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Roberto Valiente (roberto.valiente@uah.es)[1,2], MSc GIS; Francisco Escobar (francisco.escobar@uah.es)[1], PhD; María Urtasun (maria.urtasun@uah.es)[2,3], MPH; Manuel Franco (manuel.franco@uah.es)[2,4,5], PhD; Niamh K. Shortt (Niamh.Shortt@ed.ac.uk)[6], PhD; Xisca Sureda (francisca.sureda@uah.es)[2,5,7,8], PhD

[1] Department of Geology, Geography and Environmental Sciences, University of Alcalá, Alcalá de Henares, Madrid, Spain.

[2] Public Health and Epidemiology Research Group, School of Medicine, University of Alcalá, Alcalá de Henares, Madrid, Spain.

[3] Cooperativa APLICA, Madrid, Spain.

[4] Department of Epidemiology, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD, United States.

[5] Department of Epidemiology & Biostatistics, Graduate School of Public Health & Health Policy, City University of New York, New York, NY 10027, United States.

[6] Centre for Research on Environment, Society and Health, School of GeoSciences, University of Edinburgh, Edinburgh, Scotland, United Kingdom.

[7] Tobacco Control Research Group, Institut d'Investigació Biomèdica de Bellvitge-IDIBELL, l'Hospitalet de Llobregat, Barcelona, Spain.

[8] Consortium for Biomedical Research in Respiratory Diseases (CIBER en Enfermedades Respiratorias, CIBERES), Madrid, Spain.

Corresponding author: Xisca Sureda, BPharm, MPH, PhD. Public Health and Epidemiology Research Group, School of Medicine, University of Alcalá. Campus Universitario - Ctra. de Madrid-Barcelona, Km. 33,600. Alcalá de Henares, Madrid, 28871, Spain. Email: francisca.sureda@uah.es - Telf: +34 918 222 351.

ABSTRACT

Introduction. To review the geographical exposure measures used to characterize the tobacco environment in terms of density of and proximity to tobacco outlets, and its association with smoking-related outcomes.

Methods. We used PubMed and Google Scholar to find articles published until December 2019. The search was restricted to studies which 1) measured the density of and/or proximity to tobacco outlets and 2) included associations with smoking outcomes. The extraction was coordinated by several observers. We gathered data on the place of exposure, methodological approaches, and smoking outcomes.

Results. Forty articles were eligible out of 3,002 screened papers. Different density and proximity measures were described. 47.4% density calculations were based on simple counts (number of outlets within an area). Kernel Density Estimations and other measures weighted by the size of the area (outlets/sq km), population, and road length were identified. 81.3% of the articles which assessed proximity to tobacco outlets used length distances estimated through the street network. Higher density values were mostly associated with higher smoking prevalence (76.2%), greater tobacco use and smoking initiation (64.3%); and lower cessation outcomes (84.6%). Proximity measures were not associated with any smoking outcome except with cessation (62.5%).

Conclusion. Associations between the density of tobacco outlets and smoking outcomes were found regardless of the exposure measure applied. Further research is warranted to better understand how proximity to tobacco outlets may influence on smoking outcomes. This systematic review discusses methodological gaps in the literature and provides insights for future studies exploring the tobacco environment.

IMPLICATIONS

Our findings pose some methodological lessons to improve the exposure measures on the tobacco outlet environment. To solve these methodological gaps is crucial to understanding the influence of the tobacco environment on the smoking outcomes. Activity spaces should be considered in further analyses since individuals are exposed to tobacco beyond their residence or school neighbourhood. Further studies in this research area demand density estimations weighted by the size of the area, population, or road length; or measured using Kernel Density Estimations. Proximity calculations should be measured through the street network and should consider travel times apart from the length-distance.

1. INTRODUCTION

Tobacco consumption remains as the most preventable and premature cause of mortality in the World, causing over 7.1 million deaths each year.[1] The World Health Organization (WHO) prompted a set of policy guidelines to combat the global tobacco epidemic, such as tobacco taxes, smoke-free policies, advertising and promotion bans, regulations of the content, packaging, and labelling of tobacco products.[2] However, regulating the built environment (i.e. the location, opening hours and sales of outlets) have experienced less progress on policy agendas for tobacco control. Tobacco outlets remain ubiquitous, resulting in high availability of and accessibility to tobacco products for the population. Given that reason, tobacco outlet regulation has been identified as the next frontier in tobacco control.[3–5]

Previous studies identified some mechanisms through which the tobacco availability and accessibility may affect the tobacco normalization and smoking prevalence,[6] encouraging smoking initiation [7] and the risk of relapse, and reducing cessation rates.[8] Whilst many authors have found an association between either availability of or accessibility to tobacco and smoking outcomes, not all research has reported a positive association. Some have reported either null or inverse (negative) findings.[9]

Such inconsistency in results may arise due to the heterogeneity of methods used to characterize the availability of and accessibility to tobacco outlets in the environment. To understand this issue, some annotations should be considered about the concepts of availability and accessibility. Although both concepts might be explored from different dimensions (i.e. social, economic, spatial, etc.), in this review, we were focused on a geographical distance-based approach. In this regard, the availability refers to the supply of tobacco outlets, considering the number of outlets in a given area and the amount of population living there; and the types of tobacco products that can be purchased in these outlets. In contrast, accessibility is the relationship between the location of the supply and the location of users, taking into account the transportation resources and the travel time, distance and associated costs to tobacco purchase.[10] To approach the availability of and accessibility to tobacco in the environment, most of the research to date use exposure measures focused on either the density of tobacco outlets across neighbourhoods and around residence and school locations; or the proximity from these spaces to tobacco outlets. Recent advances in Geographic Information Systems (GIS) have assisted in the development of these exposure measurements.[11] In brief, GIS are computer-based methods and tools, which allow the organization, management and analysis of spatial and thematic information collected from different data-sources.[12–14]

