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The neighborhood environment and its association with the spatio-temporal footprint of tobacco consumption and changes in smoking-related behaviors in a Swiss urban area

Juan R. Vallarta-Robledo [a,b,c], Pedro Marques-Vidal [c,d], José Luis Sandoval [c,e], David De Ridder [a,b,c,f], Emmanuel Schaffner [g,h], Jean-Paul Humair [b], Jacques Cornuz [i], Nicole Probst-Hensch [g,h], Stéphane Joost [b,c,f,j], Idris Guessous [a,b,c,*]

[a] *Faculty of Medicine, University of Geneva, Geneva, Switzerland*
[b] *Department and Division of Primary Care Medicine, Geneva University Hospitals, Geneva, Switzerland*
[c] *Group of Geographic Information Research and Analysis in Population Health (GIRAPH), Geneva, Switzerland*
[d] *Department of Medicine, Internal Medicine, Lausanne University Hospital (CHUV) and University of Lausanne, Lausanne, Switzerland*
[e] *Department of Oncology, Geneva University Hospitals, Geneva, Switzerland*
[f] *Laboratory of Geographic Information Systems (LASIG), School of Architecture, Civil and Environmental Engineering (ENAC), École Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland*
[g] *Swiss Tropical and Public Health Institute, Basel, Switzerland*
[h] *University of Basel, Basel, Switzerland*
[i] *University Centre for General Medicine and Public Health, University of Lausanne, Lausanne, Switzerland*
[j] *La Source, School of Nursing, University of Applied Sciences and Arts Western Switzerland (HES-SO), Lausanne, Switzerland*

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ABSTRACT

This study aimed to evaluate the association of the neighborhood environment with the spatio-temporal dependence of tobacco consumption and changes in smoking-related behaviors in a Swiss urban area.

Data were obtained from the CoLaus cohort (2003–2006, 2009–2012, and 2014–2017) in Lausanne, Switzerland. Local Moran's I was performed to assess the spatial dependence of tobacco consumption. Prospective changes in tobacco consumption and the location of residence of participants were assessed through Cox regressions. Analyses were adjusted by individual and neighborhood data.

The neighborhood environment was spatially associated with tobacco consumption and changes in smoking-related behaviors independently of individual factors.

1. Introduction

Tobacco smoking is one of the main risk factors for premature death and several comorbidities (National Center for Chronic Disease Prevention and Health Promotion (US) Office on Smoking and Health, 2014). Numerous psychological, socioeconomic, cultural, biological, and environmental factors influence smoking behaviors (Caraballo et al., 2019; National Center for Chronic Disease Prevention and Health Promotion (US) Office on Smoking and Health, 2012; Wellman et al., 2016). The study of the neighborhood environment gained attention in recent years as evidence suggests that the place where people live influences smoking independently of individual factors (Pearce et al., 2012).

For instance, it is widely recognized that deprived neighborhoods present higher smoking prevalence (Algren et al., 2015), lower smoking cessation rates (Turrell et al., 2012), higher tobacco marketing exposure (Lee et al., 2015), and higher density of tobacco retailers (Galiatsatos et al., 2018; Yu et al., 2010). At the same time, individuals located in neighborhoods with higher accessibility to tobacco retailers present lower smoking cessation and higher smoking rates (Chuang et al., 2005; Finan et al., 2019; Halonen et al., 2014). Similarly, higher levels of urbanity and traffic noise are important stress factors (Hänninen and Knol, 2011; Lederbogen et al., 2011) and may be related to smoking behaviors (Cui et al., 2012; Peris and Fenech, 2020; Roswall et al., 2018). Furthermore, greater availability of green spaces in neighborhoods is associated with a higher prevalence of smoking cessation and a lower

* Corresponding author. Department of Primary Care Medicine, Geneva University Hospitals, Rue Gabrielle-Perret-Gentil 4, 1205 Geneva, Switzerland.
E-mail address: idris.guessous@hcuge.ch (I. Guessous).

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prevalence of smokers (Martin et al., 2020).

Additionally, other neighborhood indicators could potentially influence health-related outcomes but the lack of studies make it difficult to assess them (Pineo et al., 2018). For instance, neighborhoods with higher proportions of unemployment or low-quality jobs and higher population densities (overcrowding) may be related to higher socioeconomic deprived areas (Badland et al., 2014). At the same time, these highly deprived areas and residential zones with low population densities may have limited access to public services (e.g. hospitals, modes of transport, schools), and recreational areas (parks and public spaces) (Badland et al., 2014). These neighborhood inequalities may limit physical activity, connectivity across the urban area, development of social networks, and access to health preventive programs, which could increase the presence of social inequalities, morbidities, stress, and mental diseases (Badland et al., 2014; Luo et al., 2022), and ultimately, may lead to undesired smoking behaviors (Stead et al., 2001). Furthermore, the inclusion of a wider set of determinants could help to better draw policy interventions. For instance, socioeconomically deprived individuals may be more likely to smoke due to poor neighborhood conditions that facilitate smoking, such as depressed or stressful environments, thus, identifying specific neighborhood attributes is key to influence a change on smoking behaviors (Pearce et al., 2012).

