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Tobacco retail availability and cigarette and e-cigarette use among youth and adults: a scoping review.

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Abstract

OBJECTIVE: States and localities are formulating strategies to reduce the widespread retail availability of tobacco products. Evidence of associations between retailer density/proximity and tobacco use outcomes can help inform those strategies. We conducted a scoping review on tobacco retail availability and cigarette/e-cigarette use in adults and youth, and considered variations in spatial units, measures of retailer exposure and outcomes across studies.

METHODS: A systematic search for studies examining the association between retailer density/proximity and youth and adult cigarette/e-cigarette use was conducted across MEDLINE (PubMed), Web of Science and Google Scholar through August 27, 2020 with no restrictions.

RESULTS: Thirty-five studies were included in our qualitative synthesis. While there were differences in neighborhood definitions (e.g. egocentric versus administrative), there is evidence for a positive association between higher retailer density in egocentric neighborhoods around homes and current smoking in adults and adolescents. Administrative unit measures in some studies showed associations with adult current smoking, and adolescent lifetime and current smoking. Studies on tobacco outlet proximity to homes obtained mixed results. Density/proximity of tobacco outlets around schools showed no or inverse association with adolescent smoking, but suggest higher susceptibility to smoking. Evidence of an association between e-cigarette retail availability and e-cigarette use is limited due to a small number of studies.

CONCLUSION: The current literature provides limited empirical evidence of the association between tobacco retailer availability and smoking or e-cigarette use. More

research with uniform measures of environmental exposure to tobacco retailers is needed to allow for greater comparability between studies.

INTRODUCTION

Smoking is the leading preventable cause of premature deaths in the United States.[1] Nevertheless, tobacco products are still widely available, with the vast majority sold through retail outlets.[2] Tobacco retailer density has been linked to smoking among youth and adults.[3, 4] There are several mechanisms through which retailer density may affect smoking. Higher density may reduce the search costs of finding and purchasing goods, [5, 6] increase opportunities to purchase tobacco products, and encourage retailers to reduce cigarette prices and increase illegal sales to minors due to increased competition.[7] Higher density may further support the ubiquity of smoking,[8] and increase environmental cues to smoke, whether through point-of-sale displays and advertising,[9] or the mere presence of an outlet.[10] Widespread availability also increases exposure to retail tobacco marketing and promotions, known to be risk factors for smoking initiation,[11] and impulse purchases.[12, 13]

The high concentration of tobacco retailers around schools [3, 14] or in areas with a large proportion of residents younger than 18 years [4] raises further concerns, as it exposes youth to high-risk environments during the ages in which the risks of initiation of tobacco use and transitions to daily use are greatest. Given the limited mobility and price sensitivity of youth, [15, 16] reducing retail density may be a particularly effective strategy to reduce youth smoking.

While there is a growing body of research examining the relationship between tobacco retailer availability and smoking behavior, there has been inconsistency in the measures used,

making comparisons difficult. For example, some studies have focused on tobacco retailer density, others on proximity to retailers. Similarly, some studies have focused on daily smoking, while others have examined smoking within the past 30 days. To date, five reviews have attempted to summarize the evidence on this topic. Notably, four reviews [17-20] focused solely on youth and young adults and one did not differentiate between youth and adult studies. [21] A meta-analysis [17] examined the relationship between retailer density near adolescents' homes and schools and past-30 day smoking, and did not consider proximity to outlets. A narrative review [18] included studies of retailer density and proximity with diverse smoking outcomes, but did not distinguish between exposure near schools versus homes. Systematic [19] and methodological [20] reviews examined studies on retailer density and proximity near schools and homes and diverse youth smoking outcomes. The conclusions emphasized fundamental challenges in study designs and measures of retailer exposure across studies. A recent methodological review [21] examined studies on retailer density and proximity, focusing on the heterogeneity of exposure measures. However, it did not distinguish between youth and adult smoking outcomes, or consider results relative to spatial units or study location (e.g. home, school, activity spaces) and did not report effect sizes. None of the prior reviews included studies on e-cigarette use, which has been increasing among US youth since 2011.[22, 23]

The aim of this scoping review is to summarize empirical evidence regarding the association between tobacco retailer density and proximity and the use of cigarettes and e-cigarettes by adults as well as youth. We aim to distinguish findings by population (adult vs. youth), various cigarette/e-cigarette use outcomes, spatial units (ego-centric buffers vs. administrative units) and study locations. In addition, we highlight variations in density/proximity measures,

differences in definitions of smoking/e-cigarette use outcomes, and control variables used, which may help account for inconsistent findings across studies.

METHODS

Literature Search Strategy

A systematic literature search was conducted on February 26, 2020 across MEDLINE (PubMed), Web of Science and Google Scholar databases, with no restrictions on year of publication, language or article types. The search was updated on August 27, 2020. The first 100 hits on Google Scholar were screened as they were considered to be most relevant to the search topic. Search strings were created via the advanced search builder using text word combinations in the Title or Abstract relating to retail availability (i.e. "retail", "sale*", "density", "proximity", "distance", "availability") and product use (i.e. "smoking", "tobacco use", "cigarette*, "e-cigarette*"). A three-step selection process was applied. First, two authors (NT and DL) independently screened titles and abstracts for eligibility. Second, full text articles of selected abstracts were retrieved from databases and screened for exclusion criteria. Finally, references of full-text articles were examined for additional relevant literature. Disagreements were discussed and resolved by consensus. The PRISMA check list for scoping reviews is available in the Supplementary Table S1.

