that residential and activity space exposures are significantly different. It also sheds light on the extent to which measurement error related to the use of residential measures of environmental exposure varies in magnitude according to socioeconomic status and urbanicity degree. Our findings also highlight the need to address the selective daily mobility bias in studies accounting for individual-level mobility in the definition of environmental exposures. Failing to do so might lead to confounding and limit causal inference (Chaix et al., 2012c; Chaix et al., 2013b). Future research will have to examine whether accounting for the full range of environmental exposures in a multiple-place perspective provides stronger evidence on the places and populations that public health interventions should target.

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5.2.8 Tables and figures

Table 1. Glossary of technical expressions

Street-network residential buffer	Isotropic buffer centered on the participants' residence, with the radius defined along the street network.
Perceived residential neighborhood	Self-defined area usually approximated by asking participants to draw their neighborhood on a map. Perceived areas offer a mean to assess (Coulton et al., 2001; Guest and Lee, 1984) the cognitive construct that participants have in relation to their neighborhood. People tend to define the spatial boundaries of their neighborhood according to their habits and location preferences (Chaix et al., 2009; Downs and Stea, 1973).
Activity space	Set of locations visited by an individual in the course of his day-to-day activities (Golledge and Stimson, 1997).
Selective daily mobility bias	It refers to the fact that the visited activity locations are determined by individuals' particular characteristics (socio-demographic, psychological, cognitive, or behavioral variables) which also influence their health status (Chaix et al., 2012c). If not carefully addressed, accounting for non-residential exposure might therefore be a source of confounding, e.g., by the behavioral preferences that influence both the places visited and behavior.
Spatial behavior	Spatial and spatio-temporal patterns of mobility
Constrained destinations	Refers to activities fixed in space and time (i.e. home, work, children's school). They cannot be rescheduled or carried out in another location (Hägerstrand, 1970).
Spatial anchor points	"Spatial anchors or pivots (Kwan, 2009) (also termed reference locations,(Kwan, 1998) fixed activity places, (Miller, 2007a) bases, or core stops (Dijst, 1999b)) refer to daily life centers (Flamm and Kaufmann, 2006; Kestens et al., 2010), (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 (Dijst, 1999b) of these quasi-obligatory activities imply that they cannot be easily relocated or rescheduled (Kwan, 1999; Miller, 2007a))" (Chaix et al., 2012c, p. 441)

Table 2. Types of activity places and related sizes of the buffer for assessing environmental exposures

Activity location	Frequency of visit	Size of the street network buffer
Domain : Residence		
Place of residence	N/A	1000m
Another address where the participant spends at least one night per week	At least once a week	1000m
Domain: Work		
Workplace	At least once a week	1000m
Domain: Services		
Supermarket	At least once a month	200m
Outdoor market	At least once a week	200m
Bakery	At least once a week	200m
Butcher	At least once a week	200m
Fruits and vegetables shop	At least once a week	200m
Fish shop	At least once a week	200m
Cheese merchant	At least once a week	200m
Specific food store	At least once a week	200m
Tobacco shop / Press shop	At least once a week	200m
Bank	Most often used	200m
Post office	Most often used	200m
Hair dresser	Most often used	200m
Domain: Transport		
Transportation station used from home	At least once a week	200m
Domain: Recreational activities		
Sports facilities	At least once a week	500m
Place of cultural activity	At least once a week	500m
Place of syndical, political, or religious activity	At least once a week	500m
Domain: Social activities		
Place of social activities (bar, restaurant, cinema…)	At least once a week	500m
Place where participants take relatives	At least once a week	500m
Places where participants visit people	At least once a week	500m

Table 3. Means and standard deviations of environmental exposures in the exposure areas by income and urbanicity degree (n=4383[a])

Variables	SRB		PRN		Full activity space		Truncated activity space	
	M (SD)	JT Test *p value*	M (SD)	JT Test *p value*	M (SD)	JT Test *p value*	M (SD)	JT Test *p value*
DENSITY 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)	
By urbanicity degree								
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)	**0.041***
Outer suburbs	0.084 (0.097)		0.077 (0.129)		0.089 (0.071)		0.078 (0.065)	
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)	
By urbanicity degree								
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)	

[a] n = 4323 when stratifying by household income.

*$p < 0.05$; SRB: street-network residential buffer; PRN: perceived residential neighborhood; M: mean; SD: standard deviation.

Table 4. Differences in environmental exposure between the exposure areas by income and urbanicity degree (n=4383[a])

Variables	PRN – SRB	Truncated activity space – SRB	Truncated activity space – PRN	Full – truncated activity space

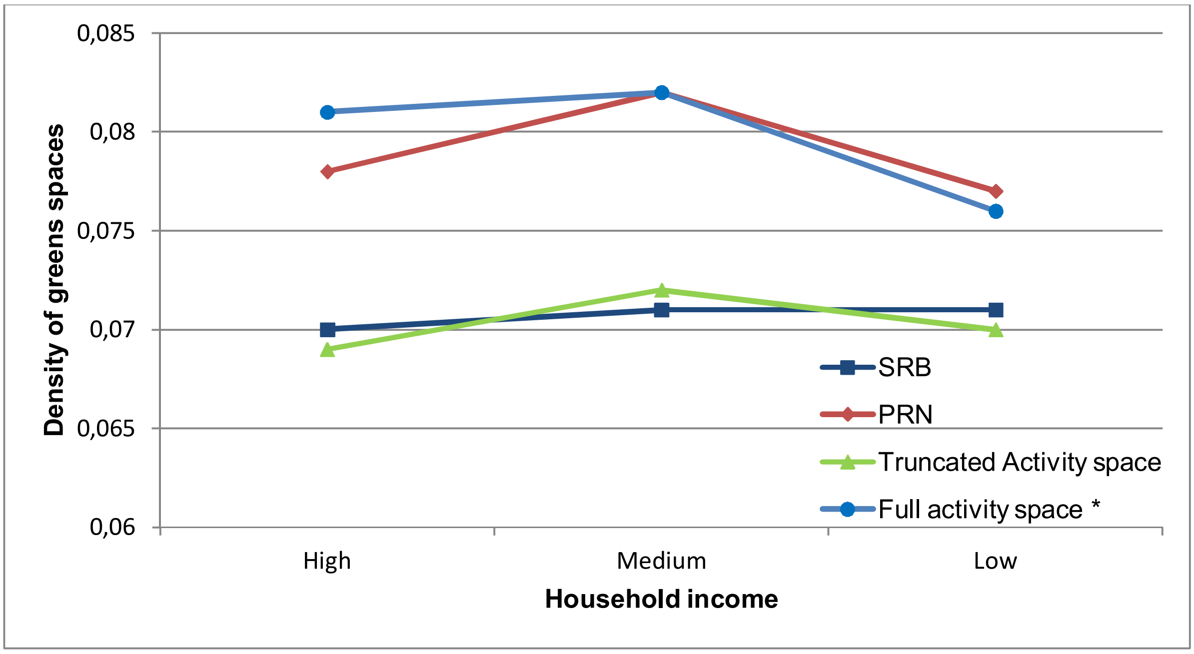
	Diff.	95% CI	Diff.	95% CI	Diff.	95% CI	Diff.	95% CI
DENSITY OF GREEN SPACES								
All	**0.009***	(0.006 ; 0.012)	-0.000	(-0.001 ; 0.001)	**-.009***	(-0.012 ; -0.006)	0.010*	(0.009; 0.011)
By household income[a]								
High	**0.008***	(0.002 ; 0.013)	-0.001	(-0.003 ; 0.002)	**-0.009***	(-0.014 ; -0.003)	**0.012***	(0.010; 0.014)
Medium	**0.011***	(0.006 ; 0.017)	0.001	(-0.001 ; 0.003)	**-0.010***	(-0.015 ; -0.005)	**0.011***	(0.009; 0.012)
Low	**0.007***	(0.002 ; 0.011)	-0.001	(-0.003 ; 0.002)	**-0.007***	(-0.012 ; -0.002)	**0.006***	(0.005; 0.007)
JT test*	0.487		0.187		0.692		**0.027***	
By urbanicity degree								
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								
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 household income[a]								
High	**126.4***	(112.0 ; 140.8)	**78.8***	(62.4; 95.3)	**-47.6***	(-69.5; -25.6)	**41.3***	(33.3 ; 49.3)
Medium	**98.7***	(85.2; 112.3)	**88.2***	(73.9; 102.6)	-10.5	(-30.3 ; 9.2)	**39.6***	(33.2 ; 46.0)
Low	**81.4***	(67.4 ; 95.4)	**76.7***	(63.9; 89.4)	-4.7	(-23.9 ; 14.4)	**39.0***	(32.6 ; 45.4)
JT test*	**<.001***		0.191		**0.003***		0.166	
By urbanicity degree								
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***	

[a] n = 4323 when stratifying by household income.

*$p<0.05$; SRB: street-network residential buffer; PRN: perceived residential neighborhood; CI: confidence interval.

Figure 1. Graphical representation of the SRB, PRN and activity space of two participants of the RECORD Cohort residing respectively in the city center and in the outer suburb

Figure 2. Mean density of green spaces according to household income



*JT test: p<0.05

5.2.9 Supplemental Material

Table S1. Analysis of variance between individual/environmental characteristic and size of the exposure areas in km² (n=4383[a])

	SRB	**PRN**	**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, mean (SD)					

City center	1.921 (0.159)	1.468 (4.022)	3.98 (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					
Density 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.

5.3 ARTICLE 4: ACCOUNTING FOR THE MULTIPLE DAILY ACTIVITY PLACES OF PEOPLE IN THE STUDY OF THE BUILT ENVIRONMENT CORRELATES OF RECREATIONAL WALKING (THE RECORD COHORT STUDY)

Camille Perchoux, Yan Kestens, Ruben Brondeel, Basile Chaix

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Authors names and affiliations: Camille Perchoux, M.Sc [a,b,c,d*]; Yan Kestens, Ph.D [c,d]; Ruben Brondeel, M.Sc [a,b, e], Basile Chaix, Ph.D [a, b]

[a] Sorbonne Universités, UPMC Université Paris 06, UMR_S 1136, Institut Pierre Louis d'Epidémiologie et de Santé Publique, 75012, Paris, France

[b] INSERM, UMR_S 1136, Institut Pierre Louis d'Epidémiologie et de Santé Publique, F-75012, Paris, France

[c] Département de médecine sociale et préventive, Université de Montréal, Montreal (QC), Canada

[d] Centre de Recherche du Centre Hospitalier Universitaire de Montréal (CRCHUM), Montreal (QC), Canada

[e] Ecole des Hautes Etudes en Santé Publique (EHESP), 35043, Rennes, France

***Corresponding author information:** Camille Perchoux

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5.3.1 Abstract

Background: Understanding how built environment characteristics influence recreational walking is of main importance to develop population-level strategies to increase levels of physical activity in a sustainable manner.

Purpose: This study analyses the environmental correlates of recreational walking both within and outside the residential neighborhood.

Methods: Point-based activity places were collected between 2011 and 2013 in the Paris region using the VERITAS software among 4,365 participants of the RECORD Cohort Study. Zero-inflated negative binomial regressions were used to investigate associations between both residential and non-residential environmental exposure and recreational walking. Data were analyzed in 2014.

Results: Density of destinations, presence of a lake or waterway and neighborhood education were associated with an increase in the odds of reporting any recreational walking time. Only density of destinations was associated with an increase in time spent walking for recreational purpose. Accounting for both the recreational space and the residential space improved the model fit and increased the environment-walking associations, compared to a model accounting only for the residential space.

Conclusions: Creating an environment supportive to walking around recreational locations may particularly stimulate recreational walking among people willing to use these facilities. For instance, people may be particularly encouraged to practice recreational walking before or after their activity when going to their tennis court or swimming pool if the surrounding environment allows for it.

Keywords: Walking, recreational activity, built environment, activity space, urban area

5.3.2 Introduction

The health benefits of walking are have been extensively investigated (Hu et al., 2001; Manson et al., 1999; Pate et al., 1995; Sesso et al., 2000b; Thompson et al., 2003) and promoting higher levels of physical activity has become a public health priority (Haskell et al., 2009; Haskell et al., 2007). During the past 15 years, there has been a growing interest in built environment characteristics that are supportive of walking when developing sustainable population-level strategies to increase levels of physical activity (McCormack and Shiell, 2011). Recent literature has emphasized that different types of interventions may be needed to promote walking for recreation and walking for transportation since findings suggest that different environmental characteristics are associated with these two components of walking (Owen et al., 2004; Saelens and Handy, 2008; Sugiyama et al., 2012b).

Environmental characteristics such as land use mix (Bourdeaudhuij et al., 2005; Van Dyck et al., 2013), residential density (Coogan et al., 2009; Van Dyck et al., 2010), neighborhood educational level (Chaix et al., 2014b; Leslie et al., 2010), access to recreational and utilitarian destinations (Chaix et al., 2014b; Charreire et al., 2012; Coogan et al., 2009; De Greef et al., 2011; Van Cauwenberg et al., 2012), access to greenness and public open spaces (Chaix et al., 2014b; Charreire et al., 2012; Giles-Corti et al., 2005; Sugiyama, 2012; Sugiyama et al., 2010), street connectivity (Cleland et al., 2008), walking infrastructures (Ball et al., 2001; Bourdeaudhuij et al., 2005; Lee and Moudon, 2006; Van Dyck et al., 2013), and aesthetics and pleasant environmental features (Ball et al., 2001; Ball et al., 2007; Cleland et al., 2008; Giles-Corti and Donovan, 2002; Inoue et al., 2010b; Lee and Moudon, 2006; Van Dyck et al., 2013) have been positively associated with recreational walking.

This available empirical evidence is mostly derived from studies exclusively focusing on the residential neighborhood. Usual representations of the exposure area to environmental conditions include administrative units or residence-centered circular or street network buffers. These geographical definitions of exposure areas do not account for individual daily mobility and corresponding exposure (Chaix et al., 2009; Cummins, 2007). The concept of activity space has been introduced in health research to emphasize that studies should consider the effects on health of both residential and non-residential environments (Chaix et al., 2012c; Chaix et al., 2013a; Matthews and Yang, 2013b; Perchoux et al., 2013). Findings for various outcomes suggest that activity space exposure may be stronger associated with health than the traditional residential exposure measures (Inagami et al., 2007; Kestens et al., 2012; Lebel et al., 2012; Setton et al., 2011; Shareck et al., 2014b). Studies accounting for daily mobility are becoming more common but remain scarce. One Australian study compared the associations between built environment characteristics and recreational walking when using both GPS locations and standard buffers to capture environmental characteristics and observed differences in associations depending on the spatial definition of the exposure area (Boruff et al., 2012). Several mobility and health studies have used GPS data to examine the spatial distribution of physical activity and the type of environments in which physical activity episodes occur (Cooper et al., 2010; Evenson et al., 2013; Maddison et al., 2010; Quigg et al., 2010; Rodríguez et al., 2012; Troped et al., 2010; Wheeler et al., 2010). To our knowledge however, no study has investigated the associations of multiple environmental exposures within and outside the residential neighborhood with recreational walking.

The aims of the present study were i) to investigate associations between both residential and non-residential environmental exposure and recreational walking; and ii) to examine the effect of environmental conditions around each type of activity places visited (workplace, services, recreational destinations, and social destinations) on recreational walking.

5.3.3 Material and methods

Study population

The present study relied on data from the second wave of the RECORD Cohort Study (Chaix et al., 2011d). Overall, 5,542 participants were surveyed between February 2011 and October 2013. The participants were recruited without *a priori* sampling (convenience sample) during preventive checkups conducted by the Centre d'Investigations Préventives et Cliniques (IPC) in 4 of its health centers located in the Paris metropolitan area (Chaix et al., 2010a; Chaix et al., 2011c; Karusisi et al., 2012; Karusisi et al., 2014; Karusisi et al., 2013; Leal et al., 2011; Lewin et al., 2014). 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. In addition to the inclusion criteria of the RECORD Study (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 study protocol was approved by the French Data Protection Authority. All the participants signed an informed consent to enter the study.

Assessment of participants' activity space

Self-reported activity locations were geocoded using the VERITAS software (Chaix et al., 2012c). The electronic questionnaire records the geographic location of the place of residence and of a series of other possible destinations regularly visited by the participants. Reported destinations included: alternative or secondary 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. No particular recall period, such as "over the past 6 months," was specified. These self-reported destinations were geocoded if they were visited at least once a week, or at least once a month for supermarkets, or regardless of the frequency of visit for the banks, post offices, and hairdressers.