As there is a clear association between smoking behaviors and the characteristics of the neighborhood environment, identifying geographic locations at risk can help to strengthen and improve smoking-related public policies on a local scale (Meng et al., 2015). However, despite the importance of place in understanding smoking behaviors and favor smoking preventive policies, studies assessing the geographic context of smoking through a spatial methodology are limited by aggregated geographic units (and thus subject to ecology fallacy), measuring few components of the neighborhood environment, and not considering temporal approaches (Brooks et al., 2021; Caraballo et al., 2019; Galiatsatos et al., 2020; Généreux et al., 2012; Kane and Farshchi, 2019; Xie et al., 2020). Studies considering time in their spatial methodology are based on cross-sectional data and focused on tobacco smuggling (Almeida et al., 2020, 2021), evaluating a maternal population only (Lee and Lawson, 2016), and assessing the effect of smoking bans (Meng et al., 2015; Vallarta-Robledo et al., 2021). Furthermore, none of these studies assessed whether the neighborhood environment influences changes in smoking-related behaviors, such as becoming a former smoker based on the characteristics of the neighborhood (i.e. social contagion) (Blok et al., 2013) or selecting the place of residence based on environments conducive to personal smoking behaviors (i.e. social homophily) (Flatt et al., 2012).

Using individual and geolocated data from a Swiss cohort, we aimed to evaluate spatio-temporal changes in tobacco consumption in a Swiss urban population. Likewise, we assessed how tobacco consumption is spatially associated with the individual and neighborhood socioeconomic, demographic, built, and natural environments, and whether the existence of such spatial footprints and their characteristics are associated with changes in smoking-related behaviors.

2. Methods

2.1. Health data

We used data from the CoLaus study, a population-based cohort that collects individual health-related data aiming to identify determinants of non-communicable diseases in participants aged 35–75 years in Lausanne, Switzerland. Baseline recruitment for the study began in 2003 and ended in 2006. The first follow-up took place between 2009 and 2012 and the second follow-up between 2014 and 2017. Self-reported information from questionnaires was collected using standardized procedures. A detailed description of the sampling and recruitment processes of this cohort can be found in Firmann et al. (2008), this process led to a representative population sample with similar age, gender, and postal codes distribution to the one in Lausanne. The study was approved by the institutional Ethics Committee of the University of Lausanne and participants provided informed written consent.

Only subjects living in the city of Lausanne, with data on tobacco consumption and a georeferenced address were selected for analysis. Individuals with missing data in covariates (see below) were excluded from the analysis.

2.2. Tobacco consumption

Tobacco consumption was defined as the average total amount of cigarettes or equivalents (1 cigarillo or pipe = 2.5 cigarettes; 1 cigar = 4.5 cigarettes) that an individual smoked per day. Never smokers, and former smokers with a history of more than 5 years without smoking, were allocated 0 cigarettes per day. Tobacco consumption was treated as a counting (numeric) variable for the spatial analysis and as dichotomous (tobacco consumption ≥ 1 vs tobacco consumption = 0) for the assessment of social homophily and contagion (see statistical analysis below).

2.3. Individual covariates

Age (years), gender, country of birth (Switzerland, other), ethnicity (Caucasian, other ethnicities), education level (low, middle, high), job status (low, middle, high, not working), and civil status (single, married, divorced, widowed) were selected to portray individual socioeconomic and demographic characteristics.

2.4. Neighborhood environment covariates

2.4.1. Socioeconomic and demographic neighborhood covariates

Annual median household income (1 CHF= 1.10 USD) at the subsector level was obtained from Lausanne's 2009 Census (https://www.vd.ch/themes/etat-droit-finances/statistique).

Neighborhood data related to population density, nationality, and gender were obtained from the population and households statistics database (STATPOP) which were available for the years 1990, 2000, and 2012–2019. Additionally, we used data from the structural business statistics (STATENT) for the 2011–2018 period and the years 1995, 2000, 2005, and 2008. Data from STATENT included the number of businesses per economic sector (1, 2, and 3), number of employments, and full-time employment equivalents. Information for both data sources was collected at a hectare scale (100 × 100 m) from the Swiss Federal Statistical Office (FSO) (https://www.bfs.admin.ch/bfs/en/home/services/geostat/swiss-federal-statistics-geodata.html).

2.4.2. Built neighborhood covariates

Built environment neighborhood data related to the number of floors and rooms of buildings were collected by the FSO (1990, 2000, and 2011–2019). Information regarding the number of schools, hospitals, parks, and public transport stops was obtained from the swissTLM3D dataset (https://www.swisstopo.admin.ch/en/geodata.html) which belongs to the Swiss Federal Office of Topography (swisstopo). Additionally, information related to tobacco consumption facilities (restaurants, cafes, bars, nightclubs, and gambling venues), where it was possible to buy tobacco before but not after the implementation of a ban (2009) in public spaces, and tobacco retailers (supermarkets, grocery stores, kiosks, and tobacco stores) was acquired from STATENT. The density of tobacco retailers and consumption facilities was calculated as the total number of these stores divided by the covered area (in km^2). Land use data were extracted from the FSO (1992/97, 2004/09, 2013/18). Built land use coverage included residential, public, recreational, industrial & commercial, and transportation (pedestrian, rail, and automobile) areas measured at a hectare scale. Finally, we included daily traffic noise exposure (at a 10 × 10 m grid-scale) using the sonBASE dataset (https

://www.bafu.admin.ch/bafu/en/home/topics/noise/state/gis-laerm datenbank-sonbase.html) from the Swiss Federal Office for the Environment (FOEN). We addressed noise levels using the median decibels (dB) in a buffer radius of 25 m.

2.4.3. Natural neighborhood covariates

Natural land use areas were obtained from the FSO at a hectare level and classified as green (forest, tree stands, lawns, etc.) and blue areas (lakes, rivers, etc.).