Density and proximity measures are often used interchangeably and reported as comparable, but they do capture different aspects of the tobacco environment. Density measures in essence account for the provision, and to a degree the clustering of tobacco in any given area. Proximity is a measure of closeness, for example, how easily one can access tobacco from a certain location measured by either distance (length) or time (travel time). Both measures may have different, but related pathways, to smoking outcomes. For example, the price pathway may operate in different ways for each measure. In an area of high density there may be greater competition between retailers thus increasing market competition and lower prices. Alternatively, high proximity may reduce costs through reduced time or travel costs to purchase tobacco.

To reflect this heterogeneity of methods, this review explores both spatial density and proximity as measures of tobacco outlet environments. Specifically, our purpose in this paper is to review the literature that characterizes the tobacco outlet environment in terms of density and/or proximity to tobacco outlets, describing the exposure measures used and indicating the magnitude and direction of the association with smoking outcomes. We also aimed to explore how the exposure measures used may affect these associations.

2. METHODS

2.1. Data extraction: search criteria, design, and procedures

We conducted a search on Pubmed (US National Library of Medicine, Bethesda, Maryland, https://www.ncbi.nlm.nih.gov/pubmed/) to identify all articles focused on tobacco availability and accessibility in the environment published prior to December 31st, 2019. The search was restricted to studies which met the following inclusion criteria: 1) papers must include measures on density and/or proximity to tobacco outlets and 2) they must include associations with at least one smoking outcome. Specifically, we considered all the outcomes related to smoking prevalence, tobacco use patterns and initiation and cessation. The final variables which were used to approach these three smoking outcomes in the reviewed articles are presented in the Table S1 in supplementary material.

We excluded all the articles that: 1) were systematic reviews, editorial letters, letters to editor, commentaries or other methodological papers which did not used original data; 2) did not explore objective measures on density of or proximity to tobacco outlets; 3) did not study associations with smoking outcomes; and 4) all the articles that were out of our scope (e.g. evaluating tobacco policy regulations, studying promotion, marketing strategies, price, illegal sales to youths or knowledge, perceptions and attitudes toward smoking).

The search terms used were as follows: (tobacco OR smoking OR cigar* OR smoker OR smokers OR cessation OR quit OR relapse) AND (retail* OR outlet OR outlets OR sale OR sales OR vending OR vendor OR "point of sale" OR point-of-sale OR "point of purchase" OR point-of-purchase OR store OR stores OR shop OR merchant OR pharmacy OR pharmacies OR supermarket OR "gas station" OR "petrol station") AND (availab* OR access* OR density OR proximity).

The screening process was carried out in two stages. In stage 1, we obtained the titles from the search in Pubmed, which were reviewed by one reviewer. We downloaded the titles of the articles which met our inclusion criteria, together with their abstracts and archived in Mendeley reference software (https://www.mendeley.com/). In stage 2, we reviewed the abstracts by pairs and then we obtained the full articles of those manuscripts that satisfied our inclusion criteria, which were carefully read by the reviewers. Each reviewer used a pre-defined extraction sheet performed in an Excel spreadsheet (Microsoft Corporation, 2016, https://products.office.com/es-es/excel) including the extraction variables to gather the needed information from each selected article. Table S2 in supplementary material shows all the variables included the coding sheet and their definition. Finally, we completed our search by and checking the references of the included papers and conducting similar searches in Google Scholar (http://www.scholar.google.com/; with search terms in English).

Data extraction was guided by a standard operation procedure, similar to the one designed by Glanz and her colleagues.[15] RV, MU and XS were involved in the screening process (both stages 1 and 2). They discussed each variable and tested the extraction sheet on a sub-sample of articles. The authors compared results and discussed discrepancies and systematic concerns the extraction process to ensure that they were addressed consistently. Once this pilot extraction process finished, the remaining articles were divided and reviewed by pairs. When discrepancies between pairs, another person was involved to solve the disagreement.

2.2. Data extraction: variables definitions

Using the coding sheet (table S2 in supplementary material), we firstly assigned an ID number to each article, compiled authors information, title, and publication characteristics: journal, country where the study was based on, year of publication, language and type of publication (i.e. research study, systematic review, editorial, letter to editor, comments, news or other). For those articles that were excluded, we also provided information about the reason why they were excluded (among those mentioned above). We then collected data about the study characteristics, exposure measures (density and proximity measures) and results (outcomes and associations) of each article.

2.2.1 Study characteristics

We classified the articles by their study design, including clinical trial, cohort study, case control studies, cross-sectional, ecological and multilevel study. We also noted whether the outcomes variables were referred to the area- (e.g. smoking prevalence in a given county) or individual-level (e.g. data on individual tobacco use). For those studies which included individual data, we described whether the studied population was focused on adults, youths, or other specific populations (e.g. pregnant or ethnic minority). In addition, we classified all the articles by the type of place from where they calculated the exposure to tobacco outlets (density and/or proximity to tobacco outlets): residence, school, or other locations (e.g. work, places for study, shop, or leisure activities, etc.).