Inclusion Criteria

Empirical studies were included if they examined tobacco retail availability as an exposure variable, and individual-level cigarette or e-cigarette use as an outcome variable (i.e. current smoking, ever-smoking, initiation, cessation, quit attempts, relapse, as well as intentions to quit and smoking susceptibility [as they are closely related to product initiation and cessation]), with full text articles in English accessible online. Studies that investigated

tobacco product categories that included e-cigarettes (e.g. alternative tobacco products) were also included. Tobacco retail availability measures included, inter alia, those described in the PhenX Tobacco Regulatory Project Toolkit, such as density (number of retailers divided by land area or by total population) in person-centered buffers around study participants' homes, schools or daily activity spaces (i.e. egocentric neighborhoods); density in administrative units (e.g., county, city, census tract); and proximity to the nearest tobacco retailer from homes, schools, daily activity spaces, or census area centroids.[24]

Exclusion Criteria

Studies were excluded if they investigated outcomes not related to cigarette or e-cigarette use (e.g. normative perception of smoking), used aggregated data to measure use prevalence, or examined associations in subpopulations rather than in the general population (e.g. treatment-seeking smokers) to allow for comparability and meaningful interpretation of results. Descriptive geospatial studies that did not aim to provide effect sizes were also excluded.

Data Extraction

The following information was synthesized from each study: first author, country, study design, data collection period, sample size, population, tobacco product type, measures of exposure, definitions of spatial units, covariates, tobacco use outcomes and effect sizes.

Qualitative Analysis

Given the heterogeneity and limited empirical comparability of studies, a scoping review was selected as the most suitable approach to provide a broad overview of research on the relationship between retailer density / proximity and cigarette/e-cigarette use in both youth and adult populations and map the differences in measures of exposure and outcomes. In

contrast to a systematic review, we included all relevant studies, without a priori attempting to synthesize them based on methodological quality.

RESULTS

We identified 553 records through the database searches and an additional 11 records through manual checks of bibliographies. After removing duplicates, 379 abstracts were screened for eligibility and 296 were excluded. Full-text articles for the remaining 83 records were retrieved and thoroughly assessed for exclusion criteria. An updated literature search following the same methods was performed through August 27, 2020, and identified 34 unique publications, of which two were included (Figure 1.)

Overall, 35 studies, published between 2003 and 2019, were included in the qualitative synthesis (Table 1). Most studies (19) were conducted in the US, while others came from Canada,[25-31] New Zealand,[32, 33] Finland,[34, 35] Australia [3, 36, 37] and Scotland.[38, 39] The majority (29) examined cigarette use; few focused on e-cigarettes [31, 40-42] or on alternative/non-combustible tobacco products that included e-cigarettes.[43, 44] Nearly half of the studies considered outcomes in adults (15), commonly ages 18+, except in three international studies,[3, 32, 38] where adults were defined as 15+ or 16+.

Studies of youth (20) included school age participants in school-based studies and youth and young adults (ranging from 7 to 23 years old) in home- and administrative unit-based studies (Table 2).

Overall, person-centered density measures were employed in 8 adult [25, 26, 28, 29, 35, 36, 45, 46] and 10 youth studies.[8, 30, 31, 33, 37, 41, 47-50] Administrative density measures per land area appeared in 5 adult [27, 38, 43, 46, 51] and 4 youth studies,[4, 39, 42, 44] and density per population count appeared in one adult [3] and 5 youth studies.[9, 52-55]

Proximity was measured as the shortest distance from home,[25, 26, 28, 29, 34, 35, 44-46, 49, 52] school [8, 42, 49, 50] or activity space [28, 29] to the nearest tobacco retailer in 15 studies, as a presence of at least one retailer per land area in 4 studies [8, 25, 31, 40] and as travel time by car to the nearest retailer in one study.[32]

Since most studies employed multiple outcomes and measures of exposure (Table 3), we grouped results for youth and adult populations by tobacco use outcomes based on the type of retailer exposure (density/proximity) and spatial units (person-centered buffers vs. administrative units). Additionally, we specified the types of buffers (circular vs. street-network) and distances (straight-line vs. roadway) used in the analyses.

Retailer density and smoking outcomes in adults

Current smoking

Five cross-sectional studies investigated the relationship between tobacco retailer density and adult current smoking, defined as daily or occasional,[3, 29, 36] "smoking at all nowadays" [38] and past 30-day smoking;[27] one cross-sectional study focused on the number of cigarettes smoked per day.[46] Using person-centered measures to capture density within 0.5 km street network buffers around participants' home address or in their daily activity spaces, higher retailer density in residential neighborhoods was associated with current smoking in two studies from Australia,[36] and Canada [29] with odds ratios (OR) ranging from 1.01 (95% CI:1.00, 1.01) [36] to 1.53 (95% CI: 1.23, 1.91; $p<0.05$),[29] and with a prevalence ratio (PR)=1.46 (95% CI: 1.26, 1.70; $p<0.05$) for density in daily activity spaces.[29] Higher density derived from administrative units, such as a count per 1,000 people within census tracts in Australia [3] or per km^2 within residential ZIP codes in Scotland [38] was associated with current smoking, with effect sizes ranging from dy/dx (predicted probability) = 0.07

(95% CI: 0.05,0.10; p<0.01)[38] to OR= 1.11(95% CI: 1.02, 1.21; p=0.018).[3] Density per km^2 within census tracts in a Canadian study was not associated with current smoking.[27] In a US study, density within 1-mile circular buffers around homes or per square mile in corresponding census tracts, was not related to the number of cigarettes smoked per day.[46]

Smoking initiation

In a cross-sectional US study, higher retailer density per 10 km of roadway within census tracts was associated with smoking initiation in young adults ages 25-34 (vs. ages 18-24) (OR=3.75, 95% CI= 1.18, 11.90, p<0.05).[43]