2.4.4. Neighborhood data allocation

For participants who were measured in a year when neighborhood data were not available, the closest year with available data was assigned. All neighborhood variables were assigned to the address of each individual at each specific wave (time-varying variables) and, except otherwise specified, contain information from a buffer radius of 800 m. We used 800 m (approximately 20 min on foot) as previous research suggests this is the distance that individuals are typically willing to walk to access public services and purchase daily needs (Victoria State Government, 2012). Because of the use of several independent variables, we selected relevant variables only using a variance inflation factor <5 as highly correlated covariates can lead to multicollinearity and unreliable statistical associations, which may influence the interpretation of the results (Vatcheva et al., 2016). A complete list of selected and removed neighborhood variables is enumerated in Table S1. As a result of this process, we only included in the analysis the neighborhood household income and foreign population levels as social neighborhood variables, density of tobacco retailers, daily dB noise traffic, and public, recreational, industrial & commercial land use areas as built variables, and green and blue land use areas as natural variables.

We did not consider the implementation of a smoking ban for closed public spaces in 2009 in the spatial analysis because this policy was constant over cohort periods and was executed in the entire state, thus, its implementation did not present geographic variations in the city of Lausanne.

2.5. Statistical Analysis

Numeric variables are described as mean ± standard deviation; binary and categorical variables are described as frequencies and percentages (%).

Local Moran's I indexes (LMI) were performed to evaluate local spatial dependence of tobacco consumption and reveal the existence of spatial clusters. LMI assesses the correlation between a given numeric variable (here tobacco consumption) and the mean of this variable in a specific studied area (spatial lag) (Anselin, 1995). This calculation produces a classification of four spatial clusters; high-high (HH) accounts for individuals with a tobacco consumption above the mean of the spatial lag surrounded by individuals with also a tobacco consumption above the mean of the spatial lag, low-low (LL) accounts for individuals with a tobacco consumption below the mean of the spatial lag surrounded by individuals with also a tobacco consumption below the mean of the spatial lag, high-low (HL) accounts for individuals with a tobacco consumption above the mean of the spatial lag surrounded by individuals with a divergent tobacco consumption below the mean of the spatial lag (spatial outliers), and low-high (LH) accounts for individuals with a tobacco consumption below the mean of the spatial lag surrounded by individuals with a divergent tobacco consumption above the mean of the spatial lag (spatial outliers). Areas located in spatial clusters of high tobacco consumption are composed of HH and LH while areas of low tobacco consumption consist of LL and HL. Values not statistically significant indicate neutral clusters with a random distribution of tobacco consumption (no spatial dependence). Statistical significance was assessed through a Monte Carlo procedure (Anselin, 1995) and 999 random permutations on a radius of 800 m, as carried out in a previous study on the same urban area (Joost et al., 2016). We defined an α level of $p \leq 0.05$. Additional analyses using spatial lags of 400, 600, 1000, and 1200 m (Fig. S1–S3), and restricted to individuals who participated in the three waves (Fig. S4) showed similar results.

Hurdle Negative Binomial regressions (HUNB) were performed to assess the impact that individual and neighborhood covariates have on the spatial dependence of tobacco consumption. HUNB is adequate when counting data have a high number of zeros and when zeros can only be shaped by one factor (i.e. non-smokers produce only zeros and smokers produce only values above zero) (Cameron and Trivedi, 2013; Mullahy, 1986). Five models were tested: i) raw tobacco consumption, ii) tobacco consumption adjusted for socioeconomic and demographic individual factors (Fig. S5), iii) model ii plus socioeconomic and demographic neighborhood factors (Fig. S6), iv) model iii plus built neighborhood factors (Fig. S7), v) model iv plus natural neighborhood factors. If the clusters' size decreased after such adjustments, those factors were spatially associated with tobacco consumption. We present the analysis stratified for baseline and the consecutive follow-ups. Supplementary analyses considering socioeconomic and demographic neighborhood factors only (Fig. S8), built neighborhood factors only (Fig. S9), and natural neighborhood factors only (Fig. S10) were also performed to identify which environment was impacting the most the size of the spatial clusters.

We ran chi-square on non-numeric data and Welch's t-tests on continuous variables to evaluate statistically significant differences ($p<0.05$) in individual and neighborhood characteristics between high and low spatial clusters of tobacco consumption.

Additionally, we performed Cox proportional-hazards models to assess social homophily: whether individuals were more likely to move their residence to a place located in a spatial cluster that favored their smoking behaviors (i.e. whether tobacco consumers [tobacco consumption ≥1] moved to clusters of high tobacco consumption and vice versa), and social contagion: whether living in spatial clusters of high or low tobacco consumption increased the likelihood to change smoking behaviors (i.e. whether tobacco consumers [≥1 cigarettes/day] became non-tobacco consumers [0 cigarettes/day]). Analysis of non-tobacco consumers becoming tobacco consumers was not possible due to the low number of individuals modifying this behavior (only 13 individuals became tobacco consumers and 11 were in neutral clusters). Cox models were performed on the raw spatial distribution of tobacco consumption and adjusted for individual and neighborhood factors. We also considered the implementation of a smoking ban in 2009, but only to adjust for changes in tobacco consumption across time (social contagion), as in the case of changes in the location of residence (social homophily), the ban was uniformly implemented in all the state without geographic variations across the city and adjacent areas. Results are presented as hazard ratios (HR) and confidence intervals (CI). Statistical analysis was performed in R 3.6.3. Additionally, we used the R libraries of rgeoda to perform LMI, pscl to run the HUNB regressions, sf and terra to make spatial calculations, survival to run the cox models, and ggplot2 to draw the maps.

3. Results

The dataset contains 15,316 observations. After removing individuals living outside the city of Lausanne (n=1,015; 7%), and with missing data on tobacco consumption (n=565; 4%) and covariates (n=345, 2%), the final sample population selected for the analysis encompassed 13,391 observations. The baseline accounts for 6,329 individuals, the first follow-up for 4,129, and the second follow-up for 2,933. The mean age at baseline was 52.2±10.8, 3,359 (53%) participants were women at baseline, 2,270 (55%) at follow-up 1, and 1,670 (57%) at follow-up 2. The mean of tobacco consumption among tobacco consumers was 18.4±13.8, 13.9±10.2, and 12.8±10.1 units per day at baseline, follow-up 1, and follow-up 2, respectively. Individual and neighborhood characteristics for the three waves, participants that were lost to follow-up, and excluded participants are presented in Table S2.