The associations between exposures at multiple places and recreational walking may be susceptible to the selective daily mobility bias (Chaix et al., 2012c; Chaix et al., 2013b). This bias stems from people selecting their daily activity places according to their socio-demographic, psychological/cognitive, or behavioral characteristics which also influences their health behavior. Considering the exposure at the activity locations specifically visited to practice recreational walking when calculating environmental exposures could lead to bias. Consequently, all the activity locations that were regularly visited to perform recreational walking were removed to determine the exposure areas of interest. We screened all the activity place names of the recreational activities reported in VERITAS and excluded all activity location referring to "promenade", "walking", "walking with a dog", "brisk walking", "Nordic walking", and "hiking".

The buffers around activity locations were of different sizes depending on the type of activity. Larger buffer sizes were applied to activity places where individuals are likely to spend more time and have more opportunity to explore the surroundings (Chaix et al., 2012c). Street network buffers of 1000m were used around the residence and the workplace, 200m around the services, and 500m around both recreational and social activities.

Overall, six exposure areas were used: i) the residence space, ii) the residence-work space - or the combination of the residence and the work space -, the residence-service space, the residence-recreational space, the residence-social space (**Figure 1**), iii) a comprehensive exposure area encompassing all buffers around all reported activity locations, i.e. the total activity space. When combining areas, the potential overlap was suppressed.

Measures

Recreational walking

Participants were asked to report retrospectively the number of hours and minutes they had walked over the previous seven days for leisure or exercise (alone or not, with their pet or not). Participants further reported recreational walking time done within or outside their self-defined residential neighborhood. The present study considers the overall time of recreational walking, created by summing up the time reported inside and outside the residential neighborhood.

Individual variables

The following socio-demographic characteristics were considered for adjustment: age, sex, individual education (4 categories: no education and primary education, lower secondary education, higher secondary education and lower tertiary education, and upper tertiary education), employment status (4 categories: stable job, precarious job, unemployed, and retired), household income per consumption unit (tertiles: 1,222 and 2,125 Euros/month), marital status (living alone or in a couple), and living with at least one child under the age of fourteen.

Contextual variables

Five contextual variables were determined. The density or proportion of area covered by green spaces derived from a 2008 geographic layer of the Institute of Urban Planning of the Ile-de-France Region (IAU-IDF); the density of destinations (number per km^2) calculated using the 2011 Permanent Database of Facilities of the National Institute of Statistics and Economic Studies (INSEE) including information on administrations, public/private shops, health services, and entertainment facilities;

the density of street intersections (number per km^2) using the 2014 street network data from the National Geographic Institute; presence of a lake or a waterways determined from the 2003 IAU-IDF land use database; neighborhood educational level was defined as the proportion of residents with university education as obtained from the 2010 population census geocoded at the residential address by INSEE.

These environmental factors were computed within each of the six exposure areas described above. All contextual variables were computed with Python scripts and ArcInfo 10.

Statistical analyses

To investigate the associations between the individual and environmental variables and recreational walking, we estimated zero-inflated negative binomial models (ZINB) (De Smet et al., 2011; Vettenburg et al., 2013) using SAS 9.3. Recreational walking time can be considered as an over-dispersed count variable due to an excess of zeros (people who do not walk for recreation). Regular Poisson or negative binomial regression models are unable to handle correctly this kind of distributions. The ZINB regression consists of two parts: a zero-inflated part that models the probability of not reporting any recreational walking, with coefficients interpreted as odd ratios, and a count part that models recreational walking time among walkers, with coefficients interpreted as rate ratios.

The model building strategy involved seven steps. Model A included all individual socio-demographic variables. Model B to G included also the environmental characteristics for the following exposure areas: residence space (B), residence-work space (C), residence-service space (D), residence-recreational space (E), residence-social space (F), and total activity space (G). We report the Akaike Information Criterion (AIC) for each model (**Tables 2 and 3**).

5.3.4 Results

Description of the study sample

From the initial available sample of 5487 participants living in the Ile de France region, we excluded 996 participants who regularly traveled outside the study area, 108 participants who regularly visited their secondary home, 3 participants with missing socio-demographic data and 15 participants with missing neighborhood education level data. The final study sample included 4365 adults. Descriptive information is provided in Table 1.

Overall, the median time of recreational walking over the previous 7 days was 180 minutes (interquartile range = 60; 360). Some 686 participants declared no recreational walking at all (16%). The participants reported a median number of 13 distinct activity locations (interquartile range = 10; 16) and a median number of 19 visits per week to these activity locations (interquartile range = 13; 25). Summary statistics regarding the sizes of participants' activity spaces are provided in Table 2.

Associations between socio-demographic variables and recreational walking

Associations between individual/environmental factors and walking are reported in Table 3 for the zero-inflation part and in Table 4 for the count part. Regarding the zero-inflation part, higher odds of not reporting any recreational walking were observed among participants with a low or middle low educational status. However, this relation disappeared when accounting for environmental characteristics. Being retired decreased the odds of not reporting any recreational walking time by 43%, compared to participants with a stable employment status.

Among recreational walkers - the count part -, being a male, having a low or middle low individual education, having a precarious employment status, being unemployed, or being retired were associated with an increase in recreational walking time, while living with at least one child under the age of fourteen was associated with a 11% decrease in recreational walking time. These associations were stable when accounting for residential and/or non-residential environmental variables.

Associations between residential neighborhood variables and recreational walking

After controlling for individual characteristics, the likelihood of not reporting any recreational walking time was lower for participants living in neighborhoods with a lake or a waterway [OR = 0.84; 95% confidence interval (CI): 0.71-0.99], with medium (OR = 0.81; 95% CI: 0.66 – 0.99) or high (OR = 0.62; 95% CI: 0.49 – 0.79) density of destinations as opposed to low, and with a high educational level (OR = 0.72; 95% CI: 0.56 – 0.93).

In the count part of the model, only the density of destinations was associated with recreational walking time. Compared to low density neighborhoods, the time of walking increased by 14% in medium, and by 22% in high density neighborhoods.

Associations between activity space environmental variables and recreational walking

Models C to F are interested in the effect of adding to the residential space, separately the work space (C), the service space (D), the recreational space (E) and the social space (F), and of adding all of these activity locations (G) in the definition of environmental exposures.

The AIC was higher - thus the fit of the model poorer - in the models considering the work space, the service space, and the social space in addition to the residential environment in the definition of the exposures. The fit of the model was clearly better in the model considering the recreational space in addition to the residential space and that the fit was slightly better in the model considering the full activity space.

These conclusions were confirmed. In the zero-inflation part of the model, the association with the presence of a lake or waterway disappeared in all models, except in the model accounting for the residence-recreational space. The association between the density of destinations and the odds of not reporting any recreational walking was stronger in the residence-recreational space than in the model with residential variables only (and to a lesser extent in the model considering the full activity space).

In the count part of the model, the recreational walking time remained associated with the density of destinations when considering the non-residential spaces. The association was only slightly stronger in the model for the residence-recreational space.

5.3.5 Discussion

Overall, a high density of destinations, the presence of a lake or waterway, and a high neighborhood education were associated with higher odds of recreational walking, while a high density of destinations was also associated with a higher recreational walking time. Accounting for exposure to environmental factors in recreational activity locations improved the prediction of the odds to undertake recreational walking and of the walking time. Accounting for other activity locations (workplace, services, social activity locations) did not contribute.

When accounting for the residential neighborhood only, the presence of a lake or a waterway was associated with reporting any recreational walking, while no association was found with time of recreational walking. This is in line with a study in Australia that showed a positive association between access to the beach and the likelihood of walking for recreation (Giles-Corti and Donovan, 2002). Similarly, the association between neighborhood education and recreational walking is consistent with previous research (Ball et al., 2001; Chaix et al., 2014b; Leslie et al., 2010). The observed positive association between the density of destinations and both reporting and total time spend in recreational walking confirms our hypothesis and is in line with previous studies (Cleland et al., 2008; Coogan et al., 2009; Karusisi et al., 2014; McCormack et al., 2008; Sugiyama et al., 2012b).

No effect of accessibility to green spaces was observed, but findings on this topic are mixed. Some have reported positive associations (Giles-Corti et al., 2005; Sugiyama, 2012; Sugiyama et al., 2010), including a previous study based on the first wave of the RECORD Cohort Study (Chaix et al., 2014b), while others have reported null findings (Giles-Corti and Donovan, 2002; Zlot and Schmid, 2005). A recent review on the subject report 44% of studies findings significant associations between green spaces and recreational walking (Sugiyama et al., 2012b). Interestingly, a longitudinal study found green spaces to be associated with the maintenance of recreational walking but not with its initiation (Sugiyama et al., 2013).

When accounting for both residential and non-residential environments, the odds of walking were no longer associated with the presence of a lake or a waterway, while the other associations were fairly stable. The odds of reporting no recreational walking remained associated with the density of destinations and with neighborhood education while the recreational walking time remained associated with the density of destinations.

The aim of this study was to analyze the contribution of environmental factors in different portions of the activity space on recreational walking. Based on the strengths of associations and on the indicator of model fit, taking into account the geographic space around the regular recreational activity locations improved the prediction of practicing of and of time spent walking for recreation. Yet, accounting for other types of activity locations did not improve the model performances, including when considering the geographic work environment, where workers spend a significant part of their time. This may be due to the fact that people have little time to practice recreational walking around their work schedule. Similarly, considering the geographic environment around participants' supermarkets may be less important when investigating recreational walking because people typically carry heavy bags.

The significant role of environmental factors around recreational activity locations however suggest that improving walkability around such settings may be effective to increase recreational walking among people using such facilities. For example, people may walk for recreation before or after their activity when going to the tennis court or swimming pool if the surrounding environment is favorable. Another interpretation however, may be that this drop in AIC and slight increase in the strength of associations was attributable, not to a causal effect of these recreational environments, but to the fact that, despite the exclusion of locations visited for recreational walking, some of these recreational locations were specifically visited to practice recreational walking (residual selective daily mobility bias). According to this hypothesis, the observed increase in the associations would be attributable to the fact that with these locations we identify people with specific interest and preferences for recreational activities including recreational walking. The increase in effect size and fit would then be due to a causal effect of preferences and values rather than to a strict causal effect of environmental conditions (Chaix et al., 2012c; Chaix et al., 2013b).

Under the assumption of a causal effect however, our results also suggest that when accounting for daily mobility in health studies, all types of visited activity locations do not equally contribute to the understanding of neighborhood effects on health. Considering some of these activity locations may add noise to the environmental measures of interest, with the type of activity locations adding noise depending on the outcome (e.g., the workplace when investigating recreational walking).

Strengths and limitations

The main limitation of the study is its cross-sectional design. It prevents taking into consideration of residential neighborhood self-selection. Individuals select their neighborhood of residence based on economic, social and environmental preferences but also according to their behavioral preferences, including their interest for recreational walking. A recent systematic review emphasized that studies show an attenuation of the association between built environment characteristics and physical activity when accounting for neighborhood self-selection (McCormack and Shiell, 2011), calling for more experimental or quasi-experimental designs to isolate the effect of the built environment on walking behavior.

A strength of our study is the large sample size with precise geocoding of the activity places. For each activity place, the nature of the activity performed was known. Based on this information, this study is one of the first to address the selective daily mobility bias by excluding activity locations that were specifically visited to practice recreational walking. Ignoring this generally leads to an over-estimation of the associations between environmental characteristics and health behaviors (Chaix et al., 2012c; Chaix et al., 2013b). Another strength is the operationalization of our activity space exposure measures to assess the specific contribution of each portion of the activity space.

5.3.6 Conclusion

Exploring the potential contributions of different portions of the regular activity space to environmental influences on walking supports the idea that it is useful to take into account non-residential environments when investigating contextual determinants of recreational walking. Taking into account the environment around recreational activity locations contributed to a better understanding of environmental effects on recreational walking.

5.3.7 References

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5.3.8 Tables and figures

Table 1. Descriptive information on the sample used in the study based on the RECORD Cohort, Paris Metropolitan Area, 2011–2013.

Variable	Category	% or mean
Sex (%)	Female	33
Age (mean, years)	-	53
Citizenship (%)	French	87
Living in a couple (%)		66
Living with a child under the age of fourteen		30
Individual education (%)		
	High	25
	Middle-High	17
	Middle-Low	29
	Low	30
Household income per consumption unit (%)		
	High (>2125 € per month)	33
	Medium (1222–2125 € per month)	34
	Low (<1222 € per months)	33
Employment status (%)		
	Stable	57
	Unstable	7
	Unemployed	10
	Retired	21
Location in the region (%)		
	City center	26
	Inner suburbs	46
	Outer suburbs	27

Table 2. Size (SD) of the exposure areas sequentially incorporating additional activity locations.

Models	Mean area (km^2)	SD	% of area added compared to the residential neighborhood
Model B[1]	2.0	0.6	-
Model C[2]	3.0	1.1	33.3
Model D[3]	2.2	0.6	9.1
Model E[4]	2.4	0.8	16.7
Model F[5]	2.5	0.8	20.0
Model G[5]	3.8	1.3	47.4

[1] Environmental measures based on the residential neighborhood

[2] Environmental measures based on the residential neighborhood and the work space

[3] Environmental measures based on the residential neighborhood and the service space

[4] Environmental measures based on the residential neighborhood and the recreational space

[5] Environmental measures based on the residential neighborhood and the social space

[6] Environmental measures based on the full activity space

Table 3. Association between individual and environmental characteristics and not reporting any recreational walking (zero inflation part), the RECORD Study, 2011-2013.

	Model A[1]		**Model B[2]**		**Model C[3]**		**Model D[4]**		**Model E[5]**		**Model F[6]**		**Model G[7]**	
	OR	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**
Socio-demographic variables														
Age *(in years)*	1.01	(1.00-1.02)	1.01	(1.00-1.02)	1.01	(1.00-1.03)	1.01	(1.00-1.02)	1.01	(1.00-1.02)	1.01	(1.00-1.02)	1.01	(1.00-1.02)
Male *(vs. female)*	0.90	(0.76-1.07)	0.88	(0.74-1.05)	0.88	(0.74-1.05)	0.88	(0.74-1.05)	0.88	(0.74-1.05)	0.89	(0.74-1.06)	0.87	(0.73-1.04)
Individual education *(vs. high)*														
Middle high	1.26	(0.96-1.65)	1.21	(0.92-1.59)	1.21	(0.92-1.59)	1.24	(0.95-1.63)	1.22	(0.93-1.60)	1.22	(0.93-1.60)	1.23	(0.94-1.62)
Middle low	1.30	(1.03-1.64)	1.16	(0.91-1.48)	1.16	(0.91-1.48)	1.21	(0.95-1.54)	1.14	(0.90-1.46)	1.17	(0.92-1.50)	1.17	(0.92-1.49)
Low	1.36	(1.07-1.72)	1.13	(0.89-1.45)	1.13	(0.88-1.45)	1.21	(0.95-1.54)	1.09	(0.85-1.40)	1.15	(0.90-1.48)	1.13	(0.89-1.45)
Employment status *(vs. permanent)*														
Precarious	0.94	(0.69-1.29)	1.00	(0.73-1.37)	0.99	(0.72-1.36)	0.93	(0.68-1.28)	1.03	(0.75-1.42)	0.99	(0.72-1.36)	0.97	(0.70-1.33)
Unemployed	0.80	(0.60-1.08)	0.79	(0.59-1.06)	0.78	(0.58-1.05)	0.73	(0.54-0.98)	0.78	(0.58-1.06)	0.78	(0.58-1.06)	0.73	(0.54-0.99)
Retired	0.57	(0.42-0.77)	0.56	(0.41-0.77)	0.56	(0.41-0.76)	0.52	(0.38-0.71)	0.58	(0.43-0.79)	0.56	(0.41-0.77)	0.53	(0.39-0.73)
Environmental characteristics														
Presence of lake or waterway		-	0.84	(0.71-0.99)	0.91	(0.76-1.09)	0.88	(0.75-1.04)	0.83	(0.70-0.98)	0.90	(0.76-1.07)	0.96	(0.78-1.18)
Density of destinations *(vs. low)*														
Medium		-	0.81	(0.66-0.99)	0.76	(0.62-0.94)	0.87	(0.71-1.06)	0.81	(0.67-0.99)	0.83	(0.67-1.01)	0.92	(0.66-1.00)
High		-	0.62	(0.49-0.79)	0.63	(0.49-0.82)	0.64	(0.50-0.81)	0.55	(0.43-0.71)	0.62	(0.48-0.79)	0.60	(0.47-0.78)
Neighborhood education *(vs. low)*														
Medium		-	0.87	(0.71-1.08)	0.85	(0.68-1.06)	0.85	(0.69-1.05)	0.87	(0.70-1.07)	0.92	(0.74-1.15)	0.74	(0.59-0.92)
High		-	0.72	(0.56-0.93)	0.79	(0.61-1.02)	0.69	(0.54-0.88)	0.73	(0.57-0.94)	0.79	(0.61-1.06)	0.74	(0.57-0.96)
AIC	52882.04		52815.42		52830.98		52823.09		52797.41		52834.79		52810.01	

*No associations were found with income, marital status, living with a child under the age of fourteen, the density of green spaces, and the density of intersections.