2.2.2. Exposure measures: density of and proximity to tobacco outlets

We procured information about the exposure measures conducted in each article. First, we indicated if the study explored the density, proximity or both measures. We collected information about the types of density measures (e.g. number of outlets within an area, number of outlets per inhabitant, etc.) or proximity calculations (e.g. distance to tobacco outlet through the street network, etc.) conducted by each study. Next, we described the geographic unit of analysis defined by the authors, which means the spatial area in which the data were aggregated and operationalized. For those articles exploring density measures, we indicated whether the authors used the existing administrative areas (e.g. census tracts, counties, etc.) or if they generated buffers around specific locations using GIS. In the case that the article used buffers, we reported whether the buffers were calculated using crow flies' distances (crow flies' buffers) or street network distances (street network buffers). For those articles which assessed the proximity to tobacco retailers, we procured whether the distances were measured as the crow flies' or through the street network.

2.2.3. Outcomes and associations

Among the literature reviewed, we explored and counted the associations between the density and/or proximity measures and any smoking outcome related to prevalence (current smoking or lifetime smoking), tobacco use patterns and initiation (e.g. number of cigarette smoked per day, time to which the first cigarette is smoked or age at which an individual smoke his first cigarette, etc.), and cessation (e.g. number of intentions to quit smoking or days of abstinence, etc.) (see table S1 in the supplementary material). We coded these associations into "positive" or "inverse". Positive associations referred to the ones in which a higher value of tobacco outlet density or proximity was related to a statistically significant increase in the values of smoking prevalence, tobacco use, initiation, or smoking cessation outcomes. In contrast, inverse association related to ones in which the higher density or proximity values were related to a statistically significant decrease in the smoking prevalence, tobacco use, initiation, or cessation outcomes. We created a third category, defined as "no association", to classify those articles when the authors did not find statistically significant differences or identified null associations (statistically significant or not).

Those associations which were significant only under some circumstances were also noted. For instance, we refer to those associations which were only significant after adjustment for socio-economic conditions of the area, individual-level characteristics (e.g. age, sex, educational attainment, etc.) or the type of place of exposure where the calculation were conducted (e.g. a given study concludes a positive association between density of tobacco outlets and smoking prevalence around the residential environment but not around the schools).

2.3. Data analyses

We described the design and methodological approaches conducted among the reviewed articles. Overall, we obtained the list of countries where these studies were based on, the types of study design, the study population and the outcomes targeted. Moreover, we counted how many articles applied density, proximity or both measures and assessed how the use of these measures has evolved during the last years.

We developed summary tables to overview the main characteristics and methods applied by each article. We generated separate tables summarizing the related information for articles that used density or proximity calculations. These tables tallied the place of exposure, the geographic unit of analysis, the type of density or proximity calculation used, and the use of GIS and buffer and street network tools. Those articles that applied both density and proximity measures were duplicated in both tables.

Last, we described the direction and magnitude of the associations between the exposure (density and/or proximity to tobacco outlets) and the smoking outcome.

3. RESULTS

3.1. Study overview

Our search strategy yielded a total of 3,002 publications, of which 2,472 were excluded by the title screening and 530 abstracts were obtained for the first revision. In this revision, we rejected 438 abstracts and we included 92 for the full-text review. From these publications, 6 were not original articles, 6 did not explore objective measures on density of or proximity to tobacco outlets, 19 did not study associations between density of and/or proximity to outlets and smoking outcomes and 21 were out of the scope of our review. Finally, 40 articles were included. Figure 1 shows a flow diagram illustrating the screening process.

Table 1 shows a general description about the characteristics of the 40 studies included in this review. 24 articles were focused on density methods (n=60%), 2 on proximity ones (n=5%), and 14 used both density and proximity metrics (35%). All the articles have been published since 2007, and the number of publications increased rapidly since 2013 in accordance with the integration of GIS-based methods in public health studies.[14] Figure S1 in the supplementary material represent the increase of the number of studies using GIS to explore density of or proximity to tobacco outlets.

These publications were based on the following countries: United States (42.5%), Canada (30%), United Kingdom (10%), New Zealand (7.5%), Finland and Australia (5%, respectively). Most of the studies were cross-sectional (55%) following by cohort (25%) and ecological studies (15%). Adolescents and children were the population targeted on most of the studies (52.5%), together with adults (37.5%). Other specific population groups such as pregnant,[16] ethnic minorities,[17] or people that aim to quit smoking[18,19] were also studied (table 1).

Our findings showed associations between density and/or proximity to tobacco outlets and smoking prevalence (n=21 and 8 articles, respectively); tobacco use patterns and initiation (n=14 and 4 articles, respectively); and smoking cessation (n=13 and 8 articles, respectively) (table 1).

3.2. Geographic measures in tobacco outlet environment research

3.2.1. Density measures

We identified 5 types of density measures: 1) number of outlets within an area (i.e. simple counts) (n=18),[6,8,27–34,17,20–26] 2) number of outlets divided by the size of the area (e.g. outlets per square kilometre) (n=8),[18,35–41] 3) number of outlets per inhabitants (e.g. outlets per 1,000 inhabitants) (n=6),[34,42–46] 4) number of outlets per road length (e.g. outlets per 10 kilometres of roadway) (n=1)[7] and, 5) kernel density estimation (KDE) (n=7).[16,46–51] Figure S2 in the supplementary material illustrates the application and results of these exposure measures using maps. Table S3 in the supplementary material summarizes detailed information about the exposure measures based on tobacco outlet density for each article in this review.