Participants were followed-up an average of 9±2 years.

3.1. Spatial clusters of raw tobacco consumption

Local spatial clusters of raw tobacco consumption are shown in Fig. 1. We observed similar spatial footprints of raw tobacco consumption at baseline (A), follow-up 1 (B), and follow-up 2 (C). Clusters of high tobacco consumption (HH and LH) were highly concentrated in the central part of the city (landmark #1) and located in the southwestern area (landmark #4). A small cluster of high tobacco consumption was also observed on the shores of the lake (landmark #6) at baseline. Clusters of low tobacco consumption (LL and HL) were observed at the east (landmark #2) for the three waves. Small concentrations of low tobacco consumption clusters were also found in landmarks #3 and #5 at baseline. Between 2 and 3% of the individuals were gathered in high-high clusters of tobacco consumption and between 4 and 15% in low-low clusters during the three periods.

Clusters of high tobacco consumption on landmarks #1 and #4, and clusters of low tobacco consumption on landmark #2, were persistent over the entire studied period (Fig. S11).

3.2. Individual and neighborhood characteristics among clusters of raw tobacco consumption

Fig. S12–S14 show individual and neighborhood characteristics between clusters of low and high tobacco consumption for the three-wave periods. We observed that individual conditions such as higher job status and education were in higher proportions in clusters of low tobacco consumption in comparison to clusters of high tobacco consumption at baseline and follow-up 1 while foreigners were in lower proportions. Women were also in higher proportions in clusters of low tobacco consumption during follow-up 1. Regarding the neighborhood environment, we identified a lower neighborhood income and higher foreign population, density of tobacco retailers, and land use for recreational, commercial & industrial areas in clusters of high tobacco consumption in comparison to clusters of low tobacco consumption during the three waves. In addition, the land use for public areas was statistically significantly higher in clusters of high tobacco consumption at baseline and follow-up 2. Natural areas showed inconclusive patterns, green areas were statistically higher in clusters of low tobacco consumption at baseline and blue areas were higher in clusters of high tobacco consumption at baseline but lower at follow-up 2. Except for the proportions of singles and public land use areas, that were constantly lower during the three waves, and traffic noise that was higher, neutral clusters presented mostly intermediate values between clusters of low and high tobacco consumption during the three waves.

3.3. Spatial clusters of tobacco consumption adjusted for individual and neighborhood socioeconomic, demographic, built, and natural factors

Adjustment for individual and neighborhood socioeconomic, demographic, built, and natural factors evidenced an important decrease in the size of the clusters for the three periods (Fig. 2). For instance, high-high clusters decreased between 89 and 97% while low-low clusters reduced their size between 89 and 98%. Small concentrations of clusters remained in the southwest area (landmark #4) at baseline and follow-up 2, and central-south (landmark #5) at baseline and follow-up 1. Particularly, as observed in Figs. S8–S10, the size of the spatial clusters of high tobacco consumption was highly reduced after adjusting for socioeconomic factors only at follow-ups 1 and 2 (84% and 80% size decrease, respectively) and built factors only at baseline (73% size decrease).

3.4. Changes in smoking-related behaviors

3.4.1. Social homophily

Around 86 of 3,606 (3%) non-tobacco consumers and 149 of 2,735 (5%) tobacco consumers changed their residence (at any point during the study period) to places located in clusters of high tobacco consumption. Similarly, 174 of 3,606 (4%) non-tobacco consumers and 91 of 2,735 (3%) tobacco consumers moved to areas located in clusters of low tobacco consumption. Table 1 presents the likelihood of changing residence to an area located in clusters of high tobacco consumption. Based on the unadjusted Cox model, tobacco consumers were more likely to move their residence to areas in clusters of high tobacco consumption in comparison to non-tobacco consumers (HR: 1.32; CI: 1.01, 1.72). However, this statistically significant association disappeared after adjustment for individual and neighborhood factors. In the adjusted analysis, males (HR: 1.45; CI: 1.10, 1.90), divorced (HR: 1.76; CI: 1.30, 2.38), and individuals with medium (HR: 3.25; CI: 1.46, 7.27) and low job status (HR: 2.68; CI: 1.17, 6.13) were more likely to move to these environments. The neighborhood environment was also associated