[1] Model A included all individual socio-demographic variables associated with the outcome

[2] Model B included all individual socio-demographic variables and the residential environmental variables associated with the outcome

[3] Model C included all individual socio-demographic variables and environmental exposures in the residential space and work space

[4] Model D included all individual socio-demographic variables and environmental exposures in the residential space and services and grocery space

[5] Model E included all individual socio-demographic variables and environmental exposures in the residential space and recreational space

[6] Model F included all individual socio-demographic variables and environmental exposures in the residential space and social space
[7] Model G included all individual socio-demographic variables and environmental exposures in the total activity space

Table 4. Association between individual and environmental characteristics and the recreational walking time among walkers (count part), the RECORD Study, 2011-2013.

	Model A[1]		Model B[2]		Model C[3]		Model D[4]		Model E[5]		Model F[6]		Model G[7]	
	RR	**95% CI**	**RR**	**95% CI**	**RR**	**95% CI**	**RR**	**95% CI**	**RR**	**95% CI**	**RR**	**95% CI**	**RR**	**95% CI**
Socio-demographic variables														
Age *(in years)*	1.00	(0.99-1.00)	1.00	(0.99-1.00)	1.00	(0.99-1.00)	1.00	(0.99-1.00)	1.00	(0.99-1.00)	1.00	(0.99-1.00)	1.00	(0.99-1.00)
Male *(vs. female)*	1.09	(1.03-1.16)	1.10	(1.04-1.17)	1.10	(1.04-1.17)	1.10	(1.04-1.17)	1.10	(1.04-1.17)	1.10	(1.03-1.17)	1.10	(1.04-1.17)
Individual education *(vs. high)*														
Middle high	1.09	(1.00-1.19)	1.09	(1.00-1.19)	1.10	(1.01-1.20)	1.10	(1.01-1.20)	1.10	(1.00-1.20)	1.10	(1.01-1.20)	1.10	(1.01-1.20)
Middle low	1.11	(1.03-1.20)	1.12	(1.04-1.21)	1.13	(1.04-1.21)	1.13	(1.05-1.22)	1.13	(1.05-1.22)	1.13	(1.04-1.22)	1.13	(1.05-1.22)
Low	1.19	(1.11-1.29)	1.22	(1.13-1.32)	1.23	(1.14-1.32)	1.23	(1.14-1.32)	1.24	(1.15-1.33)	1.23	(1.14-1.33)	1.24	(1.15-1.34)
Employment status *(vs. permanent)*														
Precarious	1.26	(1.13-1.40)	1.22	(1.10-1.36)	1.25	(1.12-1.39)	1.22	(1.10-1.36)	1.21	(1.09-1.35)	1.23	(1.10-1.37)	1.23	(1.10-1.37)
Unemployed	1.61	(1.46-1.77)	1.60	(1.46-1.76)	1.65	(1.50-1.82)	1.61	(1.47-1.77)	1.61	(1.46-1.77)	1.61	(1.49-1.77)	1.63	(1.48-1.79)
Retired	1.45	(1.31-1.60)	1.44	(1.30-1.8)	1.47	(1.34-1.62)	1.44	(1.31-1.59)	1.43	(1.29-1.57)	1.44	(1.30-1.58)	1.46	(1.32-1.61)
Living with a child under the age of 14 years	0.89	(0.83-0.95)	0.90	(0.84-0.96)	0.90	(0.84-0.96)	0.90	(0.84-0.96)	0.91	(0.85-0.97)	0.91	(0.85-0.97)	0.91	(0.85-0.97)
Environmental characteristics														
Density of destinations *(vs. low)*														
Medium		-	1.14	(1.07-1.22)	1.14	(1.07-1.22)	1.05	(0.98-1.13)	1.13	(1.05-1.21)	1.07	(1.00-1.15)	1.07	(1.00-1.14)
High		-	1.22	(1.14-1.31)	1.20	(1.12-1.28)	1.19	(1.11-1.28)	1.25	(1.16-1.33)	1.19	(1.11-1.27)	1.23	(1.15-1.31)
Dispersion	0.71	(0.68-0.74)	0.71	(0.68-0.74)	0.71	(0.68-0.74)	0.71	(0.68-0.74)	0.71	(0.68-0.74)	0.71	(0.68-0.74)	0.69	(0.66-0.72)
AIC	52882.04		52815.42		52830.98		52823.09		52797.41		52834.79		52810.01	

*No associations were found with income, marital status, presence of lake or waterway, neighborhood education, the density of green spaces, and the density of intersections.

[1] Model A included all individual socio-demographic variables associated with the outcome

[2] Model B included all individual socio-demographic variables and the residential environmental variables associated with the outcome

[3] Model C included all individual socio-demographic variables and environmental exposures in the residential space and work space

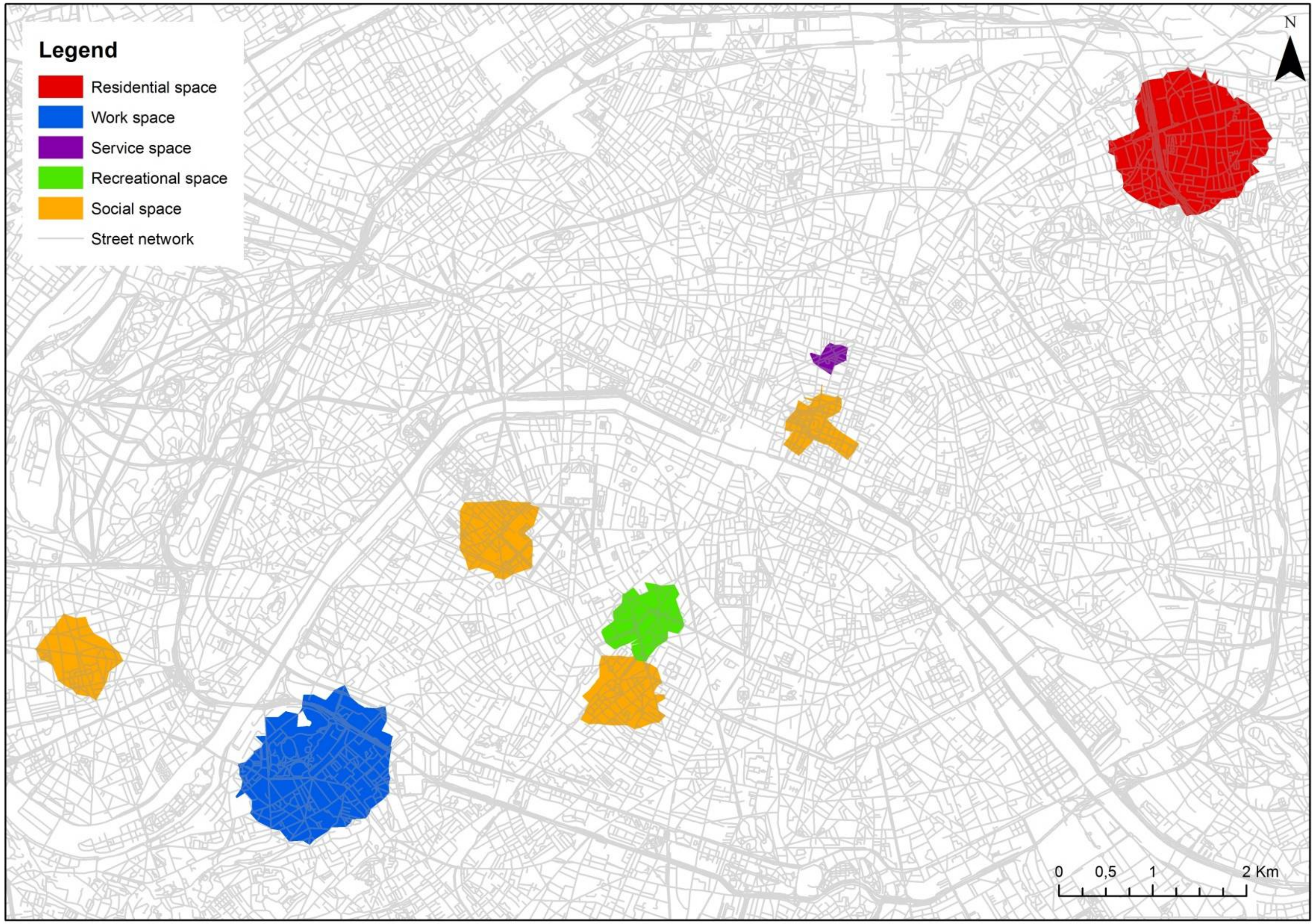
[4] Model D included all individual socio-demographic variables and environmental exposures in the residential space and services and grocery space

[5] Model E included all individual socio-demographic variables and environmental exposures in the residential space and recreational space

[6] Model F included all individual socio-demographic variables and environmental exposures in the residential space and social space

[7] Model G included all individual socio-demographic variables and environmental exposures in the total activity space

Figure 1. Representation of the different portions of an individual's activity space



CHAPTER 6. DISCUSSION AND CONCLUSION

The overarching aim of this thesis was to examine whether accounting for multiple activity places and corresponding exposures is helpful for understanding environmental effects on health behaviors. In the following paragraphs, an overview of the main findings, their significance and potential contributions will be presented, followed by a discussion of the limitation and strengths of the thesis and the directions for future research.

6.1 SUMMARY OF RESULTS

This thesis comprised three empirical studies that allowed to progress from the characterization of mobility (first study), to the assessment of environmental exposures related to this mobility (second study), to the examination of the effects of these exposures on behavior (third study). The first empirical study examined participants' patterns of spatial behavior by developing a set of novel mobility indicators based on regular activity locations. Five structural dimensions of spatial behavior were identified: i) the size of the activity space, ii) the elongation of the activity space, iii) the centering of the activity space on the residential neighborhood, iv) the volume of activities, and v) the specialization of the activity space toward local food stores and services or toward recreational and social activity places. Socio-demographic differences and spatial variations (city center vs. suburbs) in mobility patterns were observed. For instance, individuals with a low socio-economic status had a smaller and more compact activity space, more centered on their residential neighborhood. They were also more likely to be engaged in fewer activities, and their activity spaces were more specialized towards food and services than towards social or recreational activities. Individuals living in the suburbs (inner and outer) were more likely to have a larger activity space, and to be engaged in fewer activities especially outside their residential neighborhood.

Following this description of mobility patterns, the next aim was to account for mobility in the definition of environmental exposures. The second empirical study examined the differences in two environmental characteristics supportive for walking (i.e., density of destination and density of green spaces) using three different exposure areas: a home-centered network-buffer, the perceived residential neighborhood, and the activity space encompassing all activity locations. Socioeconomic and spatial disparities in the difference of exposures according to these spatial definitions were explored. The findings support the concept that the anisotropic perceived residential neighborhood includes to a greater extent areas that have natural and pleasant features and a high density of destinations than a purely isotropic buffer would do. Exposure differences between the home-centered buffer and the perceived neighborhood show significant positive trends from low-to-high income groups and from outer suburb to city center residents. Activity space based estimates were different from those based only on the residential neighborhood. Participants living in the city center had a higher density of destinations in their residential neighborhood whereas participants living in the suburbs had a higher density of destinations around their non-residential activity locations. Finally, in an attempt to address the selective daily mobility bias, two definitions of the activity space were compared: a full vs. a truncated activity space. In the truncated activity space, only non-voluntary exposures were retained; activity places visited with the explicit purpose of accessing to parks or to destinations were excluded. Results suggested that individuals of different socioeconomic levels had a similar level of access to green spaces but that high-income participants were more likely to visit parks regularly than low-income participants. Thus the failure to correct the measure of exposure to parks would likely generate confounding in the association between this exposure and, for example, walking or exercising.

The third empirical study examined the association between residential and non-residential environmental exposures and recreational walking. The potential contribution of different portions of the regular activity space (based on the type of activity places) on walking was explored. A medium to high density of destinations, a high neighborhood education level and the presence of a lake or a waterway were all positively associated with recreational walking. Accounting for the recreational activity places in addition to the residential neighborhood allowed for a better identification of the environmental influence on recreational walking.

6.2 CONNECTIONS WITH THE CURRENT LITERATURE

Since the limitations inherent to the 'local trap'(Cummins, 2007) and the 'residential trap' (Chaix et al., 2009) were first pointed out (several years ago), place and health research has evolved rapidly, especially over the past five years, with a growing interest in examining daily mobility and multi-place exposure (Crawford et al., 2014; Shareck, 2014; Shareck et al., 2014a; Vallée et al., 2014). This section draws a parallel between the findings presented above and the literature mainly published during this thesis. This research is timely, as obvious from the increasing number of papers accounting for daily mobility in the past few years. More broadly, this thesis is part of a novel avenue of research experimenting innovative strategies to account for mobility in environmental health research.

In summary, the results of this thesis support the importance of defining the relevant geographic context to avoid potential exposure misclassification (Chaix et al., 2012b; Chaix et al., 2009; Cummins et al., 2007), also referred to as 'spatial misclassification' (Duncan et al., 2014; Vallée and Shareck, 2014) or 'uncertain geographic context problem'(Kwan, 2012a, b). In line with results from Article 3, evidence on how to best operationalize and measure exposure areas relating to i) the residential neighborhood (Clark and Scott, 2014; Duncan et al., 2014; James et al., 2014; Robinson and Oreskovic, 2013; Vallée et al., 2014), ii) the active behavior neighborhood (Boruff et al., 2012; Madsen et al., 2014; Robinson and Oreskovic, 2013; Villanueva et al., 2012), is currently emerging. Few studies have performed comparisons between these different definitions of the exposure area (Boruff et al., 2012; Crawford et al., 2014; Villanueva et al., 2012). For instance, similar research conducted by Hurvitz et al. (2012), examining a small sample of participants with GPS receivers (N= 41) in the Seattle area, quantified differences in exposure between the residential and non-residential neighborhoods (Hurvitz and Moudon, 2012). Their results revealed that more than 90% of the built environment measures differed between residential (<833 m of home) and non-residential (>1666m) locations (Hurvitz and Moudon, 2012). Similar differences were also found in other studies (Basta et al., 2010; Crawford et al., 2014; Inagami et al., 2007; Kestens et al., 2010; Shareck et al., 2014b; Zenk et al., 2011). Since in Article 3, measurement differences depending on the exposure area further varied with socioeconomic status and degree of urbanicity, a major development of this thesis concerns exposure misclassification of residential environmental exposure measures. Similarly, Shareck et al. (2014) reported the difference in exposure to area-level deprivation within and outside the residential neighborhood varied by educational levels (Shareck et al., 2014b).

The results of this thesis showed that there are socio-spatial inequalities in mobility patterns and access to resources, findings that have recently been supported elsewhere (Casas, 2007; Páez et al., 2010; Shareck et al., 2014b; Vallée and Chauvin, 2012). Furthermore, specific patterns of mobility, such as explored in Article 2, have been linked to certain high-risk behaviors. Based on declarative information on whether daily activities were mainly performed within or outside the residential neighborhood, Vallée et al. (2012) showed that women with low mobility patterns centered on the perceived residential neighborhood had a higher incidence of delayed cervical screening (Vallée and Chauvin, 2012). In another study, a high volume of activity/trips was associated with a decreased risk of social exclusion (Stanley et al., 2011).