All the studies which calculated the density as the number of outlets within an area used buffers to define a neighbourhood where the calculations were taken around the studied place of exposure, either residence (n=11), schools (n=7) and/or other activity spaces such as studying or working places, grocery shops, physical activity facilities or leisure venues (n=4). Furthermore, most of the articles which calculated the number of outlets divided by the size of the area used buffers (n=6) with the exception of two articles that divided the number of outlets by the extension of administrative areas such as census tracts[40] or public health units[41] (table S3).

The buffer is a GIS tool to define an area or zone around a given location within a specified distance and shape.[11,12] Just over half of the articles which applied buffers (n=24) used distances guided by the street network (street network buffer, n=13), while the remaining ones used crow flies' distances (crow flies' buffer, n=11) (table S3). While crow flies' distances represent the distance as the straight line without taking into account the obstacles in the space, the street network measures represent the path distance between two points through the streets (see differences in figure S2). The buffer sizes ranged from 50 to 1,600 metres for crow flies' buffers and from 250 to 3,000 metres for street network buffers. One study defined the buffer as the area within a radius of 6 blocks from the studied location.[20] The geographic unit of analysis used in all these measurements was the buffer area.

Other articles used density calculations in which the number of outlets was weighted by the total population who live in (number of outlets per inhabitants) or the length of roads and streets (number of outlets per road length) within an area. In these cases, the geographic unit of analysis was an administrative area such as census tract (n=1),[7] city (n=2),[42,45] public health unit (i.e. service area, n=1),[44] or county (n=2).[43,46]

Last, we found 7 studies that used kernel density estimations (KDE). The KDE is a spatial smoothing method to transform a sample of georeferenced point data (i.e. tobacco outlets) into a smooth continuous surface. Specifically, this technique estimates the intensity of tobacco outlets across a surface by calculating the overall number of outlets situated within a given search radius from a target point. This tool enables to weight the density calculation around each georeferenced point and introduces a distance function in which those points lying near the centre of the search area are weighted more heavily than those lying further.[11,12] This technique have been used to assign density values of specific points in the space, representing the locations of residential (n=4)[16,47,49,50] and/or schools (n=1) [47] addresses or postcodes. Other studies used KDE to calculate mean density values per inhabitants (e.g. 1000 inhabitants), within census tracts,[48] neighbourhoods,[51] or counties[46] (using these administrative areas as geographical units of analysis).

3.2.2. Proximity measures

We found several ways to approach the proximity to tobacco outlets in the literature. Most of the studies used GIS tools to calculate proximity by length (i.e. meters or miles) using crow flies' distances (n=2),[31,36] or street network distances (n=11).[17,18,39,24,28–30,32,35,37,38] We found only one article which expressed the distance between two points by time (i.e. travel times) (n=1).[52] Other authors calculated buffers to examine the presence or absence of tobacco outlets around the studied locations (n=2).[6,19] These studies applied crow flies' buffers whose size varied from 250 to 800 metres. Figure S3 in the supplementary material shows how these types of exposure measures based on proximity work in a map. Table S4 in the supplementary material shows the exposure measures based on proximity calculations to tobacco outlets among the reviewed articles.

Most of these articles analysed distances from residence (n=14) and/or school (n=4) locations to tobacco outlets (table S4). We found other articles that also assessed the proximity to tobacco outlets from other daily locations (activity spaces, e.g. places for studying, working, grocery shopping, physical activity or leisure) (n=2).[24,32] In most of the articles, the distances to tobacco outlets were operationalised from specific address locations, being the address the geographic unit of analysis, with exception of two studies that used the centroid of the postcodes.[19,52]

3.3. Associations between geographic measures and smoking outcomes

3.3.1. Associations between density of tobacco outlets and smoking outcomes

Table 2 shows the associations between density measures and smoking outcomes according to different methodological approaches. Among the studies assessing density of tobacco outlets, 21 explored associations with smoking prevalence, 14 with tobacco use patterns and initiation, and 13 with cessation.

Most of the studies assessing tobacco outlet density found positive associations with smoking prevalence (n=16/21, 76.2%), indicating that a higher tobacco retail density was associated with a higher smoking prevalence.[6,16,42,44,46,47,49,51,20,21,24,32,34,38–40] Similarly, nine out fourteen articles identified positive associations between tobacco outlet density and tobacco use patterns and initiation (n=9/14, 64.3%), demonstrating that a higher tobacco outlet density relates to a higher frequency of smoking, a higher susceptibility to smoking, an earlier tobacco initiation and, a shorten the time to the first cigarette in the morning.[7,8,21,22,25,26,36,42,48] In terms of cessation, eleven out of thirteen studies revealed inverse associations between the tobacco outlet density and cessation outcomes (n=11/13, 84.6%). All these articles showed that a higher tobacco outlet density is associated with a reduction in the number of days of abstinence, pro-cessation attitudes or quitting attempts among the current smokers.[8,18,50,27–30,32,37,41,49] Despite these results showed an overall association between the tobacco outlet density and worse smoking outcomes (i.e. all mentioned above in this paragraph), we did not identify large differences in the direction and magnitude of these associations according to the type of density calculation applied. In addition, we made the following observations based on further analysis of these findings.