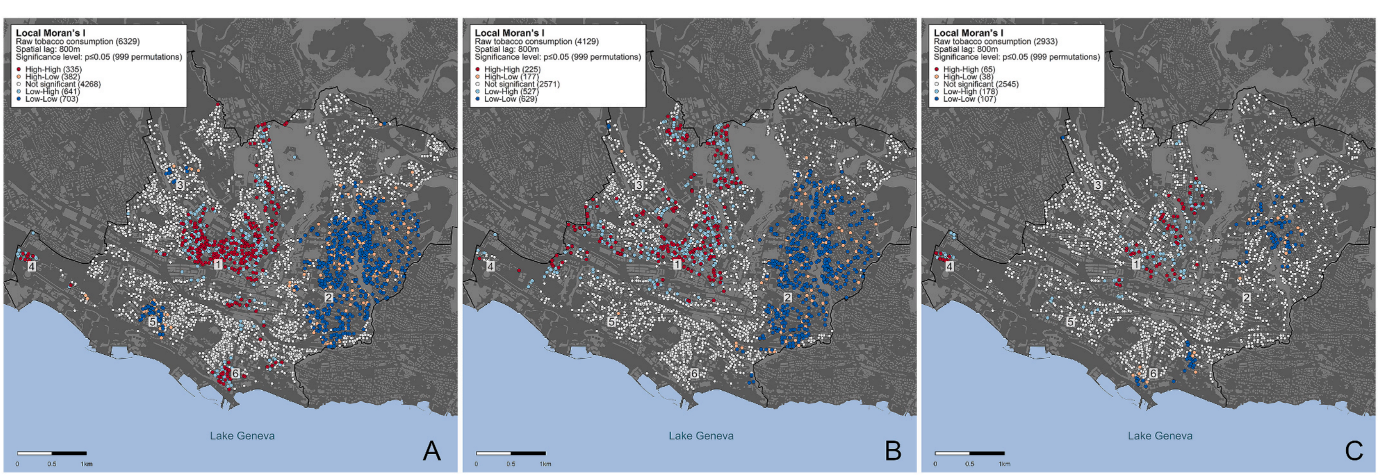

Fig. 1. Local Moran's I spatial clusters of raw tobacco consumption at baseline (A), follow-up 1 (B), and follow-up 2 (C). Red dots correspond to individuals with high tobacco consumption surrounded by individuals with also high tobacco consumption (High-High). Blue dots correspond to individuals with low tobacco consumption surrounded by individuals with also low tobacco consumption (Low-Low). Pink dots correspond to individuals with high tobacco consumption surrounded by individuals with divergent low tobacco consumption (High-Low). Light blue dots correspond to individuals with low tobacco consumption surrounded by individuals with divergent high tobacco consumption (Low-High). White dots correspond to individuals without spatial dependence on tobacco consumption (random distribution). Landmarks (1–6) are shown to facilitate interpretation of the results.

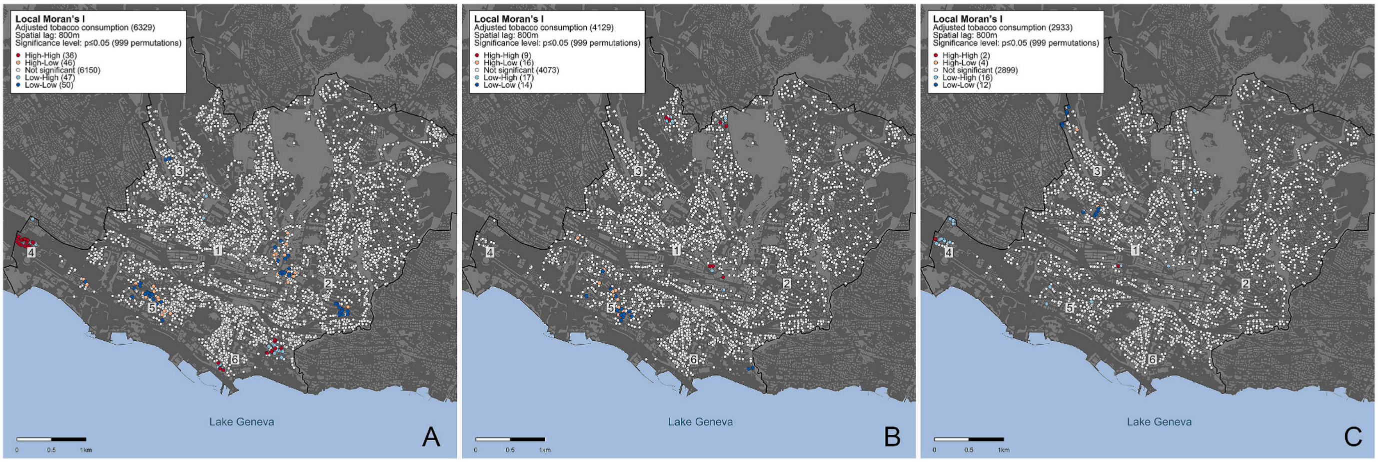

Fig. 2. Local Moran's I spatial clusters of tobacco consumption adjusted for individual and neighborhood socioeconomic, demographic, built, and natural factors at baseline (A), follow-up 1 (B), and follow-up 2 (C). Red dots correspond to individuals with high tobacco consumption surrounded by individuals with also high tobacco consumption (High-High). Blue dots correspond to individuals with low tobacco consumption surrounded by individuals with also low tobacco consumption (Low-Low). Pink dots correspond to individuals with high tobacco consumption surrounded by individuals with divergent low tobacco consumption (High-Low). Light blue dots correspond to individuals with low tobacco consumption surrounded by individuals with divergent high tobacco consumption (Low-High). White dots correspond to individuals without spatial dependence on tobacco consumption (random distribution). Landmarks (1–6) are shown to facilitate interpretation of the results.

with this behavior; a higher density of tobacco retailers (HR: 1.38; CI: 1.23, 1.55), neighborhood foreign population (HR: 1.46; CI: 1.32, 1.61), and recreational (HR: 2.30; CI: 1.84, 2.88), green (HR: 1.94; CI: 1.74, 2.17), and commercial & industrial land use areas (HR: 3.30; CI: 2.51, 4.34) increased the likelihood to move to these locations. There was not a statistically significant association of non-tobacco consumers changing their residence to areas located in clusters of low tobacco consumption (Table S3).