Lastly, exploring environmental correlates of recreational walking in both residential and nonresidential environments can be related to current physical activity studies relying on GPS, GIS and accelerometry. However, such studies do not distinguish between transportation and recreational walking, with the exception of few studies (Boruff et al., 2012; Suminski et al., 2014), making the comparison with the findings of this thesis difficult. Nonetheless, several GPS studies have shown that the majority of adults' moderate-to-vigorous physical activity (MVPA) and walking takes place outside the residential neighborhood (Rodríguez et al., 2005; Troped et al., 2010). Hurvitz et al. (2014) observed more balanced patterns with an approximately equal time of physical activity done within or outside the residential neighborhood (Hurvitz et al., In press). Closely related to our study is Troped et al.'s (2010) assessment of place-based physical-activity around the home and work activity places (Troped et al., 2010). After controlling for individual characteristics, the authors found an association between intersection density, land use mix, residential population density and residential housing unit density and location-based MVPA within 1-km home buffers; yet only the residential population density and the residential housing density were associated with location-based MVPA within 1-km work buffers (Troped et al., 2010). In a similar vein, this thesis provides evidence for the influence of the characteristics of both the residential neighborhood and the recreational space on recreational walking. Altogether, such findings represent a step toward better understanding the mechanisms through which environmental characteristics around specific activity locations are influential in constraining or promoting recreational walking.

6.3 CONTRIBUTIONS

6.3.1 Definition and operationalization of the activity space

Should exposure measures distinguish or combine the residential and the non-residential space?

Studies assessing multi-place exposure have varied in their consideration of residential and non-residential environmental exposure. They have taken into account the residential and non-residential information either separately (Chum, 2013; Hurvitz and Moudon, 2012; Hurvitz et al., In press; Inagami et al., 2007; Kestens et al., 2012; Shareck et al., 2014b; Zenk et al., 2011), or jointly - by using one single index combining all the information (Almanza et al., 2012; Crawford et al., 2014; Kestens et al., 2012; Setton et al., 2011). In this dissertation, I examined the effect of residential and non-residential activity locations by merging these two sub-areas into one. This methodological choice was driven by the important overlap between residential and non-residential buffers. As mentioned in Article 1, individuals are likely to cluster their activity locations around major activity places (i.e. daily life centers) like the place of residence (Flamm and Kaufmann, 2006). Therefore, drawing a boundary between the residential and non-residential spaces would have been somewhat arbitrary. Also, in their activity space study, Zenk et al. (2011) recognized that disregarding the overlap between residential and non-residential buffers could have introduced redundancy and thereby affected the significance of their results (Zenk et al., 2011). I therefore chose to consider the activity space as a continuum, considering that separating the residential from the non-residential space might be artificial. However, this conceptual and analytical issue remains insufficiently explored.

Defining the size and the shape of the exposure areas

Looking at previous studies, the activity space has been defined in many different ways: using a combination of census tracts (Inagami et al., 2007), street network buffers (Shareck et al., 2014b), a convex hull (Buliung and Kanaroglou, 2006; Buliung et al., 2008; Sherman et al., 2005; Villanueva et al., 2012), a standard deviational ellipse (Arcury et al., 2005; Crawford et al., 2014; Rai et al., 2007; Schönfelder and Axhausen, 2003; Sherman et al., 2005; Zenk et al., 2011), the daily path area (Almanza et al., 2012; Basta et al., 2010; Boruff et al., 2012; Rodríguez et al., 2012; Sherman et al., 2005; Zenk et al., 2011) or kernel density estimations (Kestens et al., 2012; Lebel et al., 2011). In Articles 3 and 4 of this dissertation, activity spaces were computed using street network buffers around regular activity locations. Such buffers allow for physical barriers (i.e., waterway, railway) and enclaves that are not connected to the rest of the street network to be taken into account (Chaix et al., 2009). As individuals walk along the road and are influenced by its immediate landscape (Oliver et al., 2007), street network buffers are potentially more appropriate to represent spatial behavior than census tracts, circular buffers, or convex hulls (Frank et al., 2005; James et al., 2014; Sherman et al., 2005). In addition to the large database of regular activity locations for numerous participants, what was especially new in this thesis was the use of buffers of different sizes (i.e., 1000m, 500m, and 200m) according to the type of the activity performed. Conceptual grounds from time geography (i.e. time budget), environmental psychology (i.e. notions of place attachment and perceptual regions) and transportation research (i.e. minor and major activity places) discussed in Article 1 were considered in the definition of this hierarchy of activity places. In general, the greater amount of time an individual spends in a specific location, the more accurate his/her perception of the surrounding opportunities will be, and the more likely he/she will be to experience or use them. Therefore, different buffer sizes were selected for the different types of activities practiced at the locations (known from the VERITAS survey) as an attempt to estimate differences in exposure potential around the various types of activity locations. This provides an easily replicable alternative to the more complex and data-demanding time-weighted exposure measurements that account for the length of time that is spent at an activity location.

Exploring specific portions of the activity space

One objective of Article 4 was to explore the specific contribution of portions of the activity space - based on the type of activity locations - on recreational walking. We found one existing study analyzing specific portions of the activity space (Troped et al., 2010). Examining location-based physical activity, they distinguished the influence of the residence and the work environments while excluding other activity locations (Troped et al., 2010). Along that line, several methods were tested in this thesis (data not shown). A first attempt to examine the contribution of specific portions of the activity space was to successively add to the residential space 1) the work space, 2) then service space, 3) then the recreational space, and finally 4) the social space. However, as presented in Article 4, there was no specific contribution of the work space and the service space on recreational walking. Keeping the work and the service space in each exposure measure precluded to observe the specific contribution of other significant portions of the activity space (i.e. the recreational space). Hence it was decided to explore each portion of the activity space separately in addition to the residential neighborhood (i.e. the residence-work space; the residence-service space; the residence-recreational space, and the residence-social space). This method allowed for the estimation of specific activity place influences on recreational walking.

6.3.2 An attempt to address the selective daily mobility bias

An increasingly recognized bias

Place and health studies aim to understand the causal mechanisms through which neighborhood contexts shape health and related health behaviors. It was an objective of this thesis to address the selective daily mobility bias, i.e., a source of bias that can distort associations between environmental exposure measures that account for daily mobility patterns and health behavior. This bias stems from confounding by unmeasured individual characteristics influencing both the visits to particular activity locations and the health outcomes of interest (Chaix et al., 2012b; Chaix et al., 2013b; Kerr, 2013). The selective daily mobility bias can be considered the 'daily' counterpart of the 'lifecycle' selective residential migration bias. Failing to address the selective daily mobility bias would thus prevent causal inferences. Few authors have discussed this potential selection bias in relation to their findings but could not mitigate it (Vallée and Chauvin, 2012; Zenk et al., 2011). For instance, Zenk et al. (2011) found an association between activity space fast food outlet density and dietary behaviors (Zenk et al., 2011). The authors recognized their incapacity to rule out confounding stemming from individuals who want to consume fast-food and who thus seek environments with a high density of fast-food outlets.

Methodological insights to address the issue of place-selection

In this dissertation, attempts were made to limit the selective daily mobility bias. For instance, in Article 3, I examined the exposure to destinations and green spaces in the activity space. I defined a truncated activity space in which activity places that were theoretically related to the exposure of interest were removed. Considering the exposure to the density of destinations, I only retained the relatively constrained and fixed activity destinations. Considering the exposure to green spaces, the reported sport activity locations were excluded. However, one can argue that sport activities can take place both indoors and outdoors, furthermore, people might also regularly go to parks for picnics as social activities. Given these limitations, the definition of the truncated activity space should be further refined in future research. In Article 4, I attempted to limit the selective daily mobility bias by excluding all activity locations - and corresponding exposure measures - that were specifically visited to perform recreational walking. To my knowledge these two articles were the first to specifically address the selective daily mobility bias.

Another perspective of place-selection

Many researchers argue that it is necessary to mitigate the selection bias to avoid circularity (Chaix et al., 2012b; Chaix et al., 2013b), ironically called "Exposure exposed" by Kerr (Kerr, 2013), and to avoid potential reverse causation. I agree with Spielman et al. (2013) who suggest that "both the neighborhood effect and sorting simultaneously contribute to geographic patterns in behavior and health" (Spielman and Yoo, 2009). A recent study from Lin et al. (2014) examined the park usage in terms of *opportunity* (access to green spaces) and *orientation* (individuals' affective, cognitive and experimental relationship toward green spaces) (Lin et al., 2014). Results suggested that *orientation* might be a stronger determinant of park use than *opportunity*; individuals with a strong orientation toward nature were more likely to travel longer distances to reach green spaces and to spend more time in parks (Lin et al., 2014). Since preferences and orientations seem to strongly influence the choice of places visited, it may be relevant to further investigate the environmental characteristics of such selected places and the cognitive process involved in choice. As mentioned by Chaix et al. (2013), information on *behavioral context* can be useful to generate and test causal hypotheses on environmental characteristics supportive to the behavior of interest (Chaix et al., 2013b).

6.3.3 Does accounting for activity places improve our understanding of place effects on health behavior?

Unequal contributions of specific portions of the activity space on health behavior

Results from Articles 2, 3 and 4 highlight the significant role of the residential neighborhood as: i) a major component of individuals' spatial behavior (i.e., centering of the activity space on the residential neighborhood); ii) a geographic life environment promoting or discouraging recreational walking behavior.

In this thesis I hypothesized that further accounting for non-residential activity locations would improve the specification of exposures and our understanding of the mechanisms through which environments influences health. In Article 4, the distinction between the types of activity places visited permitted the examination of how exposure in specific types of activity locations shaped walking behavior. To my knowledge, this study is the first to examine the potential contribution of environmental conditions around activity places, categorized by the type of activity performed (i.e., home, work, food and non-food services, recreational activities, and social activities). There was evidence that considering both the residential space and the recreational space improved our understanding of how the built environment influences recreational walking, compared to considering only the residential space, the full activity space or the addition of other types of activity places. I discuss below the implication of this finding for urban planning and public health interventions. However, this result might also be attributable to some residual daily mobility bias. Despite the screening conducted prior to the analyses for excluding the locations that were specifically visited for recreational walking, some recreational locations specifically visited to practice recreational walking might not have been discarded.

Beyond the environmental exposure, which mechanisms are at play?

Assuming a causal effect of environmental exposures around recreational activity places on recreational walking, this result questions the mechanisms through which context influences health behaviors. One hypothesis is that the type of activity place is a proxy for unmeasured factors related to "coupling constraints" (i.e., the feasibility of having, at a given place and time, the required individuals, resources and personal time-budget to perform an activity) (Hägerstrand, 1970). Indeed, people typically might not have leisure time to practice recreational walking when working. Similarly, people might not have the physical capability and the desire to walk when they are carrying heavy bags after going to the supermarket. Conversely, the practice of recreational activities might imply less physical or time constraints (i.e., people may be less often in a hurry when they go or return from sport or cultural activities), and people might be more likely or desirous of having a recreational walk in this context. This result suggests that measures of exposure around activity places should not only consider *where people go* (the location of these places) and the corresponding environmental characteristics, but should also account for *what they actually do* and the constraints associated with the activity performed. Conceptually, this study paves the way for future research to explore the additional contribution of the different activity places to the relationship between the built environment and health. Mechanisms explaining why certain parts of the activity space seem to have stronger effects on behavior are unclear. Additional studies that examine through which pathways (i.e., cognitive, psychological, physical, etc.) various types of activity locations influence the practice of recreational walking are therefore needed.

6.3.4 Implications for Public health and related interventions

Encouraging people to be more active while traveling, to access quality resources and to be physically active has likely health benefits. The results of this thesis mainly support place-based interventions.

Increasing mobility potentials

Evidence from Article 2 and 3 suggests that daily mobility potentials and access to resources are socially and spatially differentiated. In order to promote equity in people's daily mobility potential, place-based interventions should target isolated neighborhood with low spatial access to transportation facilities or to resources. Relevant urban planning intervention could consist in providing more transportation resources (i.e., public transportation, active transportation facilities) for individuals with low mobility who are trapped in neighborhoods with limited resources, or increase local resources by changing zoning schemes and promoting mixed land use.

Providing supportive environments for recreational walking

From a health promotion perspective, interventions that act on the characteristics of the built environment could increase the practice of physical activity at a population level (Rose, 1992). Based on results from Article 4, urban planning interventions should promote greater access to destinations, as well as access to lakes or waterways which seem to promote recreational walking. Lakes and waterways provide an attractive and pleasant context for recreational walking, and a high density of destinations promotes walking even when people do not aim to purchase items. (Chaix et al., 2014b; McCormack and Shiell, 2011; Owen et al., 2004; Saelens and Handy, 2008; Sugiyama et al., 2012). Evidence suggests that creating supportive built environments around the home would specifically stimulate recreational walking in the residential neighborhood. However, the mechanism linking environment to recreational walking observed in the residential neighborhood may not be generalizable to other areas. As such, a complementary place-based intervention would be to target more precisely the specific activity places which may stimulate recreational walking among people travelling to these environments to perform activities. Based on our finding that environmental factors around recreational activity locations may be more particularly associated with recreational walking, examples of interventions include the creation of supportive environments around sports and cultural facilities in the Paris metropolitan area. Indeed, promoting a walking-friendly environment around recreational activity places could result in additional physical activity, and may have for example a stronger beneficial influence than a walking-friendly environment around other destinations such as supermarkets. Lastly, as argued elsewhere (Cummins et al., 2007; Zenk et al., 2011), interventions addressing multiple contexts simultaneously may have a stronger health impact.

Finally, some authors suggested that urban sprawl and resulting low-density suburbs caused a decrease in recreational trips and physical activity (Frank and Engelke, 2001; McCormack et al., 2008). Indeed, the slow pace of building in the suburbs and the new fringe of the metropolitan area delays the development of local opportunities for a walking-friendly neighborhood (Giles-Corti et al., 2014). Evidence from Article 3 further suggested that suburbanites tend to compensate for the lower number of destinations in their residential neighborhood by visiting non-residential activity places surrounded by greater numbers of destinations. Given the importance of infrastructures in the residential neighborhood on recreational walking, local interventions that target suburbs and newly built areas are critical for creating environments that promote walking.

6.4 STRENGTHS AND LIMITATIONS

One of the strengths of this thesis relates to the high quality of data collected. This thesis benefited from a large sample with precise geocoding of the activity locations and the assessment of the perceived residential neighborhood. When responding to the VERITAS questionnaire, participants identified their regular activity places, without specific recall periods (e.g., "over the past week") (Chaix et al., 2012b). As such, participants' regular activity places were collected in a more comprehensive manner than is collected by the usual one-day travel survey (Basta et al., 2010). Furthermore, by guiding the participants through a spatio-temporal cognitive journey, the VERITAS software attempts to minimize memory bias (Chaix et al., 2012b). The survey questions also stimulate the participants' recall and the electronic map provides more geographical information than a traditional questionnaire (Chaix et al., 2012b). Relying on the VERITAS software is also less costly than to use GPS receivers. Lastly, the geographical and epidemiological nature of the data collected in the RECORD Cohort Study made it possible to realize an interdisciplinary thesis encompassing a spatial examination of individuals' mobility and corresponding exposures and an epidemiological application to recreational walking.

The limitations of this dissertation relate to the study sample and design, the nature of the health outcome, the mobility data, and the operationalization of the activity space. Regarding the study design, the RECORD Cohort sample is not representative of the general population in the Ile-de-France Region. The participants were recruited without prior randomization in the general population, and some of the participants were excluded because of their inability to fill out the questionnaires, while others refused to participate to the RECORD Cohort Study (Chaix et al., 2011).

The cross-sectional design of Article 4 meant that I was unable to address the issue of residential neighborhood self-selection. As emphasized in the article, when people move, the choice of their new residential neighborhood is influenced by socio-demographic characteristics, psychological variables, and environmental preferences, and by their interest in physical activity practice (Frank et al., 2007; McCormack and Shiell, 2011; van Lenthe et al., 2007). Not accounting for the neighborhood self-selection prevents the possibility of making causal inferences about the relationship between the environment and the practice of recreational walking. This issue makes it difficult to evaluate to which extent changes in characteristics of the built environment might produce changes in the practice of recreational walking (McCormack and Shiell, 2011). Indeed, few studies examining associations between the built environment and recreational walking have attempted to address residential neighborhood self-selection (Cao, 2010; Coogan et al., 2009; Frank et al., 2007; Handy et al., 2006; Owen et al., 2007; Sallis et al., 2009), although a recent systematic review highlighted an attenuation of the association between attributes of built environment and physical activity after accounting for neighborhood self-selection (McCormack and Shiell, 2011).