First, all the studies which used KDE underlined positive associations with smoking prevalence (n=5),[16,46,47,49,51] and tobacco use patterns and initiation (n=1);[48] or inverse associations with cessation (n=2).[49,50] However, two of them only showed significant associations among residential environments [47] or urban areas.[46]

Second, among those articles which used densities based on simple counts (i.e. number of outlets within an area), we identified that those which applied crow flies' buffers more often found positive associations with smoking prevalence (n=4/5)[6,20,21,32] than those which used street network buffers (n=2/4).[24,34] In turn, those studies using street network buffers reported a higher number of positive associations between density and tobacco use patterns and initiation (n=3/3)[8,25,26] in comparison to those using crow flies' buffers (n=2/5).[21,22] The size of these buffers did not influence the associations between tobacco outlet density and smoking prevalence or tobacco use patterns and initiation. However, those articles which explored associations between density and cessation and considered buffer distances shorter than 800 metres (n=6)[8,27–30,32] seemed to find higher number of inverse associations than those which used buffer distances larger than 800 metres.[31]

Third, to date, density calculations weighted by the size of the area (i.e. number of outlets weighted by the size of the area) or population (i.e. number of outlets per inhabitants) have been mostly positively associated with smoking prevalence,[38–4034,42,44,46] but no patterns of association have been found with tobacco use patterns and initiation.[41,43] In terms of cessation, we only found exposure measures based on densities weighted by the size of the area, and most of them highlighted inverse associations (n=3/4).[18,37,41]

Finally, we found a sole article which quantified density as the number of outlets per road length and found positive associations with tobacco use patterns and initiation.[7]

3.3.2. *Associations between proximity to tobacco outlets and smoking outcomes*

Table 3 shows the associations between proximity measures and smoking outcomes according to different methodological approaches. Eight studies explored associations between proximity and smoking prevalence, 4 with tobacco use patterns and initiation, and 8 with cessation.

Overall, there is no consensus about the association between the proximity to tobacco outlets and the smoking prevalence and the tobacco use patterns and initiation. Whilst the half of articles assessing associations between proximity and these smoking outcomes did not find a statistical significant association, the remaining ones showed a positive relations, indicating that closest distances to tobacco outlets may increment the smoking prevalence (n=4/8),[24,28,32,52] the frequency of smoking and, shorten the time to first cigarette in the morning (n=2/4).[19,52] However, our results show strong evidence of the influence of proximity to tobacco outlets on cessation outcomes: 62.5% of studies which analysed these relationship highlighted a significant inverse association (n=5/8),[18,19,29,32,37] demonstrating that the proximity to tobacco outlets may reduce cessation rates, abstinence and quitting attempts amongst current smokers. Whilst the type of proximity calculation applied appeared to have little relevance to the associations between proximity to tobacco outlets and smoking outcomes, we drew three conclusions from our review of proximity.

First, no studies using crow flies' distances identified an association between proximity and smoking prevalence, tobacco use patterns or cessation.[31,36] In contrast, studies using street network distances were more frequent and reported some positive associations with smoking prevalence (n=3/3)[24,28,32] and inverse with cessation (n=4/6).[18,29,32,37] However, some of these articles noted that these associations were only significant under adjustment by socioeconomic conditions[37] or measuring the proximity to activity space locations[24,32] (table 3). Network distances better capture actual travel patterns and may be more realistic interpretations of proximity.

Second, the use of time distance (i.e. travel time) to approach proximity to tobacco outlets was infrequent (n=1). Overall, this type of calculation showed positive associations with smoking prevalence and tobacco use patterns and initiation. Nevertheless, this effect were less evident in models adjusted by socioeconomic conditions[52] (table 3). Furthermore, the use of travel time in any future studies would need to acknowledge the differences between modes of transport, for example walking versus travel by private car.

Finally, we found conflicting results among those studies which measured the presence or absence of tobacco outlets within a buffer area. On the one hand, the unique study which assessed the relationship between proximity and cessation found an inverse association.[19] On the other hand, two studies measuring the relationship with tobacco use patterns and initiation showed both positive[19] and no statistical significant associations,[6] respectively. Last, no evidence exists about the influence of the presence of tobacco outlets within a buffer distance on the smoking prevalence.[6]

4. DISCUSSION

4.1. Key findings and interpretation of results

In this review, we investigated which exposure measures have been used in the literature to characterize the tobacco availability and accessibility in the environment, in terms of density of and proximity to tobacco outlets. Forty articles published between 2007 and 2019 were included. Most of them used density measures rather than proximity ones.

The findings showed a lack of agreement on how the tobacco outlet environment should be measured and modelled. We also observed an increase in the number of publications including GIS-based methods on this field of research, mainly since 2013. Beyond the valuable applications which GIS offers to store, manage, analyse, visualise, and integrate different sorts of spatial data, the incorporation of these tools to tobacco research has allowed the development of more precise exposure measures. For instance, the first article included in our review, which was published in 2007, used density measures based on the number of outlets within an area defined by a 6 blocks radius buffer.[20] In the last years, some authors suggested the application of GIS to estimate more accurate buffer measures using the street network or to calculate the activity space of the targeted population. In addition, more complex measures on density were published later on by other authors, such as the number of outlets per inhabitants (2012),[42] by area size (2014),[18] per road length (2016),[7] or measures based on KDE (2015)[48] (see table S3).