3.4.2. Social contagion

Regarding social contagion, by the end of follow-up 2, 250 of 434 (58%) tobacco consumers located in clusters of low tobacco consumption had become non-tobacco consumers, while 207 of 475 (44%) tobacco consumers presented the same behavior in clusters of high tobacco consumption. Table 2 shows the likelihood of becoming a non-tobacco consumer due to living in clusters of high tobacco consumption. In the unadjusted Cox model, tobacco consumers located in clusters of high tobacco consumption had a lower likelihood of becoming non-tobacco consumers (HR: 0.78; CI: 0.65, 0.93), however, this statistically significant association was not observed after adjustment for individual and neighborhood factors and a smoking ban. In the adjusted model, divorced (HR: 0.66; CI: 0.58, 0.76), widowed (HR: 0.74; CI: 0.59, 0.93), participants with low educational level (HR: 0.82; CI: 0.70, 0.95), and higher density of tobacco retailers (HR: 0.95; CI: 0.92, 0.98) were associated with reduced likelihoods of changing this smoking behavior. On the contrary, age (HR: 1.04; CI: 1.03, 1.15), individuals having a medium job (HR: 1.26; CI: 1.01, 1.56), land use for public areas (HR: 1.11; CI: 1.00, 1.22), and the implementation of a smoking-ban (HR: 1.23; CI: 1.09, 1.40) were associated with increased likelihoods that tobacco consumers became non-tobacco consumers.

4. Discussion

Spatial clusters of tobacco consumption were observed during the three waves of the CoLaus cohort in Lausanne, Switzerland. The neighborhood environment was associated with the spatial dependence of tobacco consumption independently of individual factors. The built, socioeconomic, and demographic environments were the strongest factors associated with this spatial dependence. The neighborhood environment was also associated with changes in tobacco consumption and the location of residence independently of individual factors.

4.1. Individual and neighborhood characteristics of spatial clusters of tobacco consumption

As observed in previous studies that used a spatial methodology to assess socioeconomic characteristics and the spatial dependence of smoking behaviors (Brooks et al., 2021; Caraballo et al., 2019; Généreux et al., 2012; Kane and Farshchi, 2019; Vallarta-Robledo et al., 2021; Xie et al., 2020), we also found socioeconomic and demographic differences regarding the spatial distribution of tobacco consumption. We detected a lower proportion of women, Swiss nationals, and highly educated and skilled participants in clusters of high tobacco consumption in comparison to clusters of low tobacco consumption. Such findings were not consistent for follow-up 2 probably because of the lower sample size at this period. We also observed persistent socioeconomic and demographic differences at a neighborhood scale during the three waves; the neighborhood household income was lower in clusters of high tobacco consumption while the population of foreigners was higher. Such results may explain the important reduction in the size of the spatial clusters of tobacco consumption observed after adjusting for these factors. Additionally, they highlight social inequalities that should be paid major attention as deprived populations are less likely to be positively impacted by tobacco control policies (Hiscock et al., 2012; U.S. National Cancer Institute, 2017).

We also observed a considerable reduction in the size of the clusters after adjusting for built environment factors. We identified that the density of tobacco retailers was higher in clusters of high tobacco consumption during the three periods of the study. Similar findings associating tobacco consumption retailers with the spatial dependence of smoking behaviors have been reported recently (Brooks et al., 2021; Galiatsatos et al., 2018; Vallarta-Robledo et al., 2021), and suggest a likely pathway of how smoking behaviors are influenced geographically since such locations promote consumption and exposure to marketing of tobacco-related products (National Center for Chronic Disease Prevention and Health Promotion (US) Office on Smoking and Health, 2012). We also found that clusters of high tobacco consumption were in regions with a higher land use of commercial & industrial, recreational, and public areas. Such characteristics closely related to the level of urbanization may indicate an association of smoking behaviors with stress levels caused by lifestyles in more urbanized and populated areas (Cui et al., 2012), and with high smoking levels in terraces and patios for hospitality settings and building entrances for outdoors (Fu et al., 2016;

Table 1
Likelihoods of changing residence to clusters of high tobacco consumption based on smoking behaviors and individual and neighborhood factors.

	Unadjusted model		Adjusted model	
	HR (CI)	p-value	HR (CI)	p-value
Tobacco consumers vs non-tobacco consumers	1.32 (1.01, 1.72)	0.04	1.03 (0.79, 1.36)	0.81
Age	0.99 (0.98, 1.00)	0.25	0.99 (0.98, 1.01)	0.76
Men vs women	1.37 (1.06, 1.76)	0.02	1.45 (1.10, 1.90)	0.008
Foreign vs Swiss	1.39 (1.07, 1.79)	0.01	1.12 (0.83, 1.51)	0.46
Other ethnicities vs Caucasian	2.12 (1.48, 3.04)	<0.001	1.33 (0.88, 2.01)	0.18
Single vs married	1.01 (0.68, 1.50)	0.96	1.14 (0.75, 1.73)	0.54
Divorced vs married	2.07 (1.51, 2.68)	<0.001	1.76 (1.30, 2.38)	<0.001
Widowed vs married	1.03 (0.56, 1.87)	0.94	1.21 (0.65, 2.24)	0.55
Medium vs high education	0.96 (0.63, 1.45)	0.83	0.88 (0.58, 1.34)	0.55
Low vs high education	1.44 (1.02, 2.02)	0.04	0.93 (0.63, 1.36)	0.70
Medium vs high job status	4.40 (2.01, 9.59)	<0.001	3.25 (1.46, 7.27)	0.004
Low vs high job status	4.70 (2.17, 10.16)	<0.001	2.68 (1.17, 6.13)	0.02
Not working vs high job status	3.16 (1.46, 6.87)	0.003	2.30 (0.96, 5.48)	0.06
Household neighborhood income (per 10,000 USD)	0.24 (0.19, 0.30)	<0.001	0.78 (0.60, 1.00)	0.05
Neighborhood foreign population (per 1,000 habitants)	1.31 (1.25, 1.38)	<0.001	1.46 (1.32, 1.61)	<0.001
Density of tobacco retailers	1.07 (1.03, 1.12)	<0.001	1.38 (1.23, 1.55)	<0.001
Commercial industrial areas	2.19 (1.98, 2.43)	<0.001	3.30 (2.51, 4.34)	<0.001
Public areas	1.11 (0.93, 1.34)	0.25	1.21 (0.84, 1.73)	0.30
Recreational areas	1.25 (1.18, 1.31)	<0.001	2.30 (1.84, 2.88)	<0.001
Daily traffic noise	0.99 (0.93, 1.06)	0.95	1.04 (0.96, 1.13)	0.37
Green areas	1.11 (1.05, 1.17)	<0.001	1.94 (1.74, 2.17)	<0.001
Blue areas	0.57 (0.45, 0.72)	<0.001	0.82 (0.60, 1.13)	0.23

Sureda et al., 2013). Traffic noise was not associated in any period possibly because it was measured at a lower buffer distance (25 m), which may not reflect what was occurring on a neighborhood scale.