Smoking cessation, quit attempts and relapse

Five studies applied person-centered density measures using circular buffers [25] or street network buffers [26, 28, 35, 45] around participants' homes and investigated associations with their cessation outcomes. In two longitudinal studies, density within 500-meter buffers was associated with reduced 30-day smoking abstinence, but only in high-poverty neighborhoods in the US (OR= 0.94; 95% CI: 0.90, 0.98; p<0.01)[45] and with lower quit attempts in high-income (vs. lower-income) neighborhoods (OR= 0.54; 95% CI: 0.35, 0.85; p<0.05) and increased relapse (OR=1.11; 95% CI: 1.00, 1.23; p>0.05) in Canada.[25] Smoking cessation was associated with low and intermediate levels of density within 500 meters from homes (PR=1.28; 95% CI: 1.10, 1.50; p<0.05) and daily activity spaces (PR= 1.28; 95% CI: 1.08, 1.51; p<0.05) in a Canadian cross-sectional study,[28] and inversely related to higher availability within 500 meters only for moderate/heavy male smokers (PR=0.63; 95% CI:0.49; 0.81; p<0.05) in a longitudinal Finnish study.[35] Density within 1 km from home showed no associations with either 30-day abstinence or relapse in a longitudinal Canadian study.[26]

In two further cross-sectional studies, higher density per km^2 or square mile within residential ZIP codes was associated with being a former (vs. current) smoker in a Scottish study (dy/dx=-0.05; CI: -0.09, -0.02; p<0.01) [38] and with lower intentions to quit in the next six months in a US study, but only among price-sensitive, non-daily smokers (likelihood ratio G2 =66.1).[51]

Proximity to tobacco retailers and smoking outcomes in adults

Current smoking

Three cross-sectional studies investigated adult current smoking, variously defined as daily smoking,[32] smoking daily or occasionally,[29] and the average number of cigarettes smoked per day.[46] Proximity from participants' homes to the nearest retailer, defined as the shortest walking distance (meters) in a Canadian study [29] or shortest straight-line distance (miles) in a US study [46], were not associated with current smoking or the number of cigarettes smoked per day. However, shortest walking distance to a tobacco retailer (meters) in daily activity spaces was related to current smoking in a Canadian study (PR= 1.42; 95% CI: 1.09, 1.86; p<0.05).[29] In New Zealand, travel time by car from census area centroids to the nearest tobacco retailer was not associated with current smoking, when adjusted for neighborhood deprivation and rurality.[32]

Smoking cessation, quit attempts and relapse

Of six studies that assessed proximity from home to the nearest tobacco outlet, three measured walking distance (meters),[25, 28, 45] two measured straight-line distance (meters, kilometers),[26, 34] and one compared both.[35] All studies but one were longitudinal. A greater walking distance was associated with higher odds of 30-day smoking abstinence in a US study, but only in high-poverty areas (OR= 2.80; 95% CI: 1.51, 5.19; p<0.001);[45] and

was otherwise unrelated to quit attempts and relapse in one Canadian study,[25], and to smoking cessation in another cross-sectional Canadian study.[28] However, the same measure in daily activity spaces was associated with smoking cessation (PR = 1.21; CI: 1.02, 1.43; p<0.05).[28] In studies from Finland [34] and Canada,[26] greater straight-line distance from home to the nearest tobacco retailer was positively associated with smoking cessation (OR= 1.16; 95% CI: 1.05, 1.28; p=0.004),[34] but not with 30-day smoking abstinence [26] or relapse.[26, 34] In another Finnish study, smoking cessation was inversely associated with closer proximity using both measures, but only in moderate/heavy male smokers (PR= 0.73, 95% CI: 0.60, 0.88; p<0.05).[35]

Retailer density and adolescents' smoking outcomes

Current smoking

Adolescent current smoking was defined in seven cross-sectional studies as past 30-day smoking,[4, 9, 49, 53, 55] smoking "at all nowadays" [39] or "any cigarette use on a given day". [48] All but one study [39] were conducted in the US. Greater density within 0.75 mile circular buffers around homes was associated with higher smoking frequency (β = 0.293; SE = 0.069; p<=0.05).[49] Density within 100 meters of daily activity space polylines was not associated with youth smoking in a study that used real-time geographic ecologic momentary assessment.[48] While density per km^2 within residential zip codes [39] and within census tracts [4] was positively associated with increased smoking, with odds ratios ranging from 1.20 (95% CI=1.01, 1.44) to 1.47 (95% CI: 1.13, 1.91; p<0.01), larger administrative measures, such as county-level density per 1,000 people (ages 17 and younger) [9, 55] and city-level density per 10,000 people [53] showed no associations.

Lifetime Smoking

Adolescent lifetime smoking was defined in five studies as ever smoking a cigarette,[39, 52] ever trying a cigarette (even one puff) [8] and ever smoking a whole cigarette (more than just a few puffs).[53, 54] Most studies were cross-sectional and conducted in the US, except for one longitudinal study [54] and one conducted in Scotland.[39] Higher retailer density within 0.5 mile of ego-centric road network buffers around homes was associated with higher odds of lifetime smoking (OR= 1.01; 95% CI: 1.00, 1.02; $p<0.05$).[8] Administrative measures, such as density per km^2 in residential ZIP codes (OR= 1.53; 95% CI: 1.27, 1.85; $p<0.001$) [39] and density per 10,000 population in cities (OR=1.12; 95% CI:1.04, 1.22; $p<0.01$ and OR=1.312; 95% CI: 1.041, 1.655; $p<=0.05$) [53, 54] also correlated with lifetime smoking, while nationwide density per 1000 persons showed no associations.[52]

Smoking initiation and susceptibility

In two cross-sectional US studies, adolescents' smoking initiation [55] and susceptibility to smoking [9] were not associated with retailer density per 1,000 people (ages 17 and younger) within a county or community.

School-level retailer density and adolescents' smoking outcomes

Current smoking

Eight cross-sectional studies considered adolescent current smoking, defined as past 30-day smoking,[37, 42, 47, 49] past 30-day smoking and more than a 100 cigarettes in a lifetime, [33, 50] occasional or daily smoking,[30] or smoking "at all nowadays".[39] Smoking was not associated with higher retailer density in ego-centric buffers around schools in three US, one Canadian (Ontario) and one Australian (Victoria) studies,[30, 37, 47, 49, 50] and inversely associated with higher density within 500 meter road network buffers in one New Zealand study (OR=0.75; 95%CI=0.65, 0.87; $p<0.05$).[33] An administrative measure of

density per square mile around schools in the US showed no association,[42] while density per km^2 within school ZIP codes in a Scottish study (OR=0.75; 95% CI: 0.59, 0.95; p<0.05) [39] showed an inverse relationship.