This systematic review provide evidence about the influence of the tobacco outlet environment on the smoking outcomes. Density measures were overall positively associated with smoking prevalence (n=16/21, 76.2%) [6,16,42,44,46,47,49,51,20,21,24,32,34,38–40] and tobacco use patterns and initiation (n=9/14, 64.3%),[7,8,21,22,25,26,36,42,48] but inversely associated with cessation (n=11/13, 84.6%).[8,18,50,27–30,32,37,41,49] In contrast, there is little evidence on the influence of proximity to tobacco outlet and smoking prevalence and tobacco use patterns and initiation. However, a small majority of studies assessing the relationship between the proximity to tobacco outlets and cessation outcomes determined an inverse association (n=5/8, 62.5%).[18,19,29,32,37] All these associations were found independently of the type of density or proximity measure applied.

4.2. Methodological gaps: recommendations for future studies

The body of evidence described in this systematic review points out some methodological concerns which should be considered in future studies.

First, the use of buffers still constitutes a methodological challenge.[12,53] Buffers are used to define a neighbouring area around specific places of exposure (residence, school, etc.) to study the surrounding tobacco outlet environment that affects population attending these places. There is no consensus about which is the most effective way to calculate buffers (crow flies' or street network distances) and their size. Some authors argue that street network buffers are preferred because they reproduce the real movement of individuals throughout the space.[29,37,54] In addition, to define the size of the buffer we should consider different contextual factors, like the rurality of the study area or the population density, in order to select a walkable distance that the population may be willing to travel to purchase tobacco. The literature shows that those articles measuring densities based on number of outlets within an area and applying crow flies' buffers reported high number of positive associations to smoking prevalence, while those applying street network buffers informed high number of positive associations to tobacco use patterns. Besides, the use of buffers shorter than 800 metres (which is frequently considered as a walkable distance)[6] shows high inverse associations between density and cessation outcomes.

Second, the definition of neighbourhoods based on buffers or administrative divisions are also controversial since they do not depict the real environment where the population move, spend their time and conduct their daily activities. The individual activities are not constrained to geographic or administrative boundaries, nor the exposure received in the residential or school environment of a given individual constitutes the whole exposure which that person may experience in their daily life.[55] Beyond this spatial uncertainty, most of the current studies overlooked the time and duration of the activities that people conducted around the space and the related exposure that they received during that time. This issue is known as the Uncertain Geographic Context Problem (UGCoP) and constitutes one of the inherent problems in the definition of exposure measures to analyse the real impact of the environment on the population health.[55,56]

To minimize the UGCoP effect, we identified some articles in which the authors defined place of exposure as a set of daily locations that comprised the activity space of the individuals included in their study (e.g. places for studying, working, grocery shopping, physical activity or leisure). Despite this method is costly at the data and analysis level, they showed an effective way to illustrate the real influence of the entire tobacco environment on the individual smoking outcomes.[24,27,32,33,57–59] In addition, the latest GIS advances based on GPS (Global Positioning System) devices and Ecological Momentary Assessment (EMA) tools have facilitated the geolocalization of these activity spaces.[60] For instance, one of the articles included in this review used that EMA methods to track the participants' daily paths throughout the space and determine the real environmental influences (e.g. tobacco outlets) at which they are exposed.[33]

Third, most of the studies analysing the density of tobacco outlets used calculations based on the number of tobacco outlets within an area (i.e. simple counts) (n=18, 47.4%).[6,8,27–34,17,20–26] The implementation of other density measures has been less explored. Density measures based on number of outlets weighted by the size of the area, population, or road length might offer a broader insight on the density analysis as they intrinsically include information about some contextual factors such as the number of inhabitants, the extension of the area studied or the density of the road network, that may influence the location and the number of tobacco outlets and their related accessibility. Similarly, KDE measures have been little explored. Nevertheless, the use of KDE may provide some advantages compared to traditional density measures based on buffers or administrative areas. KDE results may be interpreted as a gravity model of accessibility expanded across a continuous surface (not constrained to a specific buffer or administrative area) in which the density values are estimated by using a distance function calculated from the location of the tobacco outlets.[11] Moreover, all articles reviewed reporting on KDE methods showed positive associations with smoking prevalence (n=3/3)[16,47,49] or tobacco use patterns and initiation (n=1/1);[48] and inverse associations with cessation (n=2/2).[49,50] However, from a public health policy perspective, the complex interpretation of the KDE analyses may difficult the implementation of their findings to reduce the tobacco retail density in the real life. For that reason, different researchers may have relied on more simple measures of tobacco retail exposures.

Last, we identified that most of the articles showing proximity analyses to tobacco outlets were based on street network distances (n=11, 81.25%).[17,18,39,24,28–30,32,35,37,38] Beyond the calculation of length distance, future studies should consider also travel time distances, which include other inherent concerns to the spatial movement such as the speed or the transportation mode (i.e. by foot, car, public transportation or mixed).[21,25] To date, we identified only one study which measured the proximity in terms of travel times. It found positive associations between proximity to tobacco outlets and smoking prevalence and tobacco use and initiation.[52]

4.3. Limitations and strengths of the systematic review

Prior to draw conclusions from this systematic review we should acknowledge its limitations. First, the articles reviewed in this study were mostly obtained from the PubMed database. This source is specially focused on manuscripts related to biomedicine and life science. We should notice that the PubMed library might overlook some articles exploring GIS-based measures on the environment. However, such disregarded articles might be focused on technical aspects of density or proximity measures and they are not probably to include associations with smoking outcomes (which is one of our inclusion criteria). Nevertheless, we also addressed similar searches on Google Scholar and checked all the references in the included articles to prevent this loss of information.