Adjusting for natural areas also evidenced a reduction in the size of the clusters. When comparing the characteristics of the natural environment between clusters of high and low tobacco consumption we observed that green areas were statistically higher in clusters of low tobacco consumption. This association may be explained by pathways of stress in smokers (Buhelt et al., 2021; Stubbs et al., 2017) and a beneficial impact of green areas on mental health (Beyer et al., 2014; Fan et al., 2011; van den Berg et al., 2010); however, this association was not significant for follow-ups 1 and 2. Furthermore, blue areas showed inconsistent results; these areas were higher in clusters of high tobacco consumption at baseline and lower at follow-up 2, a not statistically significant difference was observed at follow-up 1. Such inconclusive results may be the result of not differentiating among subcomponents of the natural environment (i.e. parks, forests, lawns areas, rivers, lakes, etc.) (Fan et al., 2011; van den Berg et al., 2010). Additionally, except for singles, public land use, and traffic noise, individual and neighborhood characteristics in neutral clusters presented mostly intermediated values in comparison to clusters of high and low tobacco consumption, which

Table 2
Likelihoods of becoming a non-tobacco consumer based on the spatial footprints of tobacco consumption and individual and neighborhood factors.

	Unadjusted model		Adjusted model	
	HR (CI)	p-value	HR (CI)	p-value
High clusters vs low clusters	0.78 (0.65, 0.93)	0.006	0.99 (0.76, 1.35)	0.98
Neutral clusters vs low clusters	0.91 (0.80 1.05)	0.19	1.12 (0.94, 1.28)	0.21
Age	1.03 (1.03, 1.04)	<0.001	1.04 (1.03, 1.04)	<0.001
Men vs women	1.13 (1.02, 1.25)	0.02	1.04 (0.93, 1.15)	0.50
Foreign vs Swiss	0.90 (0.81, 1.00)	0.06	1.00 (0.90, 1.12)	0.96
Other ethnicities vs Caucasian	0.81 (0.65, 1.01)	0.06	0.91 (0.72, 1.16)	0.46
Single vs married	0.78 (0.67, 0.90)	<0.001	0.86 (0.74, 1.00)	0.06
Divorced vs married	0.64 (0.56, 0.74)	<0.001	0.66 (0.57, 0.76)	<0.001
Widowed vs married	0.97 (0.77, 1.22)	0.78	0.74 (0.59, 0.93)	0.01
Medium vs high education	0.90 (0.78, 1.05)	0.18	0.88 (0.75, 1.02)	0.10
Low vs high education	0.85 (0.75, 0.95)	0.01	0.82 (0.70, 0.95)	0.01
Medium vs high job status	1.15 (0.95, 1.41)	0.16	1.26 (1.01, 1.56)	0.04
Low vs high job status	0.90 (0.74, 1.09)	0.30	1.11 (0.89, 1.42)	0.35
Not working vs high job status	1.37 (1.14, 1.65)	<0.001	0.95 (0.76, 1.20)	0.65
Household neighborhood income (per 10,000 USD)	1.09 (1.03, 1.15)	0.001	1.05 (0.98, 1.12)	0.14
Neighborhood foreign population (per 1,000 habitants)	0.99 (0.97, 1.01)	0.26	1.02 (0.98, 1.06)	0.34
Density of tobacco retailers	0.98 (0.96, 0.99)	0.03	0.95 (0.92, 0.98)	0.004
Commercial industrial areas	0.96 (0.90, 1.03)	0.25	1.03 (0.94, 1.13)	0.47
Public areas	1.01 (0.94, 1.10)	0.64	1.11 (1.00, 1.22)	0.04
Recreational areas	0.98 (0.94, 1.02)	0.33	0.96 (0.91, 1.01)	0.12
Daily traffic noise	0.97 (0.95, 0.99)	0.02	0.98 (0.96, 1.01)	0.32
Green areas	0.99 (0.98, 1.02)	0.91	0.96 (0.92, 1.00)	0.06
Blue areas	1.01 (0.98, 1.04)	0.41	1.01 (0.98, 1.04)	0.56
Implementation of a smoking ban policy	1.30 (1.14, 1.48)	<0.001	1.23 (1.09, 1.40)	0.001

further illustrates the disparities that existed between those spatial clusters.

4.2. Persistent footprints of tobacco consumption

Even though we observed an encouraging decrement in tobacco consumption over time, the spatial footprints of tobacco consumption were similar across periods and presented some persistent clusters. These spatial footprints were consistently associated with individual and neighborhood inequalities. We observed that after adjusting for socio-economic factors, the size of the clusters was significantly reduced during follow-ups 1 and 2, whereas a similar pattern was observed after adjusting for built factors at baseline. This finding could suggest an encouraging effect of the smoking law on the built environment as the evaluation at follow-up 1 was conducted just after the implementation of a smoking ban in public areas, and may evidence the lack of successful tobacco control policies to reduce social inequalities (Smith et al., 2020). Moreover, the persistence of geographic clusters of high tobacco consumption should be of concern as it may contribute to the formation of future clusters of lung cancer (Czaderny, 2019). Contrary to other studies (Almeida et al., 2020, 2021), we do not assume that tobacco smuggling plays an important role in these spatial clusters since the implementation of tobacco policies was the same across the studied area and adjacent regions.