Lifetime and experimental smoking

Five cross-sectional studies considered adolescent lifetime smoking, defined as ever smoking a cigarette [39, 47] or ever trying a cigarette (even one puff),[8] or experimental smoking, defined as past 30-day smoking and having smoked less than a 100 cigarettes lifetime.[33, 50] In two US studies, higher densities within 0.5 mile and 1 mile circular buffers around schools were associated with adolescent lifetime smoking (OR=1.10; 95% CI: 0.99, 1.20; p=0.51),[47] and with experimental smoking (OR=1.11; 95% CI =1.02, 1.21) only for high-school students in urban areas.[50] Density within 0.5 mile, 500 meter and 1 kilometer road network buffers around schools showed no association with lifetime smoking in the US [8] or experimental smoking in New Zealand.[33] In one Scottish study, higher density per km^2 within schools' ZIP codes was inversely associated with lifetime smoking (OR=0.66; 95% CI: 0.50, 0.86; p<0.01).[39]

Susceptibility to smoking

Susceptibility to smoking (intention to try a cigarette soon or in the next year or if offered to try by a best friend) was associated with higher density within 1 kilometer circular buffers in a cross-sectional Ontario study (OR=1.03; 95%CI: 1.01, 1.05; p<0.05)[30] and within 1 kilometer road network buffers around schools in a cross-sectional New Zealand study (OR=1.07; 95%CI: 1.01, 1.16; p<0.05).[33]

Retailer proximity to homes and adolescents' smoking outcomes

Current and lifetime smoking

In two cross-sectional US studies, past 30-day and lifetime smoking was not associated with proximity to the closest retailer from home, measured either as a straight-line distance [49] or distance in roadway miles.[52]

Retailer proximity to schools and adolescents' smoking outcomes

Current smoking

Three cross-sectional US studies examined current adolescent smoking, defined as past 30-day smoking [42, 49] or past 30-day smoking and more than 100 lifetime cigarettes [50] and retailer proximity to schools, measured as a straight-line distance in feet [50] or in miles [49] and street network distance.[42] None found significant associations.

Lifetime and experimental smoking

Two cross-sectional US studies explored the relationship between retailer proximity to adolescents' schools, defined both as a distance in roadway miles, and the presence of at least one outlet within 1000 feet,[8] or as a straight-line distance,[50] and lifetime smoking or experimental smoking. Neither found an association.

E-cigarette retailer density /proximity and e-cigarette use

Four cross-sectional studies investigated the density of e-cigarette retailers near schools and adolescent lifetime and/or current (past 30 day) use. In a US study a count of tobacco retailers that sold e-cigarettes within a 0.5 mile circular buffers around schools was associated with current use (aPR=1.04; 95% CI: 1.01, 1.08; $p<0.05$) and lifetime use (aPR=1.03; 95% CI: 1.00, 1.05; $p<0.05$).[41] However, the number of vape shops within 0.5, 1.0 and 1.5

kilometer circular buffers was not associated with current or lifetime use in a Canadian study. [31] In a US study, the number of e-cigarette retailers per square mile within schools ZIP codes was not related to current use among students.[42] Proximity, defined as a presence of at least one e-cigarette specialty store within a 0.25 mile buffers from schools was only associated with lifetime use in middle school students (vs. high-school students) (OR=1.70; 95% CI: 1.02, 2.83) and not associated with current use.[40] In a Canadian study, the presence of at least one e-cigarette retailer within 0.5, 1.0 and 1.5 kilometer circular buffers around schools was not associated with lifetime or current use.[31] In a US study, walking distance from school to the closest e-cigarette retailer was not associated with students' current e-cigarette use.[42]

While no studies examined the initiation of e-cigarettes (exclusively), two considered initiation of alternative/non-combustible tobacco products (including e-cigarettes) among youth and young adults. A longitudinal study in the US showed that living in census tracts with higher tobacco retailer density per square mile was positively associated with adolescents' initiation of alternative tobacco products (OR=1.22, 95% CI: 1.07, 2.12), but no association was found for retailer proximity from home measured in roadway miles.[44] In a cross-sectional US study, living in tracts with higher tobacco retailer density (count per 10 km of roadway) was not associated with non-combustible product initiation in young adults. [43]

DISCUSSION

Our scoping review summarizes evidence on the association between tobacco retailer availability and the use of cigarettes and e-cigarettes in adults and adolescents, while considering variations in tobacco use outcomes and measures of density/proximity.

For adults, evidence from cross-sectional research showed a positive association between current smoking and both person-centered measures around homes (two of two studies)[29, 36] or in daily activity spaces (one of one)[29] and administrative units (two of three)[3, 38] of retailer density. Evidence on the relationship between current smoking and retailer proximity to homes, daily activity spaces or administrative unit centroids was more limited (one of three).[29] There was also evidence, mainly from longitudinal studies, of associations between higher person-centered density near homes and lower smoking cessation (two of two),[28, 35] quit attempts (one of one),[25] 30-day abstinence (one of two),[45] and higher relapse (one of two).[25] However, these associations were usually limited to specific populations, such as price-sensitive nondaily smokers,[51] moderate/heavy male smokers,[35] or residents of high poverty [45] or high-income neighborhoods.[25] Farther retailer proximity from homes showed associations with higher cessation (two of three),[34, 35] but was not related to smoking relapse (none of three).