Another limitation of this thesis is the fact that the main behavioral outcome (Recreational walking, Article 4) relied on participant self-reports, which may have resulted in information bias. Participants were asked to report the number of hours and minutes they had walked for recreational purposes over the previous seven days, with possible under- or over-estimations in self-reports. Such bias may further be dependent of individual-level demographic or socio-economic characteristics. Recently, the RECORD GPS and MultiSensor Studies have been developed to try to address this bias. A subsample of participants are equipped with GPS and accelerometers and followed-up during seven days to collect 'objective' data on mobility and physical activity. (Chaix et al., 2014a; Chaix et al., 2013a; Chaix et al., 2013b; Thierry et al., 2013). GPS tracking represents an innovative way to assess objectively the exact time and spatial location of daily activities. Broadly, GPS and accelerometer data can be used to measure physical activity related to walking or cycling (Krenn et al., 2011), providing information on the time spent in each activity, the start and the end point of an episode, and the distance covered (Boruff et al., 2012; Maas et al., 2013). For instance, in their study, Boruff et al. (2012) used the average speed to determine the mode of transportation, and classified as walking any speed slower than 7 kilometers per hour (Boruff et al., 2012). An increasing number of studies use GPS and accelerometer data to examine the built environmental correlates of physical activity (Krenn et al., 2011; McCrorie et al., 2014; Wheeler et al., 2010).

Limitations also relate to the nature of the mobility data collected with the VERITAS software. No information was collected on the path or the mode of transportation used to travel from one activity place to another. Considering the utility maximization theory (Schlich and Axhausen, 2003), "shortest paths", defined as the shortest street-network itinerary between two activity locations, could have been a good approximation of the actual trajectories, especially for activity locations in close proximity (Karusisi et al., 2014; Madsen et al., 2014). This limitation has little impact if recreational walking is performed around particular activity locations, and does not involve commuting from one destination to another, as does walking for transportation. However, in Article 4, the relatively large amount of time that was reported for recreational walking (median time: 180 minutes over the last seven days) raises questions about where recreational walking occurs. Indeed, one can imagine that recreational walking episodes were not restricted to loops around activity locations, but did also involve leisure trips from home to other activity places (e.g., to a coffee shop or to a friend's house). In the three empirical conducted analyses, only part of the temporal dimension of spatial behavior was accounted for, since only the frequency and not the duration of the visits to places was observed. The lack of information on the duration of activities did not allow for environmental exposure to be weighted by time spent at each activity location, as recommended elsewhere (Chum, 2013; Cummins, 2007). Furthermore, no information was recorded on the variability of spatial behavior between week days and the week-end or by season.

In this dissertation, exposure areas both within and outside the residential neighborhood were operationalized using street network buffers (Oliver et al., 2007). The isotropic nature of such buffers results in exposure areas spreading in all direction around the activity location (Chaix et al., 2009). However, as highlighted in Articles 2 and 3, individuals have a selective representation and spatially oriented definition of their neighborhood, partly due to the unequal distribution of resources around their activity places. Therefore, isotropic buffers might have misrepresented the neighborhood experience and the corresponding exposure. How distance thresholds are defined to draw buffers is also matter of debate. A 1000 m radius around the residence and the work place has previously been used in place and health studies (Brondeel et al., 2014; Chaix et al., 2014b; Frank et al., 2005; Karusisi et al., 2013; Lewin et al., 2014; Oliver et al., 2007; Troped et al., 2010). However, the radius size chosen for social/recreational activities (500m) and food and services activities (200m) was chosen in a relatively arbitrary way and would have benefited from sensitivity analyses. In Article 4, such choices might have had a significant impact on the assessment of contextual effects on recreational walking by types of activities.

Finally, a methodological note should be made in relation to the exclusion from the analyses of participants regularly traveling outside the Ile-de-France Region or participants regularly commuting to a secondary home. The point was that only daily mobilities in the Ile-de-France Region were of interest in this thesis. Another possible solution would have been to exclude only the regular activity places located outside the Ile-de-France region. These activity locations corresponded mostly to major anchor points - workplace, secondary home or family residence – surrounded by clusters of minor activity locations (e.g., bakery, supermarket, tobacco shops). Exclusion of these activity places would however have resulted in the suppression of a significant part of these individuals' activity spaces and corresponding exposures, which could have introduced a classification bias. I thus opted to exclude these participants completely from the analysis. This might however result in the underestimation of favorable environmental exposures for recreational walking among high-income participants.

6.5 FUTURE DIRECTIONS AND RECOMMENDATIONS

Accounting for daily mobility is a promising avenue to increase specificity in the measurement of environmental exposures (e.g., noise, air pollution, social deprivation, features of the built environment). Doing so should improve our understanding of the mechanisms by which such environmental exposures get *under the skin*. Accounting for daily mobility also appears promising for the study of contextual effects on various health outcomes such as physical activity (Almanza et al., 2012; Zenk et al., 2011), tobacco or alcohol consumption (Basta et al., 2010), diet (Kestens et al., 2012; Kestens et al., 2010), the use of health care services (Vallée et al., 2010; Vallée et al., 2011; Vallée and Chauvin, 2012), or cardiovascular diseases (Chum, 2013).

Inequalities in mobility may be intrinsically linked to socio-spatial health inequalities. As commented in Article 2, variations in mobility patterns are closely linked to transportation behavior and to accessibility to public transportation facilities, and have been pointed out as a key determinant of health inequalities (Giles-Corti et al., 2014). Accessibility to public transportation facilities has also been related to physical activity (McCormack et al., 2008). In order to promote transportation equity, researchers should examine the spatial distribution of public transportation facilities as well as active transportation facilities (sidewalks, street connectivity, etc.). Such research would provide data to reduce inequalities in the distribution of transportation infrastructures and could provide relevant insight for health equity. However, increasing potential access to resources *per se* might have a limited impact, considering the influence of personal factors (i.e., cognitive, psychological) on individuals' capacity to actually use resources (Shareck et al., 2014a). Public education campaigns are thus also needed to modify the perceptions of mobility in order to: i) convert mobility potential into realized mobility, and ii) stimulate and enhance individuals' capacity to access places and resources (Shareck et al., 2014a).

Activity diaries or travel surveys, even when based on electronic maps, are limited in their ability to assess time activity patterns and might also provide inexact or biased information due to the self-reported measures (Maas et al., 2013; Shareck et al., 2013). In more recent studies, researchers have relied on GPS tracking in order to assess daily life exposure (Almanza et al., 2012; Chaix et al., 2013b; Elgethun et al., 2003; Rodríguez et al., 2012; Thierry et al., 2013; Zenk et al., 2011). Studies have emphasized that GPS data could provide more accurate information than self-reported travel surveys (Badland et al., 2010; Duncan and Mummery, 2007; Maas et al., 2013;

Stopher et al., 2007). GPS studies might therefore provide a step forward in the assessment of exposure in health studies. However, as stated throughout this dissertation, a particular attention should be given to the selective daily mobility bias, especially in GPS studies. Without caution, GPS studies are suited to provide information on where physical activity takes places, but might be limited in their ability to estimate the causal influence of neighborhoods on the practice of physical activity. Conceptual and methodological insights into how to address the selective daily mobility bias in GPS studies have been examined in previous studies (Chaix et al., 2013b; Thierry et al., 2013).

Additional research on the selective daily mobility bias could be conducted by further exploring the temporal and spatial structure of activity spaces. Collecting data on the fixed and flexible activity places visited in space and time would provide relevant material for determining whether the exposure to a specific location is sought or endured by the participant. Doing so would help correcting exposure measures and provide further evidence for causality (Chaix et al., 2012b; Chaix et al., 2013b). Additionally, the question of place selection when constructing exposure measures requires further examination. Identifying places specifically visited to perform recreational walking would provide information on the environmental characteristics people seek when going for a walk. For instance, it would be of interest to examine which characteristics of green spaces (i.e., specific equipment, pedestrian trails, race tracks, aesthetic features, size threshold, height difference, sunlight) are attractive for recreational walkers. Additionally, the types of destinations (i.e., utilitarian, recreational) that are sought by walkers during recreational walks would warrant further examination. Such information on the *behavioral contexts* selected by the participants for their recreational activities has the potential to guide urban planning strategies in order to create supportive environments (Chaix et al., 2013b).

A promising avenue for future research lies in longitudinal designs, which would allow identifying specific environmental characteristics of activity places are most influential in changing health behavior. Considering that space-time interactions between individuals, places and resources evolve over time, a longitudinal perspective would address the question of how residential and non-residential neighborhood factors are involved overtime in the production of health inequalities.

6.6 CONCLUSION

This thesis examined the influence of multiple geographic life environments on health behaviors (with an application to recreational walking), based on the assumption that the traditional definition of the neighborhood provides an inaccurate definition of the exposure area. This dissertation illustrates to some extent that accounting solely for residential exposures in place and health research provides an incomplete and somewhat biased understanding of environmental effects on health. By exploring individuals' mobility patterns through an interdisciplinary perspective, this thesis provides conceptual and methodological insights that will allow to better account for daily mobility in epidemiological studies. Considering both residential and non-residential exposures is a step forward in the specification of environmental exposures and increases our understanding of the mechanisms through which context shapes our health behaviors. This research also warns about the potential for self-selection bias in mobility and health studies and developed a strategy to mitigate the selective daily mobility bias. Finally, findings from this thesis demonstrate the unequal influence of multiple geographic contexts on the practice of recreational walking, and encourage researchers to take a closer look not only at *where people go* in terms of the characteristics of these places, but also at *what people do* in these places. Identifying which activity places or what part of the activity space is most influential on physical activity will provide further guidance on the geographical contexts health promotion interventions should target.

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APPENDICES

APPENDIX I: RECORD consent form

<u>Etude RECORD</u>

Responsable de la recherche :

Dr. Basile Chaix

Etiquette code-barres IPC

Formulaire d'information et de recueil du consentement

L'Institut National de la Santé et de la Recherche Médicale (Inserm) et le Centre d'Investigations Préventives et Cliniques (IPC) vous invitent à participer à l'Etude RECORD. Cette étude concerne les inégalités sociales et spatiales de santé.

L'objectif est de voir si les conditions de vie et l'endroit où l'on habite influencent la santé. Cette recherche permettra de mieux connaître les problèmes de santé qui existent et de proposer des solutions.

Si vous acceptez de participer à cette étude, un enquêteur de l'Inserm vous aidera à remplir différents questionnaires informatisés. Ces informations ainsi que les données de l'Examen Périodique de Santé seront analysées par l'équipe de l'Inserm dont les coordonnées sont fournies ci-dessus. Par ailleurs, conformément à l'autorisation reçue de la CNIL, l'Inserm accédera aux données qui vous concernent dans les registres de l'Assurance Maladie, d'hospitalisations, de l'Assurance Vieillesse et de mortalité.

Pour cette étude, l'Inserm a besoin de conserver vos nom et prénoms et coordonnées postales et téléphoniques, et d'enregistrer vos déménagements au cours du temps. Ces informations seront gardées de façon ultra-sécurisée et ne seront accessibles qu'au responsable de l'étude (Basile Chaix) et à ses assistants. Grâce à vos coordonnées, l'Inserm pourra vous faire parvenir les résultats globaux de l'étude et vous recontacter dans le futur pour vous inviter à une phase suivante de l'étude. Par contre, les données utilisées pour les analyses seront **complètement anonymes**. Personne d'autre que l'Inserm et le Service de Recherche du Centre IPC n'aura accès à vos données. Ces données seront traitées avec un niveau de confidentialité absolu.

Vous pourrez obtenir toutes les informations que vous souhaitez sur l'étude en contactant directement le responsable de l'étude, Basile Chaix (UMR-S 707, Faculté de Médecine Saint-Antoine).

Conformément à la loi sur l'informatique et les libertés, vous avez le droit d'accéder aux fichiers qui vous concernent, de les modifier ou de demander à l'Inserm de les détruire. Vous pourrez exercer ce droit auprès de Basile Chaix, responsable de l'étude, ou par l'intermédiaire du médecin qui vous suit qui contactera le responsable de la recherche.

Vous pouvez choisir de participer ou de ne pas participer à l'étude. Cela n'aura aucune conséquence sur l'Examen Périodique de Santé que vous allez recevoir au Centre IPC. Vous pouvez également à tout moment retirer votre consentement à participer à l'étude en le disant aux personnes qui s'en occupent.

Recueil du consentement :

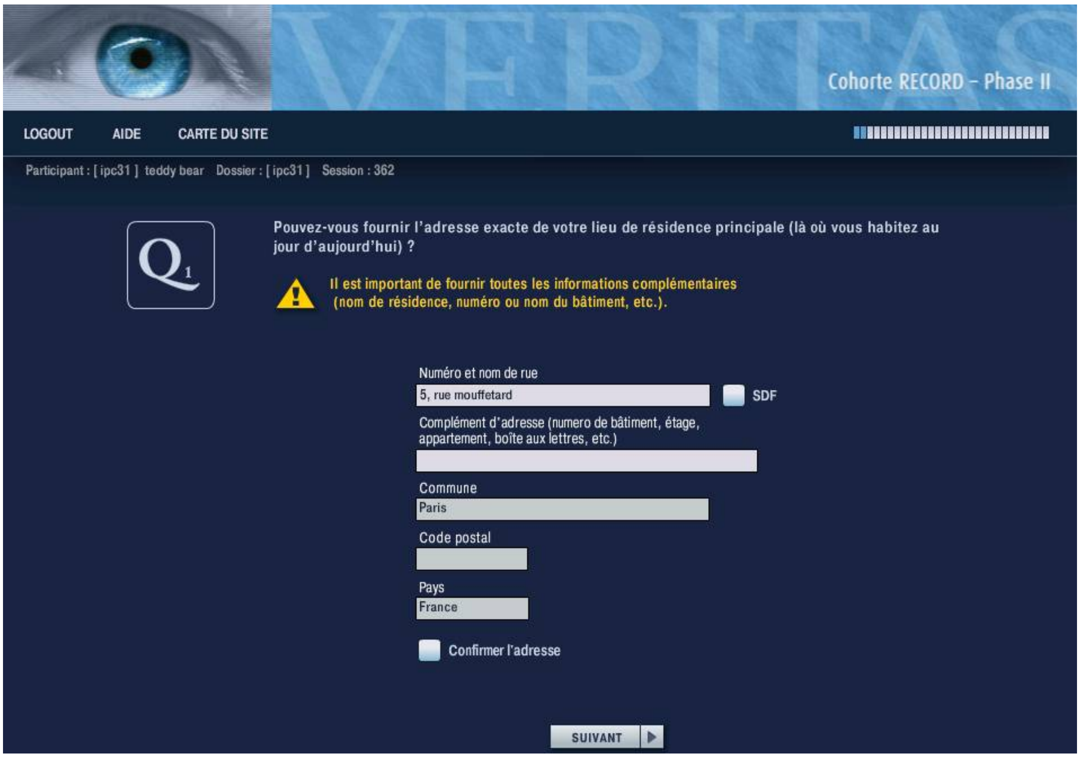
« Sur la base des informations fournies ci-dessus, j'accepte de participer à l'Etude RECORD ».