4.3. Changes in smoking-related behaviors

We found that tobacco consumers living in clusters of high tobacco consumption were less likely to become non-tobacco consumers in comparison to those in clusters of low tobacco consumption. However, no association was observed after adjusting for individual and neighborhood factors. These results were in concordance with two longitudinal studies (Blok et al., 2013; Ivory et al., 2015) that found weak associations between neighborhoods with high smoking prevalence and changes in smoking behaviors. Similarly, we found that tobacco consumers were more likely to change their residence to areas located in clusters of high tobacco consumption, but again, this finding was only observed in the unadjusted model. Interestingly, some characteristics of these clusters of high tobacco consumption such as a higher foreign population and density of tobacco retailers, and higher coverage of commercial & industrial, recreational, public, and green areas were associated with these behavioral changes even after adjusting for individual factors and a smoking ban, which proposes that indeed, the neighborhood environment influences smoking-related behaviors.

4.4. Neighborhood indicators

We initially proposed a large compilation of indicators to measure the neighborhood environment. However, when assessing multicollinearity many of them were strongly correlated, which is not entirely surprising as they are related to socioeconomic deprivation (e.g. full-time employments and business per economic sector), population density (e.g. total population, gender population, number of buildings, and floors per building), and access to public services and connectivity (e.g. number of parks, public transport stops, hospitals, and schools). Similarly, we observed a correlation coefficient of 0.97 between tobacco retailers and tobacco consumption facilities and very similar spatial patterns (data not shown) indicating a strong association among these indicators as reported in a previous study in Switzerland (Vallarta-Robledo et al., 2021). There are different approaches to deal with highly correlated variables, such as the creation of composite indexes, theory-based selection, and variable selection through VIF. We decided to use VIF because, as stated in the methods, avoids unstable statistical findings (Vatcheva et al., 2016), and in comparison to the use of indexes, facilitates the interpretation of the results as it is easier to understand which specific factors are influencing the outcome.

4.5. Strengths

Our study has several strengths. First, we used data at the individual level which allowed us to consider space as continuum rather than as isolated aggregated components. Second, we objectively assessed the neighborhood environment from different settings and a wide variety of open data sources, proving this can be a useful methodology to assess the neighborhood environment. Third, we adjusted our analyses for time-varying individual and neighborhood data which allowed us to assess the evolution of the spatial clusters of tobacco consumption and changes in smoking-related behaviors.

4.6. Limitations

A major limitation was the 54% decrement in the sample size at follow-up 2 in comparison to the baseline, which probably also explains the small size of the clusters observed in this period. Nevertheless, the analysis performed using only individuals who participated in the three waves showed very similar patterns and we observed similar distributions in most of the variables; the higher percentage of not workers presented in this last wave is expected due to the nature of the population (mean age at this wave is 63 years and many individuals might be retired by that time). Moreover, some environmental variables were not consistently collected during the 2003–2010 period. However, we observed similar results for the 2011–2018 period and many of the neighborhood characteristics we measured are not likely to drastically change over time. We could not assess whether the change of residence in participants was driven by personal motivations or other factors, such as change of work or lease termination. Indeed, we observed that marital and job status were associated with a change of residence, however, the density of tobacco retailers was also associated independently of these individual factors, suggesting the neighborhood environment also plays a role in this behavior. Results cannot be generalized to other populations as the characteristics of the neighborhood may vary. The CoLaus study focuses only on residents of Lausanne, and not commuters of near areas, because it would be very difficult to assess how much their smoking behaviors would be influenced by the city of Lausanne and how much by the area where they live.

4.7. Policy Implications

Our findings can help guide preventive smoking policies that consider the geographic location and target local populations at risk. Our policy recommendations for local areas follow the suggested by Moon et al. (2018) and Pearce et al. (2012). Particularly, we consider that tobacco retailers, or stores that facilitate smoking, should be limited in areas where exist a high consumption of tobacco, giving close attention to areas that are frequented by schoolers and adolescents since their easy accessibility may favor the initiation of smoking. These regulations should also be extended to tobacco advertising since individuals are exposed to the built environment in their daily interactions (e.g. ads located in public transport stops).

Furthermore, given that we observed important social inequalities in clusters of high tobacco consumption, policies that improve living conditions and ensure the message is sent and received well (through a better understanding of the sociodemographic and built environment context) should be encouraged. These policies may focus, for example, on developing non-stressful and non-depressive environments or increasing resources for accessing smoking cessation interventions at local clinics or community centers.

Finally, smoking comprehensive smoking bans are strongly encouraged, nowadays, many countries (including Switzerland) have partial smoking bans, allowing smoking in public spaces that have a dedicated area, this can be a temptation for smokers trying to quit or may facilitate smoking initiation through social interactions.

5. Conclusions

The spatial analysis highlighted geographic footprints of tobacco consumption and significant inequalities in Lausanne, Switzerland. The neighborhood environment may spatially impact tobacco consumption and was associated with changes in smoking-related behaviors, such as quitting smoking and the selection of residence independently of individual factors. The neighborhood environment should be given greater attention when developing smoking preventive policies.

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Data availability statement

Due to the sensitivity of geolocated data and the lack of consent for online posting, data cannot be made accessible. Individual reasonable requests that meet the criteria for access to confidential data may be possible on the corresponding study website https://www.colaus-psycolaus.ch.

Declaration of competing interest

None.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.healthplace.2022.102845.

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