For adolescents, evidence gathered from predominantly cross-sectional research indicated a positive association of person-centered measures of retailer density near homes and daily activity spaces with current smoking and the number of cigarettes smoked (two of two),[48, 49] as well as lifetime smoking (one of one).[8] For administrative units, there was some evidence of a positive association with density and current smoking (two of five),[4, 39] but evidence for lifetime smoking was more consistent (three of four).[39, 53, 54] Higher density near schools showed no or inverse association with adolescent current smoking, but was related to greater susceptibility to smoke (two of two).[30, 33] There was no evidence that retailer proximity to homes or schools was related to adolescent smoking.

Given e-cigarette popularity among youth, research on association of use with retail density/proximity of e-cigarettes is surprisingly scarce. Existing studies focused on e-

cigarette retailer availability near schools and suggest that adolescent current e-cigarette may be related to retailer density (one of three),[41] but not proximity (none of three). Inadequate data about which tobacco retailers sell e-cigarettes is an obstacle to research on this topic. Studies of vape shops (that sell e-cigarettes exclusively) may underestimate retail availability of e-cigarettes, while studies of all tobacco retailers surely overestimate it.

Our findings are consistent with a meta-analysis that found a small but significant positive relationship between tobacco retailer density around adolescents' homes (but not schools) and past-month smoking.[17] While results of a narrative review [18] were inconclusive due to heterogeneity and small number of included studies, systematic [19] and methodological [20] reviews also found some support for a positive association of youth smoking with higher retailer density around homes, but not with proximity to homes or schools. A recent methodological review [21] concluded that there was an overall positive relationship between tobacco retailer density and smoking prevalence and initiation, with retailer proximity inversely related to smoking cessation. However, these findings did not distinguish between adult and youth smoking outcomes or the location of retailer exposure, thus limiting comparability of included studies and a meaningful interpretation of results. In contrast, our review provides a more comprehensive analysis, highlighting that while tobacco retailer density/proximity around homes and in activity spaces is related to both adolescent and adult smoking, retailer availability around schools is not (or inversely) related to adolescent smoking prevalence, but rather to susceptibility to smoking and cigarette experimentation.

Variation in measurements of retailer density/proximity across studies may partially explain the inconsistent evidence, since inaccurate definition of neighborhoods contributes to spatial misclassification of exposure. Administrative definitions of neighborhoods are more

common and convenient, but assuming the same exposure for all individuals may mask true associations. Egocentric definitions of neighborhoods or activity spaces are optimal to estimate individual-level retailer exposures, but the data are more difficult to obtain. Although circular buffers are more commonly used to define egocentric neighborhoods, street-network buffers better reflect real life settings since they account for physical barriers.[56] Similarly, roadway distance or travel time are more appropriate measures of proximity as opposed to straight-line distance[35], but they require data about participant locations (home, work, school) that can be difficult to obtain.

In this review, most studies with adult participants focused on retailer density in egocentric neighborhoods, using street network buffers around home or constructed activity spaces, while several opted for administrative measures per land area, particularly in census tract and residential ZIP codes. In adolescent studies, density measures within egocentric circular buffers near schools and in administrative units relative to population count were more commonly employed. These measures were generally consistent with recommendations of the PhenX Toolkit for tobacco regulatory research [24] and, similar to the findings of the recent methodological review [21], none provided a clear advantage in revealing associations. Retailer proximity for both populations was commonly measured as the shortest road network distance or straight-line distance to the nearest retailer. Less common measures that were not included in the PhenX Toolkit, such as travel time by car, or presence of at least one retailer within a certain distance were used, did not show a significant advantage in revealing associations.

Differences between local or national tobacco policies across study settings may further limit comparability and partially explain null findings. Compliance with youth access laws, for example, may mitigate/moderate the relationship between retail density and

adolescent smoking.[33, 39] Smoke-free air policies have also been shown to moderate this association.[53] However, with the exception of a few studies,[43, 47, 53] the effects of such policies have not been accounted for. Another moderating influence may be point-of-sale advertising and display bans, which are effective in reducing smoking in adolescents [57, 58] and adults [59] and therefore are likely to be another moderating influence. Notably, studies from Quebec, Canada and Finland, where point-of-sale advertising restrictions have long been in place, still found retailer density/proximity associated with lower adult cessation rates,[28, 34, 35] suggesting that retail availability affects smoking behavior independent of advertising exposure. Finally, given that racially diverse and socioeconomically disadvantaged neighborhoods have significantly higher density of tobacco retailers,[3, 4, 34, 60, 61] the relationship between retailer density and individual smoking behavior is likely modified by neighborhood socioeconomic status (SES),[46] which many studies did not address. Inconsistent findings may also be attributed to the different operational definitions of this concept across studies. Future research should also include spatial measures that better capture racial residential disparities, such as historical redlining.[62]

Increasingly, jurisdictions are implementing policies to reduce the spatial availability of tobacco products.[63, 64] Evidence is beginning to emerge regarding their impact on tobacco use,[65, 66] although it may take years before changes may be seen at the population level.[67] Simulation models examining the impact of various retail restrictions estimate reduced smoking prevalence and health benefits.[5, 68-70] However, evidence suggests that there is no standard approach to retailer reduction policies, and their effects may vary across different settings.[6]

Overall, this review supports the view that reducing tobacco retailer density may help reduce adult and youth smoking prevalence. To our knowledge, this is the first review to

consider the relationship between tobacco retailer availability/accessibility in different geographical settings and cigarette and e-cigarette use by adolescents and adults. An important strength of this review is that it considered multiple tobacco use outcomes and compared various measures of density and proximity. However, the review has several limitations. Since the emphasis of this scoping review was to provide a comprehensive overview of the current literature regardless of the standard of evidence, the critical assessment of the quality of included studies was not performed. This limits our ability to provide concrete guidance to inform policy making. Further, most studies were cross-sectional, making it difficult to distinguish whether increased retail density/proximity increases the odds of smoking, or whether tobacco retailers are locating their businesses in response to high market demand. Nevertheless, evidence from longitudinal studies suggests a causal effect of living in areas with densely distributed tobacco retailers or in their close proximity and decreased adult cessation.[34, 35] Finally, while some studies had a fixed neighborhood buffer zone to measure retailer density, others chose increasing intervals of buffers. In such studies, we reported a buffer size closest to the one across the included studies for the purpose of comparability, which may have biased the results. Future research should consider sensitivity analysis regarding buffer sizes used across studies, perhaps separately for urban and rural areas. A uniform grid unit method for geo-spatial distribution of tobacco retailers, with larger grid units in rural vs. urban areas, is recommended.[71] Tobacco retail accessibility may play an important role in individual smoking behavior, particularly in rural areas,[72] but remains largely unexplored. Specific measures of retail accessibility, such as travel time by car, should be considered in the PhenX Toolkit of recommended measures for tobacco regulatory research.