Fait à ______________, le _________________

Prénom et nom du participant :

Signature du participant : Signature de l'investigateur :

APPENDIX II: Screen copy of the VERITAS-RECORD Application




Q2
Pouvez-vous confirmer que le lieu sur la carte correspond à votre lieu de résidence actuel ?
Sinon, pouvez-vous localiser votre résidence principale actuelle ?
Tapez une adresse ou un nom de commerce...
1 Km.
Résultats de la recherche..
Plan
Mixte
Atlas
Le Panthéon
Pl. du Panthéon
Rue Soufflot
Rue Descartes
Rue Thouin
Rue du Cardinal Lemoine
Rue de l'Estrapade
Rue Lacépède
Rue Monge
Rue Mouffetard
Rue Saint-Jacques
Rue Gay-Lussac
Rue d'Ulm
Rue Pierre et Marie Curie
Rue des Écoles
Rue Jussieu
Square Capitan
Place Monge
500 pieds
100 m
Données cartographiques ©2012 Cybercity, Google - Conditions d'utilisation
Résidence
Travail
Courses et services
Transport
Activités récréatives
Activités sociales
Résidence : 5 Rue Mouffetard, 75005 Paris, France
IFR
PRÉCÉDENT
SUIVANT


Q3
A l'aide de la souris, pouvez-vous dessiner la zone qui correspond à votre quartier tel que vous le percevez ?
Consigne : Sur la carte, double-cliquez pour indiquer les points qui marquent, selon vous, les limites de votre quartier. Lorsque vous avez fini, cliquez sur l'icône "Dessiner une zone". Vous pouvez par la suite modifier la forme de la zone en déplaçant ses limites.
Tapez une adresse ou un nom de commerce...
1 Km.
Résultats de la recherche..
Plan
Mixte
Atlas
Bd Saint-Michel
Centre Sorbonne
Rue Soufflot
Le Panthéon
Rue de la Montagne Sainte-Geneviève
Square Paul Langevin
Rue des Écoles
Rue Descartes
Rue Thouin
Rue de l'Estrapade
Rue du Cardinal Lemoine
Rue Monge
Square Capitan
500 pieds
100 m
Données cartographiques ©2012 Cybercity, Google - Conditions d'utilisation

Q4

Y a-t-il une ou plusieurs autres adresses où vous passez la nuit <u>au moins une fois par semaine</u> (logement du conjoint, d'amis ou d'autres membres de la famille, résidence secondaire, etc.) ?

- [ ] Oui
- [x] Non

Q5

Avez-vous l'intention de déménager dans les deux prochaines années ?

- [ ] Oui
- [ ] Non
- [ ] Ne sait pas

Q6

Travaillez-vous actuellement (en tant que salarié(e) ou non, à temps plein ou à temps partiel, pour une durée indéterminée ou de façon temporaire) ?

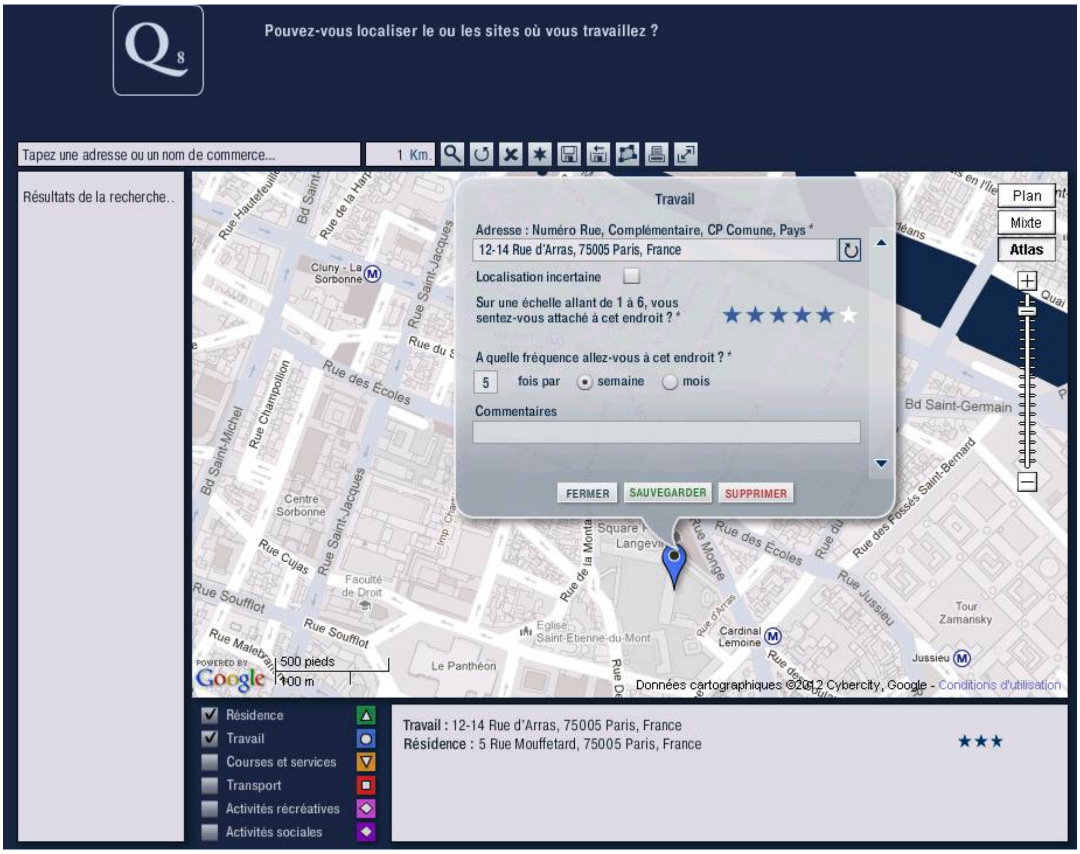
- [ ] Oui
- [ ] Non

Q7

Certaines personnes passent l'essentiel de leur temps de travail sur un site défini – bâtiment, espace extérieur délimité - alors que d'autres sont amenées à se déplacer sur un ensemble de lieux au cours de leur travail.

Sur combien de sites définis passez-vous au moins un tiers de votre temps de travail ?

- [ ] Un seul site
- [ ] Deux sites réguliers
- [ ] Trois sites réguliers
- [ ] Ne passe pas un tiers de son temps de travail sur un site régulier (beaucoup de déplacements)

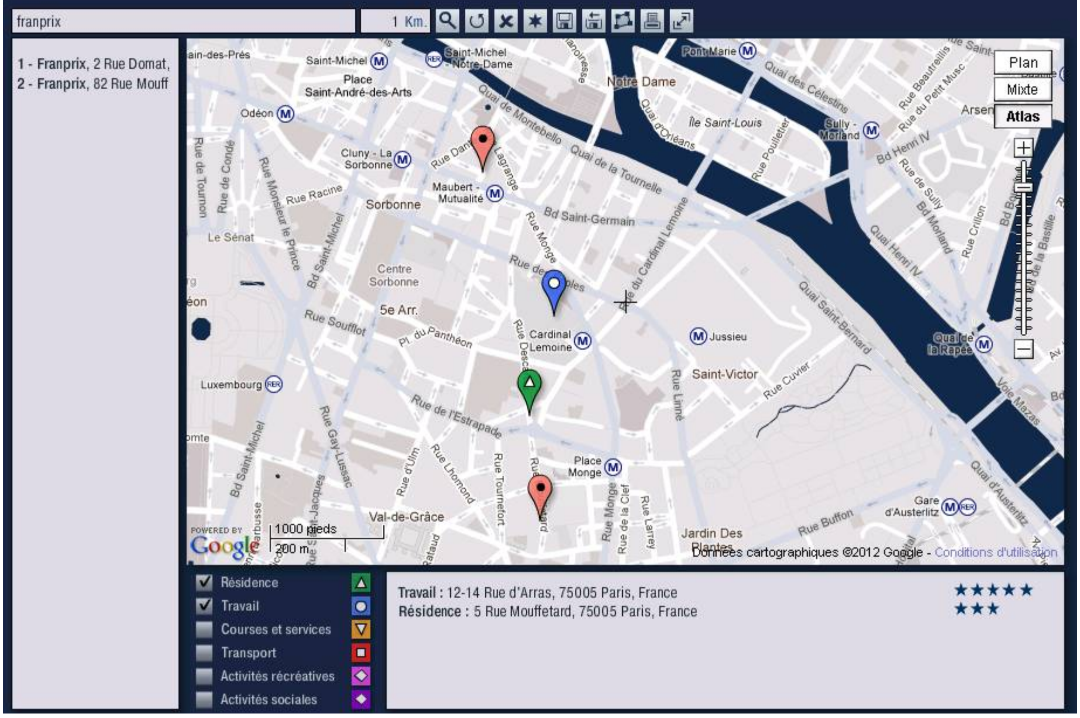

Pouvez-vous localiser le ou les sites où vous travaillez ?
Tapez une adresse ou un nom de commerce...
1 Km.
Résultats de la recherche..
Travail
Adresse : Numéro Rue, Complémentaire, CP Comune, Pays *
12-14 Rue d'Arras, 75005 Paris, France
Localisation incertaine
Sur une échelle allant de 1 à 6, vous sentez-vous attaché à cet endroit ? *
A quelle fréquence allez-vous à cet endroit ? *
5 fois par semaine mois
Commentaires
FERMER
SAUVEGARDER
SUPPRIMER
Plan
Mixte
Atlas
Données cartographiques ©2012 Cybercity, Google - Conditions d'utilisation
Résidence
Travail
Courses et services
Transport
Activités récréatives
Activités sociales
Travail : 12-14 Rue d'Arras, 75005 Paris, France
Résidence : 5 Rue Mouffetard, 75005 Paris, France

Q9

Faites-vous vous-même au moins une fois par mois des courses dans un supermarché ?

☑ Oui ☐ Non

Pouvez-vous localiser le ou les supermarchés dans lesquels vous vous rendez vous-même au moins une fois par mois ?



Q10

Vous rendez-vous au moins une fois par semaine au marché ?

☐ Oui ☑ Non

Q11

Vous rendez-vous au moins une fois par semaine chez un boulanger ?

☐ Oui ☐ Non

Q12

Vous rendez-vous au moins une fois par semaine chez un boucher ?

☐ Oui ☐ Non

Q13 — Vous rendez-vous au moins une fois par semaine chez un marchand de fruits et légumes ?

- [ ] Oui
- [ ] Non

Q14 — Vous rendez-vous au moins une fois par semaine chez un poissonnier ?

- [ ] Oui
- [ ] Non

Q15 — Vous rendez-vous au moins une fois par semaine chez un fromager ?

- [ ] Oui
- [ ] Non

Q16 — Vous rendez-vous au moins une fois par semaine dans un magasin alimentaire spécialisé ?

- [ ] Oui
- [ ] Non

Q17 — Vous rendez-vous au moins une fois par semaine dans un bureau de presse ou de tabac ?

- [ ] Oui
- [ ] Non

Q18 — Pouvez-vous localiser sur la carte la banque où vous allez le plus souvent ?

- [ ] Ne va jamais ou très rarement à la banque

Q19 — Pouvez-vous localiser le bureau de poste où vous allez le plus souvent (pour votre courrier) ?

- [ ] Ne va jamais ou très rarement à la poste

Q20 — Pouvez-vous localiser votre coiffeur où vous allez le plus souvent ?

- [ ] Ne va jamais ou très rarement chez le coiffeur

Q21

Utilisez-vous <u>au moins une fois par semaine</u> les transports en commun <u>à partir de chez vous</u> ?

☑ Oui ☐ Non

Pouvez-vous localiser la ou les stations de métro, de train ou de tram ou les arrêts de bus (au maximum 3) que vous utilisez à partir de votre domicile au moins une fois par semaine ?

⚠ Indiquez également les stations où vous vous rendez en voiture ou en vélo à partir de chez vous.

Q22

Vous rendez-vous quelque part au moins une fois par semaine pour pratiquer une activité sportive ?

☑ Oui ☐ Non

Pouvez-vous localiser le ou les lieux que vous fréquentez au moins une fois par semaine pour pratiquer une activité sportive ?

Q23

Vous rendez-vous quelque part au moins une fois par semaine pour pratiquer une activité culturelle (par exemple cours de chant ou de dessin, groupe de musique, atelier d'artistes, etc.) ?

☐ Oui ☐ Non

Q24

Vous rendez-vous quelque part au moins une fois par semaine pour pratiquer une activité associative, religieuse ou spirituelle ?

☐ Oui ☐ Non

Q25

Accompagnez-vous des personnes à charge (enfants, parents, grands-parents, etc.) dans un ou plusieurs lieux réguliers au moins une fois par semaine ?

☐ Oui ☐ Non

⚠ Il ne s'agit pas des visites que vous rendez à des personnes à leur domicile.

Q26

Rendez-vous visite à une ou plusieurs personnes à un endroit spécifique au moins une fois par semaine ?

☐ Oui ☐ Non

Q27

Y a-t-il un ou plusieurs restaurants ou lieux de restauration, cafés, bars, cinémas ou salles de spectacle où vous vous rendez au moins une fois par semaine (<u>même établissement chaque semaine</u>) ?

☐ Oui ☑ Non

APPENDIX III. Characteristic of environmental variables as possible correlates of recreational walking

Neighborhood characteristic	Data source	Measurement approach
Domain: Neighborhood socio-demographic environment		
Neighborhood education	Population Census of 2010 geolocated at the residential address by INSEE	Aggregation of population data within road network buffers. Proportion of residents with University education
Domain: Neighborhood physical environment		
Surface of green space	Linear and polygonal data from IAU-IDF on public parks and green spaces in 2008	GIS processing: proportion of surface covered with green space within road network buffers
Presence of a lake or waterway	Polygonal data from IAU-IDF on land use 2003	GIS processing: presence of water in road network buffers
Density of street intersections	Data on street network in 2014 from IGN	GIS processing: count of intersections with at least 3 ways within road network buffers
Domain: Neighborhood services environment		
Density destinations	Geocoded destinations from the 2011 permanent Database of facilities of INSEE	GIS processing: count of destinations (supermarket, other shop, administrations, public/private shops, health services, entertainment facilities,) within road network buffers

APPENDIX IV. Résumé étendu

1. Contexte de l'étude

L'étude des effets de l'environnement sur la santé remonte à la tradition hippocratique de la médecine, et a évolué au cours de l'histoire de la santé publique à travers différents paradigmes et liens causaux (Susser and Susser, 1996a, b). Ce n'est qu'à partir des années 90 que les études examinant le rôle de l'influence environnementale sur la production et le maintien de la santé ont commencé à proliférer (Diez Roux, 2007; Kawachi and Berkman, 2003; Kawachi and Subramanian, 2007). Plus spécifiquement, ces études ont examiné les caractéristiques sociales et environnementales des environnements géographiques de vie comme potentiels facteurs de risque pour la santé. Conjointement, les chercheurs ont investigué le lien entre la répartition inégale des ressources environnementales dans l'espace et la production des inégalités sociales de santé (Berkman and Kawachi, 2000; Diez Roux, 2001; Diez Roux and Mair, 2010). Enfin, cet engouement pour l'étude des effets du contexte sur la santé a largement bénéficié de la démocratisation des systèmes d'information géographique et le développement de méthodes d'analyse multiniveaux, particulièrement adaptées à l'analyse des effets de l'environnement sur les individus dans leur quartier (Diez-Roux, 1998; Diez Roux and Mair, 2010).

Plus récemment, la recherche sur les effets du contexte sur la santé a évolué vers un *tournant spatial* (Schipperijn et al., 2013). Un certain nombre de constats scientifiques a montré que dépendamment de la définition géographique de la zone d'exposition d'intérêt, les résultats des études sur les effets de l'environnement sur la santé variaient. Dès lors, la question de la définition géographique de la zone d'exposition en termes d'échelle, de taille et de forme et de lieu est apparue de première importance pour évaluer des effets de environnement sur la santé (Bernard et al., 2007; Chaix et al., 2009; Cummins et al., 2007; Macintyre et al., 2002).

Les études qui ont analysé l'influence des environnements géographiques de vie sur la santé ont porté exclusivement sur les effets du quartier de résidence (Chaix et al., 2009; Cummins, 2007). Ces études ont majoritairement opérationnalisé le quartier de résidence en utilisant des unités administratives (zones de recensement ou zones de codes postaux), ou encore des zones tampons (traduction de *buffers*) circulaires ou utilisant le réseau de rues centrées sur le domicile des individus (Cummins et al., 2007; Diez Roux and Mair, 2010; Leal and Chaix, 2011; Rainham et al., 2010). D'autres ont utilisé le quartier résidentiel perçu comme alternative à une délimitation relativement arbitraire de la zone d'exposition (Coulton et al., 2001). Enfin, très peu d'études ont examiné l'impact des environnements autour d'autres lieux d'activité d'intérêts tels que l'école ou le lieu de travail. Une revue de littérature publiée en 2011 sur l'influence des environnements géographiques de vie sur les facteurs de risque métabolique a montré que 90 % des études recensées ont porté exclusivement sur le quartier de résidence, 6 % des études ont porté sur des environnements non-résidentiels et seulement 4 % des études ont pris en compte des environnements résidentiels et non-résidentiels (Leal and Chaix, 2011).