Next, the overall variety of study settings, exposure measures and smoking outcomes approached in the reviewed studies might limit the comparability between methods and results. We found some studies that proposed specific density or proximity calculations that have not been used in other studies (e.g. number of outlets per road length unit, n=1).[7] Future studies should deep on these calculations to analyse the extent to which may influence the results of their associations with smoking outcomes.

In addition, our review does not evaluate the quality of the data sources used by the reviewed articles, their accuracy, and veracity. Nevertheless, a recent-published systematic review assessed the influence of the quality of methods on the associations between tobacco outlet density and smoking behaviours among youths. Their findings did not provide consistent support to claim an effect of tobacco outlet density or proximity on youth smoking and emphaticise on the need for more research with improved methodology.[9] In this regard, our study offers a broader insight including those manuscripts which targeted other population groups beyond youths; and provides some methodological advice to improve the quality of exposure measures to characterize the tobacco environment in future studies.

Despite these limitations, this review presents several strengths. As far as we know, this is the first systematic review to analyse how associations between tobacco outlet density or proximity and smoking outcomes may vary by the exposure measure used. This systematic review comprises a large number of publications (n=40), from the first publications in this field of research to today. Moreover, this study offers a discussion about the progress in the methods used to characterize the tobacco environment; and suggests some methodological recommendations to enhance the accuracy of the exposure measures in future studies of this innovative research field. Despite all the articles reviewed in this study were based on developed countries, these methodological implications may also be applicable and useful for future studies in less developed settings.

5. CONCLUSIONS

This study poses a methodological review on how to quantitatively describe the tobacco outlet environment and how different exposure measures associate with smoking outcomes. Our findings identified a great heterogeneity of measures used to analyse the availability of and proximity to tobacco outlets in the environment. Overall, the density of tobacco outlets was positively related to smoking prevalence and tobacco use patterns and initiation; and inversely associated with cessation. All these complex associations were found regardless of exposure measure used to explore tobacco outlet density. However, further research is warranted to better understand how proximity to tobacco outlets may contribute to the smoking outcomes. Future studies should deal with the UGCoP, by including other places of exposure in the analyses (i.e. activity spaces). In addition, more complex density calculations such as those weighted by the size of the area, population or road length or KDE; and proximity calculations based on travel times should be considered to achieve higher precision in the characterization of the tobacco environment in further studies.

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TABLES

Table 1. Overview of the general characteristics on the studies included in the systematic review

	Type of measure			
	Only Density (n=24, 60%)	**Only Proximity** (n=2, 5%)	**Both** (n=14, 35%)	**Total** (n=40, 100%)
Country				
USA	11		6	17 (42.5%)
Canada	6	1	5	12 (30%)
United Kingdom	3		1	4 (10%)
New Zealand	2	1		3 (7.5%)
Finland			2	2 (5%)
Australia	2			2 (5%)
Study design[a]				
Cross-sectional	13	2	7	22 (55%)
Cohort study	5		5	15 (25%)
Ecological	5		1	6 (15%)
Case and controls	1		1	2 (5%)
Study population				
Adolescent and children	14		7	21 (52.5%)
Adults	9	1	5	15 (37.5%)
Specific population	1	1	2	4 (10%)
Associations of the density and/or proximity measures with smoking outcomes[b]				
	Density		**Proximity**	
Smoking prevalence	21		8	
Tobacco use patterns and initiation	14		4	
Cessation	13		8	

[a] All the studies were only classified in one of these categories.

[b] Note that one article may study several associations. On the one hand, the same paper may analyse the influence of density of tobacco outlets on different smoking outcomes (e.g. prevalence and cessation). On the other hand, there are articles that used density and proximity measures to analyse their association with a given smoking outcome (e.g. prevalence). In these cases, we have considered all the associations within a given article.

Table 2. Associations between density measures and smoking outcomes according to different types of calculations.

	Prevalence (n=21)			**Tobacco use patterns and initiation (n=14)**			**Cessation (n=13)**		
Type of density calculation	+	-	NA	+	-	NA	+	-	NA
Number of outlets within an area	6	1	2	5		3		6	1
*Crow flies' buffer area**	4		1	2		3		3	1
Building blocks	1								
Buffer ≤800 m	2		1	1		2		3[a]	
Buffer >800 m	1			1		1			1
*Street network buffer area**	2	1	1	3				3	
Buffer ≤800 m	2	1	1	2				3	
Buffer >800 m	1	1		2				1	
Number of outlets/Area	3			1		1		3	1
*Crow flies' buffer area**									
Buffer ≤800 m									
Buffer >800 m				1[a]					
*Street network buffer area**	2							2	1
Buffer ≤800 m	1							2	1

Buffer >800 m	1							1	1	
Administrative area	1[a]					1		1		
Number/Population	4[a]	1	1	1		1				
Number/Road length unit				1						
Kernel Density Estimations	5[a]			1				2		

+ Positive associations; - Inverse associations; NA No association

* One study may include different buffer sizes and test different types of calculations.

a Some of the articles found the underlined association after adjustment for socioeconomic conditions, individual-level characteristics (e.g. age, sex, educational attainment, etc.) or the type place of exposure where the density calculations were conducted (i.e. residential or school environment).

Table 3. Associations between proximity measures and smoking outcomes according to different methodological approaches.