CONCLUSION

This scoping review finds some evidence of an association between tobacco retailer availability and smoking outcomes in youth and adults. More research is needed, particularly of longitudinal design, with representative samples, uniform measures of exposure and outcome variables, and consistent inclusion of major individual and area-level characteristics, such as racial diversity and neighborhood SES. Quasi-experimental before-after studies are also needed to fill the gap in evidence regarding causality between retailer density/proximity and outcomes in youth and adults. Studies on the risk of cigarette initiation and tobacco retailer availability are particularly scarce and should be the focus of future research. Finally, studies examining associations between retailer availability and e-cigarette use are scarce and further research is warranted.

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What this paper adds:

- Limiting tobacco retail availability may be an effective tobacco control strategy to reduce smoking and improve public health. Evidence on the associations between tobacco retailer density/proximity and cigarette/e-cigarette use is mixed and inconsistencies in measures of retailer exposure across studies have been reported. There was need for a comprehensive literature review to summarize the existing evidence for both youth and adults and highlight the methodological gaps.

- This review suggests that tobacco retailer density, but not proximity, may be a contributing factor in promoting smoking among youth and adults. In particular, future tobacco control policies limiting retailer exposure in residential areas may be successful in reducing smoking, while reducing tobacco retailer availability around schools may not be as effective. Research on e-cigarette use and density/proximity of e-cigarette retailers is surprisingly scarce, given their popularity among youth. There is need for more research with representative samples, uniform measures of exposure and outcome variables, and consistent control for major area-level characteristics, such as racial diversity and neighborhood disparity

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Table 1. Main Characteristics of Studies on the Associations between Tobacco Retailer Density/Proximity and Adult Smoking Outcomes

First author	Country and data collection period	Design	Sample size (n)	Participants	Tobacco product	Spatial units	Density Measure	Proximity measure	Main outcome variables	Control variables	Observed associations
Barnes et al., 2016[36]	Australia (Western Australia). 2003-2009	CS	12,270 (smokers and non-smokers)	Adults 18+ (mean age 53)	Cigarettes	Ego-centric buffers	Number of tobacco outlets within 1600 m (0.5 mile) street network buffers from home	N/A	Current smoking (daily or occasional)	Individual-level: Age, sex, highest level of education, household income. Socioeconomic index for areas (SEIFA)	Increase in density positively associated with being a current smoker vs. past smoker. OR=1.01; 95% CI: 1.00, 1.01
Cantrell et al., 2016[43]	USA. 2013	CS	4,288 (smokers and non-smokers)	Young adults ages 18-24; 25-34	Cigarettes and noncombustible tobacco products (incl. e-cigarettes)	Census tracts	Number of tobacco outlets per 10 kilometers of roadway	N/A	Product initiation	Individual-level: Age, sex, race, education, depression. Census tract level: population, % below poverty, % Hispanic, % non-Hispanic black. State-level: smoking prevalence, level of clean indoor air laws	Increase in density positively associated for initiation of cigarette use in ages 25-34. OR = 3.75, 95% CI = 1.18, 11.90, p<0.05. No association with initiation of noncombustible products (incl. e-cigarettes).
Cantrell	USA.	L	2,377	Adults ages	Cigarettes	Ego-	Number of	Shortest	Smoking	Individual-level:	Density within 500

et al., 2015[45]	2008-2010		smokers	18-49		centric buffers	tobacco outlets within: a) 500 m b) 1 km and c) 1.6 km of road network buffers around homes	street network distance in meters from participant's residence to the nearest outlet categorized into quartiles	abstinence >30 days	age, sex, race, marital status, heaviness of smoking, tobacco-related disease, education, awareness of media campaign, living with a smoker, mental health condition. Census tract level: % of African-Americans,% Hispanic, % below poverty	m negatively associated with abstinence (OR: 0.94; 95% CI: 0.90, 0.98; p<0.01) only in high poverty areas. Farther distance (proximity) to retailers was positively associated with abstinence only in high poverty areas (OR: 2.80; 95% CI:1.51, 5.19; p<0.001 for a proximity of about 900 m vs. < 500 m)
Chaiton et al.,2018[25]	Canada: Ontario. 2005-2008; 2011	L	2,414 past month daily smokers	Adults 18+ (mean age not reported)	Cigarettes	Ego-centric buffers	Number of outlets within 500 m circular buffer with a straight line radius from participants' homes	1)Walking distance from home to the nearest tobacco outlet 2) Presence of at least 1 tobacco outlet within 500 meters	Quit attempts, relapse	Individual-level: age, sex, marital status, having kids under 18 in household, education, region, perceived addiction, use of quit aids, heaviness of smoking index. Census-level: household income, %	Increased density negative associated with quit attempts only in high-income neighborhoods (OR: 0.54, 95% CI: 0.35, 0.85, p<0.05). Presence of at least one retailer within 500 m positively associated with relapse (OR: 1.11, 95% CI: 1.00, 1.23,