Ces différentes approches ont été largement critiquées par l'absence de prise en compte des mobilités quotidiennes des individus et des environnements géographiques de vie non-résidentiels pour évaluer les effets de l'environnement sur la santé (Chaix et al., 2009; Cummins, 2007). En effet, les mobilités quotidiennes des individus ne se limitent pas à leur quartier de résidence. Des concepts tels que la « polygamie spatiale » (Matthews and Yang, 2013) et « l'espace d'activité » (Golledge and Stimson, 1997) ont mis en avant que les individus sont liés spatialement à leur quartier de résidence, mais également d'autres lieux d'activité. Or la majorité des études sur les effets du contexte ont ignoré les lieux d'activité localisés à l'extérieur du quartier de résidence, tels que les lieux de travail, les lieux de courses alimentaires et de services, les lieux récréatifs, ou encore les lieux sociaux. À titre d'exemple, une étude ethnographique conduite à Boston (USA), a mis en évidence que 6 % des activités quotidiennes étaient réalisées dans l'unité administrative résidentielle, 21 % des activités étaient réalisées dans les unités administratives adjacentes au lieu de résidence et 73 % des activités étaient réalisées dans d'autres parties de la ville (Matthews et al., 2005). En conséquence, la notion de quartier résidentiel comme unique zone d'exposition d'intérêt apparait inadéquate (Kearns and Parkinson, 2001). Il semble donc nécessaire de prendre en compte les mobilités quotidiennes des individus en épidémiologie afin de mieux estimer les effets des expositions environnementales sur la santé.

Comme cela a été souligné par Chaix et al. (2012), il existe deux raisons majeures de prendre en compte les mobilités quotidiennes dans les études de santé : i) la mobilité comme vecteur d'exposition à des environnements géographiques de vie ; ii) la mobilité comme pratique de l'activité physique (Chaix et al., 2012). Cette thèse tend à fournir des apports conceptuels et méthodologiques pour prendre en compte des mobilités individuelles dans les études de santé. Plus précisément, cette thèse vise à montrer les contributions de la prise en compte des lieux d'activité visités régulièrement sur la compréhension des effets de l'environnement sur l'activité physique, avec pour cas d'étude la marche récréative.

En terme d'exposition, considérer uniquement le quartier résidentiel peut conduire à une sous-estimation ou surestimation des effets de l'environnement sur la santé (Chaix et al., 2005; Diez Roux, 2008). En effet, les caractéristiques environnementales autour de la résidence peuvent être différentes de celles autour d'autres lieux d'activités non-résidentiel tels le travail, l'école, ou encore les supermarchés (Basta et al., 2010; Hurvitz and Moudon, 2012). Cependant, la façon dont les expositions environnementales diffèrent à l'intérieur et l'extérieur du quartier de résidence reste largement inconnue.

Enfin, prendre en compte les mobilités quotidiennes dans les études des effets du contexte sur la santé requiert certaines précautions relatives au *biais de mobilités quotidiennes sélectives* (Chaix et al., 2012; Chaix et al., 2013). Le biais de mobilités quotidiennes sélectives a été défini comme "the fact that people who visit particular activity places during their daily lives have particular characteristics (e.g., socio-demographic, psychological, or cognitive characteristics; behavioral habits) that also influence their health status" (Chaix et al., 2012, p. 441). Le biais de la mobilités sélectives peut être considéré comme le pendant «quotidien» du biais de migration résidentielle sélective (Frank et al., 2007; Oakes, 2004). Cependant, si les études ayant pris en compte les mobilités quotidiennes pour estimer les effets de l'environnement sur la santé restent très marginales, aucune ne semble avoir tenté de réduire les effets de confusions additionnels relatifs au biais de mobilités sélectives.

2. Objectifs de la thèse

L'objectif général de cette thèse est d'évaluer si la prise en compte des lieux d'activité dans lesquels les individus se déplacent et des multiples environnements auxquels ils sont régulièrement exposés permet de mieux comprendre l'impact de l'environnement sur la pratique de la marche récréative. Les objectifs spécifiques de la thèse sont :

1- Identifier les différents types de comportement spatiaux des individus vivant en Île-de-France et leurs déterminants sociodémographiques.

2- Évaluer si l'exposition à des facteurs environnementaux facilitant la marche diffère entre le quartier résidentiel, le quartier perçu et l'espace d'activité ; et si cette différence d'exposition varie en fonction du niveau socio-économique et localisation de la résidence dans la région Île-de-France.

3- Évaluer quelles caractéristiques environnementales résidentielles et non-résidentielles sont associées à la marche récréative.

3. Éléments de méthode

Afin de répondre à ces objectifs, des analyses transversales ont été conduites sur la seconde vague de la Cohorte RECORD (Residential Environment and COROnary heart Disease). La seconde vague de la Cohorte RECORD était constituée au 17 octobre 2014 de 6240 adultes âgées de 30 à 85 ans et résidant en Île-de-France. Les participants de la seconde vague de la cohorte ont été, soit nouvellement recrutés, soit revus suite à une première inclusion en vague 1, depuis février 2011. Les participants de la première et de la seconde vague ont été recrutés dans le cadre des Examens Périodiques de la Sécurité Sociale dans quatre sites des Centres d'Investigation Préventive et Clinique (IPC) de la région Île-de-France, localisés à Paris, Argenteuil, Trappes et Mantes-la-Jolie. Lors de la première vague de l'étude, trois critères d'inclusion ont été spécifiés afin de pouvoir participer à la Cohorte RECORD : i) les participants devaient avoir entre 30 et 79 ans au moment de l'examen, ii) ils devaient résider dans un des 10 (sur les 20) arrondissements de Paris ou dans l'une des 111 communes sélectionnées *a priori* ; iii) les participants devaient être en mesure de répondre par eux-mêmes au questionnaire de l'étude proposé en langue française. Lorsque les consultants des Centre IPC répondaient à ces trois critères d'inclusion, il leur été alors proposé de participer à l'Étude RECORD. Des données biologiques, médicales, socioadministratives, comportementales et psychologiques ont été recueillies lors du passage des participants au Centre IPC.

Les données relatives aux mobilités quotidiennes des participants ont été collectées par le biais de l'application VERITAS (Visualization and Evaluation of Regular Individual Travel destinations and Activity Spaces). L'application VERITAS est un questionnaire interactif qui intègre des fonctionnalités de cartographie. Avec l'aide d'un technicien, chaque participant a été invité à géocoder une liste de lieux d'activité régulièrement visités, et à délimiter son quartier résidentiel perçu. À travers 27 questions successives, les participants géocodent leur lieu de résidence principale et une succession de lieux visités au moins une fois par semaine, tels que : les lieux où le participant dort au minimum une nuit par semaine, le lieu de travail, les supermarchés, les boulangers, les magasins de fruit et légumes, les poissonneries, les fromageries, les magasins d'alimentation spécifique, les tabacs, les stations de transport utilisées depuis le domicile, les lieux d'activité sportive, les lieux d'activité de divertissement, les lieux d'activité culturels, les lieux d'activité associatifs ou religieux, les lieux où les participants emmènent leurs proches (enfants, parents ou autre) et les lieux de visites aux personnes. La banque, le bureau de poste ainsi que le salon de coiffure des participantes ont également été référencés, sans fréquence de visite minimum. En date du 17 octobre 2014, 6240 participants avaient rapporté 90670 lieux d'activité.

4. Résultats

Dans la première partie des analyses, j'ai identifié les différentes composantes du comportement spatial des individus résidants Île-de-France et leurs déterminants sociodémographiques. Dans un premier temps, j'ai défini une succession de 24 indicateurs permettant de quantifier et de qualifier les comportements de mobilité individuels. Différents domaines d'indicateurs ont été créés : i) des indicateurs relatifs au style de vie des individus (nombres de lieux d'activité, type de lieux d'activité, etc.) ; ii) des indicateurs relatifs à la géométrie de l'espace d'activité (surface, périmètre, élongation de l'espace d'activité) ; iii) des indicateurs relatifs à l'importance relative du quartier de résidence dans l'espace d'activité (nombre de lieux d'activité dans le quartier de résidence, proportion du quartier résidentiel perçu dans l'espace d'activité total, etc.). Une analyse en composante principale (ACP) a été réalisée sur les 24 indicateurs afin de déterminer les composantes majeures du comportement spatial. Cinq composantes majeures sont ressorties : i) la taille de l'espace d'activité, ii) l'élongation de l'espace d'activité, iii) le centrage de l'espace d'activité sur le quartier de résidence, iv) le volume d'activités, et iv) les types d'activités réalisées. J'ai ensuite testé les associations entre ces cinq composantes majeures du comportement spatial et les caractéristiques démographiques et socio-économiques des participants, leur perception de la mobilité et la localisation de leur résidence dans la région Île-de-France. Ces analyses ont révélé que le statut socio-économique et la localisation de la résidence dans l'aire urbaine parisienne étaient des déterminants fortement associés au comportement spatial.

Dans la seconde partie des analyses, j'ai évalué si l'exposition à deux facteurs environnementaux favorisant la marche - la densité de destinations et la densité d'espaces verts - varie en fonction de la définition géographique de la zone d'exposition. Quatre zones d'exposition différentes ont été définies : le quartier résidentiel, le quartier résidentiel perçu, un espace d'activité total incluant l'ensemble des lieux d'activité visités par le participant, et un espace d'activité tronqué prenant en compte le biais de mobilité sélective. Le quartier résidentiel perçu a été directement estimé à partir de la définition du participant dans l'application VERITAS. À l'aide d'un système d'information géographique, le quartier résidentiel a été opérationnalisé à partir d'une zone tampon de 1000 m utilisant le réseau de rues autour du domicile de chaque participant. Les deux types d'espaces d'activité (total et tronqué) ont quant à eux été définis en utilisant des zones tampons de tailles variables (200 m, 500m et 1000 m) autour des lieux d'activité de chaque participant. L'espace d'activité total prend en considération l'ensemble des lieux d'activités visités. L'espace d'activité tronqué vise à réduire le biais de mobilité sélective en conservant uniquement une exposition environnementale non-volontaire ; ainsi, les lieux d'activité visités théoriquement liés à l'exposition d'intérêt on été supprimés. Des zones tampons de taille plus large correspondent à des lieux d'activité majeurs tels que la résidence ou le lieu de travail, dans lesquels les participants passent davantage de temps et en conséquence ont davantage d'opportunités d'explorer l'espace environnant. Les résultats de cette étude ont montré que les mesures d'exposition environnementale varient significativement en fonction de la définition de la zone d'exposition. L'exposition aux densités de destinations et d'espaces verts apparait significativement supérieure dans le quartier résidentiel perçu comparé au quartier résidentiel définit pas une zone tampon de 1000 m. Cette observation combinée à la taille inférieure du quartier perçu tend à confirmer la nature anisotropique du quartier résidentiel perçu qui ne prend pas en compte les zones de faible densité dans lesquelles les individus ne se déplacent pas ou peu, en opposition à la nature isotropique du quartier résidentiel classique défini par une zone tampon. De plus, les mesures d'exposition environnementale prenant en compte les mobilités quotidiennes des individus (espace d'activité total et tronqué) diffèrent des mesures estimées à partir du quartier résidentiel perçu et du quartier résidentiel défini par une zone tampon de 1000m. Dans la majorité des cas, les différences d'exposition entre les quatre zones géographiques ont montré des variations par niveaux socio-économiques et localisation du ménage dans la région Île-de-France. Concernant le gradient d'exposition socio-économique, les résultats montrent une plus grande différence d'exposition aux densités de destinations chez les participants à forts revenus, comparés aux participants à faibles revenus. Ce résultat peut être attribuable à une forte accessibilité de services dans le quartier résidentiel perçu des participants à fort revenu. Concernant le gradient d'exposition relatif à la location de la résidence dans la région Île-de-France, les résultats tendent à montrer que i) les participants résidants dans le centre-ville sont exposés à davantage de ressources dans leur quartier de résidence ; ii) les participants résidant en petite et grande couronne de l'agglomération parisienne ont accès à davantage de destinations autour de leurs lieux d'activité non-résidentiels (c.-à-d. leur espace d'activité). Enfin, nos résultats montrent des différences d'exposition significatives entre les deux définitions de l'espace d'activité (total et tronqué). Aucun gradient socio-économique d'accès aux espaces verts n'a été observé dans l'espace d'activité tronqué ; cependant, un gradient socio-économique a été observé dans l'espace d'activité total. Ce résultat suggère que les participants ont un accès comparable aux espaces verts au cours de leurs activités quotidiennes, et ceux, indépendamment de leur niveau socio-économique ; cependant, les individus à forts niveaux socio-économiques auraient davantage tendance à visiter des parcs volontairement. Ce résultat confirme qu'il est nécessaire de prendre en compte le biais de mobilité sélective dans l'étude des effets de l'accès aux espaces verts sur la marche afin de ne pas introduire de biais de confusion additionnels.

Dans la troisième partie des analyses, j'ai dans un premier temps évalué les caractéristiques environnementales résidentielles et non-résidentielles associées à la pratique de la marche récréative. Dans un second temps, j'ai regardé l'apport spécifique de l'exposition autour de chaque type de lieux d'activités (lieux résidentiels, lieux de travail, lieux de services alimentaire et non-alimentaire, lieux récréatifs et lieux sociaux), sur la compréhension des effets de l'environnement sur le comportement de marche récréative. À l'aide d'un SIG, j'ai défini six zones d'exposition distinctes : 1) l'espace résidentiel, 2) l'espace résidentiel additionné à l'espace de travail, 3) l'espace résidentiel additionné à l'espace de services, 4) l'espace résidentiel additionné à l'espace récréatif, 5) l'espace résidentiel additionné à l'espace social, 6) et un espace d'activité total incluant l'ensemble des types de lieux d'activité. Afin de prévenir le biais de mobilités quotidiennes sélectives, j'ai exclu de l'échantillon l'ensemble des lieux d'activités spécifiquement visités par les participants pour effectuer de la marche récréative. J'ai ensuite testé plusieurs variables contextuelles (densité d'espace vert, densité de destination, densité de connexion de rues, présence de lacs ou de voies d'eau, et éducation du quartier) afin de déterminer si l'environnement de résidence, les environnements de travail, de services, récréatifs et sociaux ainsi que l'espace d'activité total étaient associés à la marche récréative. Après ajustement sur les caractéristiques individuelles, la présence de lac ou de voie d'eau, la densité de destinations et le niveau d'éducation du quartier étaient associés à la pratique de la marche récréative. Seule la densité de destinations était associée au temps de marche récréative. La comparaison des modèles a montré que le fait de considérer l'espace récréatif conjointement à l'espace résidentiel améliorait nettement la compréhension des effets de l'environnement sur la marche récréative, comparé à un modèle considérant uniquement l'espace résidentiel. La force de l'association entre la densité de destination et la pratique de la marche récréative augmentait nettement dans le modèle incluant l'espace résidentiel et l'espace récréatif. Dans une moindre mesure, les mêmes observations apparaissaient dans le modèle considérant d'espace d'activité total.

5. Discussion et conclusion

Les résultats de cette thèse soulignent l'importance de considérer conjointement le quartier de résidence avec les lieux d'activités dans lesquels les individus se déplacent au cours de leurs activités quotidiennes, pour mesurer les effets de l'environnement sur la santé. Plus spécifiquement, j'ai montré que selon leurs caractéristiques sociodémographiques et la localisation de leur résidence en Île-de-France, les individus ont des caractéristiques de comportement spatial allant de profil d'individus à mobilité réduite, cloisonnés dans leur quartier de résidence, à des profils d'individus extrêmement mobiles. Par ailleurs, j'ai montré que selon la définition géographique de la zone d'exposition d'intérêt, les mesures d'exposition environnementales varient grandement, et montrent des variations en fonction du niveau socio-économique des individus et de la localisation de leur résidence dans l'agglomération parisienne. De fait, considérer uniquement l'exposition environnementale résidentielle tend à sous-estimer ou surestimer l'exposition réelle des individus au cours de leurs activités quotidiennes. Cette erreur de mesure relative à l'utilisation d'estimations basées exclusivement sur le quartier de résidence varie en fonction de groupes socio-économiques et géographiques. Enfin, le cas d'étude de la marche récréative a permis de montrer que la prise en compte des mobilités quotidiennes tend à augmenter la compréhension des effets de l'environnement sur la santé, comparé à une étude basée uniquement sur le quartier de résidence. Cependant, il a également été montré que tous les types de lieux d'activité visités n'améliorent pas de manière égale notre compréhension des effets de l'environnement sur les comportements de santé. En effet, les types de lieux d'activité et en conséquence les activités effectuées semblent jouer un rôle sur la façon dont l'environnement influence les comportements de santé. À titre d'exemple, il semble peu probable que les individus aient assez de temps libre pour pratiquer la marche récréative lorsqu'ils sont sur leur lieu de travail. De même, les individus peuvent ne pas avoir la capacité physique ou le désir de marcher lorsqu'ils transportent de lourds sacs de course après être allés au supermarché. À l'inverse, la pratique d'activités de loisirs implique moins de contraintes physiques ou temporelles. Par exemple, les individus peuvent être moins souvent à la hâte quand ils vont ou reviennent d'activités sportives ou culturelles, et en conséquence être plus susceptibles ou désireux de faire une promenade récréative dans ce contexte. Afin de mieux mesurer les effets de l'environnement et les mécanismes par lesquels l'environnement « nous rentre dans la peau », les résultats de cette thèse préconisent de prendre en considération, non seulement, *où les gens vivent*, mais également *où les gens vont* en termes de caractéristiques environnementales, et *ce que les gens font* ainsi que les contraintes reliées aux activités effectuées.