	Prevalence (n=8)			Tobacco use patterns and initiation (n=4)			Cessation (n=8)		
Type of proximity calculation	+	-	NA	+	-	NA	+	-	NA
Crow flies' distances						1			1
Street network distances	3[a]		3					4[a]	2
Time	1[a]			1[a]					
Presence/absence of outlets within buffer			1	1		1		1	
*Crow flies' buffer**			1	1		1		1	
Buffer ≤800m			1	1		1		1	
Buffer >800m						1			

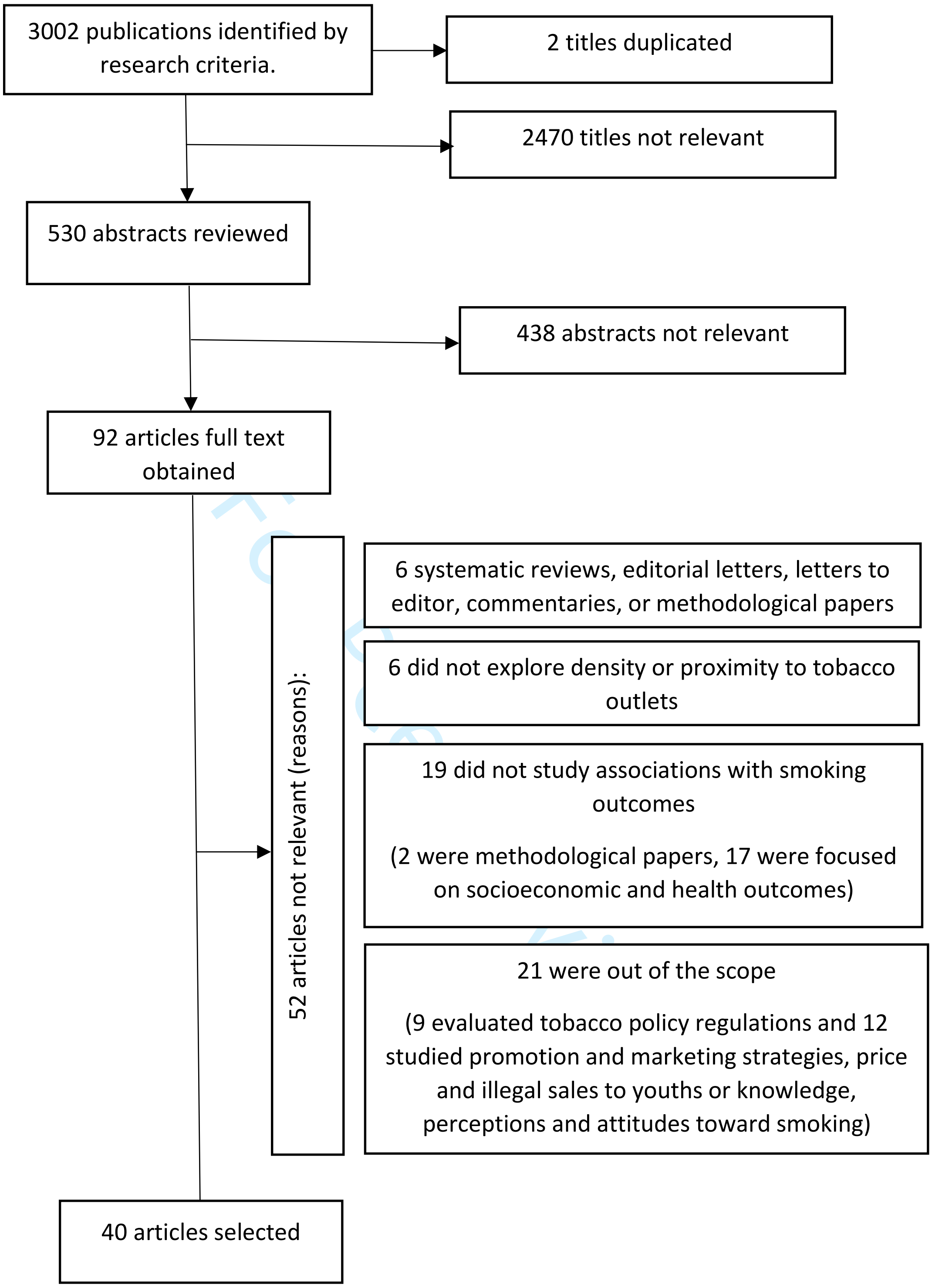
+ Positive associations; - Inverse associations; NA No association

* One study may include different buffer sizes

a Some of the articles found the underlined association after adjustment for socioeconomic conditions, individual-level characteristics (e.g. age, sex, educational attainment, etc.) or the type place of exposure where the density calculations were conducted (i.e. residential or school environment).

FIGURES

Figure 1. Flow diagram for the identification and selection of studies included in the review


3002 publications identified by research criteria.
2 titles duplicated
2470 titles not relevant
530 abstracts reviewed
438 abstracts not relevant
92 articles full text obtained
52 articles not relevant (reasons):
6 systematic reviews, editorial letters, letters to editor, commentaries, or methodological papers
6 did not explore density or proximity to tobacco outlets
19 did not study associations with smoking outcomes
(2 were methodological papers, 17 were focused on socioeconomic and health outcomes)
21 were out of the scope
(9 evaluated tobacco policy regulations and 12 studied promotion and marketing strategies, price and illegal sales to youths or knowledge, perceptions and attitudes toward smoking)
40 articles selected