								from home		immigrants.	p<0.05).
Chuang et al., 2005[46]	USA: California. 1979-1990	CS	8,121 (smokers /non-smokers)	Adults ages 25-74	Cigarettes	1) Census tracts, census block groups, combination of both (n=82) 2) Ego-centric buffers	1) Number of convenience stores per 1 square mile divided into tertiles (density) 2) Number of convenience stores within 1 mile circular buffers divided into tertiles (count)	Straight-line distance from home to the nearest convenience store in miles	Number of cigarettes a day	Individual-level: age, sex, race, SES (education, household income). Census-level: neighborhood SES	High census-level density positively associated with smoking (b=0.174, SE=0.077, p<0.05). Density as count in ego-hoods showed no association. Proximity negatively associated with smoking (b=-0.154, SE=0.066, p<0.05). No associations for any three measures in a model adjusted for neighborhood SES.
Fleischer et al., 2019[26]	Canada (10 provinces). 2005-2011	L	4,388 smokers (Abstinence outcome); 866 smokers (Relapse	Adults (mean age 47 and 53, depending on the wave and sample)	Cigarettes	Ego-centric buffers	Number of outlets within 1km street network buffers around home addresses or postal	Straight-line distance from home to the nearest outlet in kilometers	30-day abstinence, relapse	Individual level: Age, sex, education, income Province-level: Province, cigarette price, Point-of-sale bans	No associations

			outcome)				code centroids				
Halonen et al. , 2014[35]	Finland. 1997-2005	L	8,751 smokers	Adults (mean age 50)	Cigarettes	Ego-centric buffers; area-level neighbor hoods as coordinat es on the 250 meter map squares	Number of outlets within 0.5 km straight-line and street-network buffers around homes	Straight-line and walking distances from home to the nearest outlet	Cessation	Individual-level: age, sex, occupational status (proxy for SES), marital status, alcohol use, smoking intensity. Registry-level : housing tenure (proxy for SES), baseline diseases Area-Level: Neighborhood SES, population density	Having one vs. no stores within 0.5 km negatively associated with cessation only in moderate/heavy male smokers (PR: 0.63, 95% CI: 0.49, 0.81, p<0.05). Proximity of <0.50 km (vs. >=0.50 km) negatively associated with cessation only in moderate/heavy male smokers (PR: 0.73, 95% CI: 0.60, 0.88, p<0.05)
Kirchner et al., 2017[51]	USA: Minnesota. 2012	CS	1,201 non-daily smokers (NDS)	Adults ages 25+ (mean age 41.38);	Cigarettes	Residenti al ZIP codes (n=1054)	Number of outlets per square mile categorize d in quartiles	N/A	Six months quit intentions	Individual-level: age, race, sex, education, household income, number of cigarettes/day, number of days smoked, time to first cigarette	Price-sensitive NDS residing in areas with higher (vs. lower) outlet density less likely to hold quit intentions (likelihood ratio test statistic=G2 =66.1, p<0.001).
Kirst et al.,	Canada:	CS	2,412 (smokers	Adults ages	Cigarettes	Census tract	Number of outlets per	N/A	Past 30-day	Individual-level: income, sex, age,	No association

2019[27]	Toronto. 2009-2011		and non-smokers)	25-54		(n=87)	km^2		smoking	marital status, immigrant status, education level, household income Census tract - level: neighborhood disorder, neighborhood income	
Marashi-Pour et al., 2015[3]	Australia: NSW. 2009-2011	CS	31,260 (smokers and non-smokers)	Adults 16+ (median age =58)	Cigarettes	Census collection districts (n=11,811)	Mean number of outlets per 1,000 persons within each census collection district or postal area	N/A	Current smoking (daily or occasional)	Individual-level: age, sex, country of birth, Aboriginal status. Census-level: Neighborhood SES, % males, % born in Australia, % minors	High density positively associated with smoking (OR= 1.11; 95%CI: 1.02, 1.21; p = 0.018).
Pearce et al., 2016[38]	Scotland. 2008-2011	CS	28,751 (smokers and non-smokers)	Adults ages 16+ (mean age not provided)	Cigarettes	Postal codes (n=152,400).	Proximity-weighted estimate of the outlet density per km^2 for each postal code	N/A	Current smoker, ex-smoker	Individual-level: age, sex, ethnicity, education, household income. Area-level: rurality	Highest (vs. lowest) density positively associated with being a current smoker (dy/dx=0.07; 95% CI: 0.05, 0.10; p<0.01) and negatively associated with being an ex-smoker (dy/dx=-0.05; 95%

											CI: -0.09, -0.02; p<0.01)
Pearce et al., 2009[32]	New Zealand. 2002-2003	CS	12,529 (smokers and non-smokers)	Adults ages 15+ (mean age not provided)	Cigarettes	Census mesh blocks (n=1,178) represented by their population-weighted centroids	N/A	Travel time by car(min) to the nearest outlet along the road network , categorized in quartiles (worst/worse/better/best access)	Everyday smoking	Individual-level: age, sex, ethnicity, social class. Census block-level: neighborhood deprivation, rurality	Best access to supermarkets (OR=1.23, 95% CI:1.06, 1.42) and convenience stores (OR=1.19, 95% CI:1.03, 1.38) positively associated with smoking. No associations in a model adjusted for neighborhood deprivation and rurality.
Pulakka et al., 2016[34]	Finland. 2008/2012; 2003/2012	L	20,729 (smokers and ex-smokers)	Adults ages 18-75	Cigarettes		N/A	Change in walking distance from home to the nearest outlet address (difference between baseline and follow up distance)	Smoking cessation and relapse	Individual-level: age, sex, education (proxy for SES), marital status, recent financial hardship, recent death or illness in family, employment status, chronic diseases	Increase in distance (proximity) positively associated with smoking cessation (pooled OR, 1.16; 95% CI: 1.05, 1.28; p=0.004) and not associated with smoking relapse.
Shareck	Canada:	CS	921	Young	Cigarettes	Ego-	Number of	Walking	Smoking	Individual-level:	Positive for low (vs.