La prise en compte de mobilités quotidiennes des individus permet mieux spécifier les effets de quartier sur la santé et donc d'identifier des cibles d'interventions en santé publique afin de favoriser des environnements sains. Dans une perspective de promotion de la santé, les résultats de cette thèse supportent des interventions d'aménagement urbain ciblant des espaces spécifiques. Un premier exemple d'intervention consisterait à augmenter les potentiels de mobilités d'individus enclavés dans leur quartier de résidence en fournissant davantage d'équipements de transport (c.-à-d., transport actif et transport public). En parallèle, les résultats de cette thèse suggèrent que pour créer un environnement favorable à la marche récréative, les interventions d'aménagement urbain devraient promouvoir la création de voies d'eau ou des lacs artificiels, et des espaces denses avec un haut niveau de destinations. Enfin, les résultats de cette thèse montrent que la création d'environnements favorables à la marche récréative autour du lieu de résidence et de lieux d'activité récréatifs pourrait stimuler la pratique de l'activité physique, et aurait par exemple une influence plus significative sur la promotion de la marche récréative que si ce même environnement était créé autour d'un hypermarché.

Plus largement, la prise en compte des mobilités quotidiennes en épidémiologie pour mieux spécifier les expositions environnementales peut être applicable à divers types d'exposition tels que le bruit, la pollution de l'air, l'environnement bâti de manière générale, ou encore la défaveur sociale. Cela apparait également prometteur pour évaluer les effets du contexte sur de multiples issues de santé telles que l'activité physique (Almanza et al., 2012; Zenk et al., 2011), la consommation de tabac ou d'alcool (Basta et al., 2010), les comportements alimentaires (Kestens et al., 2012; Kestens et al., 2010), l'utilisation des services de santé (Vallée et al., 2010; Vallée et al., 2011; Vallée and Chauvin, 2012), ou encore les maladies cardiovasculaires (Chum, 2013).

En conclusion, cette thèse examine l'influence de multiples environnements géographiques de vie sur les comportements de santé (avec un cas d'étude sur la marche récréative), basée sur l'hypothèse que la définition traditionnelle du « quartier » en épidémiologie fournit une définition inexacte de la zone d'exposition réelle. Cette thèse illustre dans une certaine mesure que la prise en compte de mesures d'exposition environnementale basée exclusivement sur le quartier de résidence produit une estimation incomplète, voire biaisée, des effets de l'environnement sur la santé. En explorant les schémas de mobilité individuels à travers une perspective interdisciplinaire, cette thèse fournit des indications conceptuelles et méthodologiques qui permettront de mieux tenir compte de la mobilité quotidienne dans les études épidémiologiques. Les résultats de cette thèse soutiennent que la prise en compte des expositions résidentielles et non résidentielles permet d'aller plus loin en termes de spécification des expositions environnementales et augmente notre compréhension des mécanismes par lesquels le contexte façonne nos comportements de santé. Cette recherche met également en garde contre le risque de biais d'autosélection dans les études de mobilité et de santé, et élabore une stratégie pour atténuer le biais de mobilités quotidiennes sélectives. Enfin, les résultats de cette thèse démontrent l'influence inégale des multiples contextes géographiques sur la pratique de la marche récréative, et encouragent les chercheurs à regarder de plus près, non seulement *là où les gens vont* en fonction des caractéristiques des lieux visités, mais également *ce que les gens font* dans ces lieux. L'identification des lieux activité (ou des parties de l'espace d'activité) qui ont le plus d'influence sur l'activité physique permet de fournir des indications supplémentaires sur les contextes à cibler en termes d'interventions en promotion de la santé.

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Vallée, J., Cadot, E., Roustit, C., Parizot, I., Chauvin, P., 2011. The role of daily mobility in mental health inequalities: The interactive influence of activity space and neighbourhood of residence on depression. Social Science and Medicine 73, 1133-1144.

Vallée, J., Chauvin, P., 2012. Investigating the effects of medical density on health-seeking behaviours using a multiscale approach to residential and activity spaces: Results from a prospective cohort study in the Paris metropolitan area, France. International Journal of Health Geographics 11, 1-11.

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 and Place 17, 1150-1161.

APPENDIX V. Curriculum vitae

PERCHOUX Camille

CURRENT STATUS

January 2011 - Present: Ph.D. Student in **Public Health - Epidemiology**. Guardianship of thesis with University of Montreal (Canada, QC)/ Montreal University Hospital Research Center (CRCHUM) and Sorbonne Université, UPMC Université- Paris 06 (France)/ National Institute of Health and Medical Research (INSERM UMR-S1136).

Thesis Title: "Accounting for residential and non-residential environments to measure contextual effects on health behavior: The case of recreational walking behavior"

Supervisors: Yan Kestens (Ph.D) and Basile Chaix (Ph.D)

EDUCATION

2008-2010 **M.Sc Geographic Sciences, Spatial analysis** - Université de Provence Aix-Marseille I (*Great distinction*)

2007-2008 **B.Sc Geographical Sciences, Land use planning** - Université de Provence Aix-Marseille I *(Distinction)*

TRAINING SESSIONS ATTENDED

2013 Writing seminar: reviewing and discussing public health papers, Montreal University, QC, Canada

2011-present Public Health seminar: attending conferences and discussing public health studies, INSERM, U-707, Paris, France

2011-2013 Public Health Journal club: discussing classic texts in public health, Montreal University, QC, Canada

2011-present SPHERELAB (Spatial Health Research Lab) seminar: discussing works-in progress and papers in health geography and spatial epidemiology, Montreal, QC, Canada

2011 "Methodology in statistics and epidemiology" – Ecole d'été de santé publique et d'épidémiologie, Université Paris-Sud 11

WORK AND RESEARCH EXPERIENCE

2011-2014 **Research assistant** – INSERM UMR_S1136, France

Main project: RECORD Cohort Study

Supervisor: Basile Chaix

- Logistic and methodological assistance
- Contribution to improve the individual mobility questionnaire to be used in the RECORD Cohort Study

2009-2010 **Research intern** – Institut de Recherche pour le Développement (IRD), Dakar, Sénégal

Main Project : ANR ACTU-PALU

Supervisor : Sebastien Oliveau

- Realization of a survey on individuals' therapeutic itinerary in Dakar

Member of the intersite research axis « ESSE » (Espaces de Santé, Santé des Espaces) de l'UMR 6012 ESPACE

2008-2009 **Research intern -** Ministère de la Santé, des Affaires Sociales et de la Famille de la République du Congo, Brazzaville, Congo

Supervisors: Elisabeth Dorier-Apprill and Frédéric Audrad

- Elaboration and validation of a population-based survey on malaria health care
- Elaboration and realization of an entomological survey, in collaboration with entomologists from WHO Congo
- Realization of a Geographic Information System on malaria in Brazzaville

PUBLICATIONS, PEER-REVIEWED

[**PERCHOUX C.** KESTENS Y. THOMAS F. VAN HULST A. THIERRY B. CHAIX B.] "Assessing patterns of spatial behavior in health studies: their socio-demographic determinants and associations with transportation modes (the RECORD Cohort Study)", *Social Science & Medicine*, (2014) 119C, 64-73.

[**PERCHOUX C.** CHAIX B. CUMMINS S. KESTENS Y.] "Conceptualization and measurement of environmental exposure in epidemiology: Accounting for activity space related to daily mobility", *Health and Place*, (2013) 21,86-93.

[CHAIX B. KESTENS Y. DUNCAN S. MERRIEN C. THIERRY B. PANNIER B. BRONDEEL R. LEWIN A. KARUSISI N. **PERCHOUX C.** THOMAS F. MELINE J.] "Active transport and public transport use as a source of physical activity, sedentary time, and energy expenditure: a combined GPS, accelerometer, and mobility survey study", *International Journal of Behavioral Nutrition and Physical Activity*, (2014) 11 (1), 124.

[CHAIX B. MELINE J. DUCAN S. JARDINIER L. **PERCHOUX C.** MERRIEN C. KARUSISI N. LEWIN A. BROODEEL R. KESTENS Y.] Neighborhood environments, mobility, and health: towards a new generation of studies in environmental health research, *Revue* *d'Epidémiologie et de Santé Publique*, (2013) 61, Supplement 3, S139-S145

[CHAIX B. MELINE J. MERRIEN C. KARUSISI N. **PERCHOUX C.** LEWIN A. LABADI K. KESTENS Y.] "GPS tracking in neighborhood and health studies: a step forward for environmental exposure assessment, a step backward for causal inference? *Health and Place*, (2013) 21, 46-51

[CHAIX B. KESTENS Y. **PERCHOUX C.** KARUSISI N. MERLO J. LABADI K.] An Interactive Mapping Tool to Assess Individual Mobility Patterns in Neighborhood Studies. *American Journal of Preventive Medicine* (2012) 43, 440-450.

[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.] "Cohort Profile: Residential and non-residential environments, individual activity spaces and cardiovascular risk factors and diseases—The RECORD Cohort Study" *International Journal of Epidemiology* (2011)

[BORDERON M. **PERCHOUX C.**] « Le paludisme urbain à Brazzaville : De la géographie du risque aux stratégies de lutte antipaludique », 18e Biennale de géographie - *Actes du colloque Géopoint 2010* - Les échelles pour les géographes et les autres, Avignon, 6p.

MANUSCRIPTS SUBMITTED (PEER-REVIEWED JOURNALS)

[**PERCHOUX C.** CHAIX B. BRONDEEL R. KESTENS Y.] "Residential neighborhood, perceived neighborhood, and individual activity space: Quantifying differences in built environment exposure - The RECORD Cohort Study", *(To submit)*

[**PERCHOUX C.** KESTENS Y. BRONDEEL R. CHAIX B.] "Accounting for the multiple daily activity places of people in the study of the built environment correlates of recreational walking (the RECORD Cohort Study)", *Preventive Medicine*

INVITED CONFERENCES AND WORKSHOP PRESENTATIONS

[**PERCHOUX C.**] “Neighborhood as environmental exposure: how to account for activity space”, Workshop “Defining neighbourhoods to measure contextual effects on inequalities: Large or small? Pre-defined or self-defined?”, June 2- 4, 2014, Biefield, Germany

ORAL PRESENTATIONS AT SCHOLARLY CONFERENCES

[**PERCHOUX C.** KESTENS Y. CHAIX B.] “Typology of individual spatial behavior and related environmental exposure in the RECORD Cohort Study”, Urban dynamic and Health, September 11-13, 2013, Paris, France

[**PERCHOUX C.** KESTENS Y. CHAIX B.] “Multi-place perspective for improved environmental exposure assessment: An analysis of individual spatial behavior in the RECORD Cohort Study”, XVth International Symposium in Medical/Health Geography, July 7-12, 2013, East Lansing, Michigan, USA

[**PERCHOUX C.** CHAIX B. KESTENS Y.] “Assessment of individual spatial behavior: results of the record cohort study”, URISA's GIS in Public Health Conference, June 17-20, 2013, Miami, Florida, USA

[**PERCHOUX C.** KESTENS Y. CHAIX B.] “Rethinking environmental exposure in epidemiology: Accounting for daily mobility”, Health & Space International Colloquium, 2nd edition, September 19-21, 2012, Marseille, France

[**PERCHOUX C.**] "Modéliser les parcours thérapeutiques individuels en milieu urbain", Health & Space International Colloquium, 8-10 September 2010, Marseille, France

[**PERCHOUX C.** BORDERON M.] “Consider a synthesis tool to malaria analysis”, Emerging New Researches in Geography of health and Impairment Conference, Geography Institute of Paris, June 10-11, 2010, Paris, France

[BORDERON M. **PERCHOUX C.**] "Urban malaria in Brazzaville: local, heterogeneity and global stake", Emerging New Researches in Geography of health and Impairment Conference, Geography Institute of Paris, June 10-11, 2010, Paris, France

[BORDERON M. **PERCHOUX C.**] « Le paludisme urbain à Brazzaville : hétérogénéité locale, enjeu global. De la géographie du risque aux stratégies de lutte antipaludique », 18ème Biénnale de Géographie, Géopoint 2010, 3-4 Juin 2010, Avignon, France

[BORDERON M. **PERCHOUX C.** DORIER E.**]** « Le paludisme urbain à Brazzaville. Présentation des résultats d'enquête », OMS Congo, April 17, 2009, Brazzaville, Congo

POSTER PRESENTATIONS AT SCHOLARLY CONFERENCES

[**PERCHOUX C.** KESTENS Y. CHAIX B.] "Considering multi-place exposures in the study of built environment correlates of recreational walking (the RECORD cohort study)", Seminaire de l'ED Pierre Louis de Santé Publique, 12ème édition, *Poster*, October 20-22, 2014, Saint-Malo, France

[**PERCHOUX C.** KESTENS Y. CHAIX B.] "Examining spatial behavior patterns for health studies: results of the RECORD Cohort study", Seminaire de l'ED Pierre Louis de Santé Publique, 11ème édition, *Poster*, October 21-23, 2013, Saint-Malo, France

[**PERCHOUX C.** CHAIX B. KESTENS Y.] "Accounting for individual space-time patterns in epidemiology" 15th Annual congress of CRCHUM's students, December 18, 2012, Montréal, Canada

[**PERCHOUX C.** KESTENS Y. CHAIX B.] "How to account for space-time behavior in epidemiologic studies?", Seminaire de l'ED Pierre Louis de Santé Publique, 10ème édition, *Poster*, October 8-10, 2012, Saint-Malo, France

[AUDARD F. BORDERON M. LALOU R. OLIVEAU S. **PERCHOUX C.**] "Malaria soon in your cities? The contribution of a micro-landscape analysis to the study of malaria transmissions risk in urban area", International Conference EDEN 2010, May 10-12, 2010, Montpellier, France

TEACHING

2010 **Introduction to Urban Geography** (30H)

B.Sc : « Environnement, Technologie et Société »

September 2010 – December 2010

Université de Provence Aix-Marseille I, France

FUNDING

2011 **Graduate Scholarship (Doctoral)** – (22,200$/year for 3 years) via CRCHUM from Canadian Institutes of Health Research

AWARDS

2013 **ESPUM Graduate scholarship** – (12,000$ for 1 year)

2012 **FRONTENAC Graduate Scholarship** – (4,500$/year for 3 years)

COMPUTING SKILLS

General: Word, Excel, PowerPoint, PubMed and Web of Science databases

Statistical: SAS, SPSS

Geographical:
- ArcGis, MapInfo - *GIS*
- Python - *Spatial programming*
- Envi, WinImage - *Remote Sensing*

- Surfer 8 - *Digital Terrain Model*
- Google Earth Advanced tools - *Web Mapping*

Other:

- Micromorph - *Mathematical Morphology software*
- Smart Elements - *Artificial Intelligence software, elaboration of expert system*

LANGUAGES

French and English (Excellent, written and spoken)

PUBLIC AND COMMUNITY CONTRIBUTIONS – UNIVERSITY RELATED

2009-2010 **Elected member of the Council of Unity of Training and Research of Geography** in Université de Provence Aix-Marseille I

2007-2010 **Member of the association of Geography « PLAGE »** *(PLateforme Associative des Géographes Etudiants aixois)*

SCIENTIFIC JOURNAL REFEREE

Health & Place