et al., 2018[28]	Montreal. 2011-2012		(individuals who smoked at least one cigarette in their lifetime)	adults ages 18-25		centric buffers	outlets in 500-m street-network buffers from home/across activity spaces (AS), categorized in tertiles (low/medium/high)	distance to the nearest outlet from home/activity space (AS) location, categorized in tertiles (closest/intermediate/furthest)	cessation	age, sex, education, time since smoking onset, number of years smoked, occupation Area-level: neighborhood deprivation	high) residential density (PR= 1.28; 95% CI: 1.10, 1.50; p<0.05) and density in AS (PR= 1.28; 95% CI: 1.08, 1.51; p<0.05). Positive for the furthest (vs. closest) proximity to AS (PR = 1.21; CI=1.02, 1.43; p<0.05). No association with proximity to homes.
Shareck et al., 2016[29]	Canada: Montreal. 2011-2012	CS	1,994 (smokers and non-smokers)	Young adults ages 18-25	Cigarettes	Ego-centric buffers	Number of outlets in 500-m street-network buffers from home/across activity spaces (AS), categorized in tertiles (low/medium/high)	Shortest walking distance to the nearest outlet from home/activity space (AS) location, categorized in tertiles (closest/intermediate/furthest)	Current smoking (defined as smoking daily or occasional)	Individual-level: age, sex, education status and attainment. Census-level: neighborhood deprivation	Positive for high (vs. low) residential density (PR= 1.53; 95% CI: 1.23, 1.91; p<0.05) and density in AS (PR=1.46; 95% CI: 1.26, 1.70; p<0.05). Positive for closest (vs. farthest) proximity to AS (PR=1.42; 95% CI: 1.09, 1.86; p<0.05 No association with proximity to homes.

SES= Socioeconomic status. SEIFA=Socio-Economic Indexes for Areas. AS= Activity space. N/A= Not applicable. CS= Cross-sectional, L=Longitudinal. OR= Odds ratio. PR=Prevalence Ratio. CI= Confidence interval.

Table 2. Main Characteristics of Studies on the Associations between Tobacco Retailer Density/Proximity and Youth Smoking Outcomes

First author	Country and data collection period	Design	Sample size (n)	Participants	Tobacco product	Spatial unit	Density Measure	Proximity Measure	Main outcome variables	Covariates	Direction of hypothesized association
Abdel Magid et al., 2019[44]	USA: California. 2015-2016	L	728 students from 10 high schools	Students ages 13-19	Alternative tobacco products incl. e-cigarettes (ATP)	Census tracts (n=191)	1.Number of tobacco outlets per square mile, categorized into tertiles	Roadway distance from home address to the nearest tobacco retailer in miles	Tobacco product initiation	Individual level: Age, sex, race, mother's education, ever cigarette use, ever alcohol use. Census tract level: % non- Hispanic white, median household income, population. School level: school demographics, socioeconomic demographics	Higher density positively associated with ATP initiation. OR=1.22, 95% CI: 1.07, 2.12. No association with proximity.
Adachi-Meja et al., 2012[52]	USA. 2007	CS	3,646 adolescents	13-18 y/o	Cigarettes	Census tracts (n=3456)	Number of tobacco outlets per 1,000	Roadway distance from home address to	Lifetime smoking	Individual level: Age, sex, race, SES, friend smoking, sibling	No associations.

							persons	the nearest tobacco retailer in miles		smoking, exposure to smoking in movies, team sports participation, sensation seeking. Census tract level: % of Blacks, % of Hispanics, % of Poverty	
Adams et al., 2013[47]	USA: Illinois. 2000	CS	9,704 students from 21 middle schools and 13 high schools	7^{th}-10^{th} graders	Cigarettes	Ego-centric neighborhoods	Number of outlets within 0.5-mile straight line buffer from school address	N/A	Lifetime smoking, past 30-day smoking	Individual level: grade, race, sex, current smoking. School-level: illegal tobacco sales rates. Census tract level: median income, mean population density.	Density positively associated with lifetime smoking prevalence. OR=1.10; 95% CI: 0.99, 1.20; p=0.51. No associations with past 30-day smoking.
Bostean et al., 2016[40]	USA: California. 2013-2014	CS	67,701 students from 130 schools	Middle schoolers and high schoolers	E-cigarettes	N/A	N/A	Presence of at least one e-cigarette specialty stores within 0.25 straight-line radius	Lifetime smoker, current (past 30 day) smoker	Individual-level: Sex, race, parent's education, tobacco, marijuana, and alcohol ever use.	Presence of at least one e-cigarette retailer (vs. none) positively associated for lifetime smoking in middle schoolers only. OR=1.70; 95% CI: 1.02, 2.83.

								(5 min walk) from schools		School-level: Free/reduced price lunch program eligibility (proxy for school level SES)	No association with current smoking.
Chan, Leatherdale, 2011[30]	Canada: Ontario. 2005-2006	CS	25,893 students from 76 secondary schools	9th -12th graders	Cigarettes	Ego-centric buffers	Number of outlets within 1km circular buffers around schools	N/A	Smoking susceptibility, occasional smoking, daily smoking	Grade, sex, peer smoking, parent who smokes, friend who smokes, older sibling who smokes. Census-level: % of families receiving government payments (proxy for neighborhood disadvantage).	Density positively associated with smoking susceptibility. OR=1.03; 95%CI: 1.01, 1.05; p<0.05. No associations with occasional or daily smoking.
Cole et al., 2019[31]	Canada: Ontario, Alberta, British Columbia, Quebec. 2017-2018	CS	63,400 students from 122 schools	7th-12th graders	E-cigarettes	Ego-centric buffers	Mean number of e-cigarette retailers within: a) 500 m b) 1 km and c)1.5	Percentage of schools with at least one retailer within: a) 500 m b) 1 km	Lifetime and current (past 30-day) cigarette use	Individual-level: grade, sex, ethnicity, spending money, friends smoking. School-level: province,	No associations

							km circular buffers around school	and c)1.5 km from school		urbanity.	
Giovenco et al., 2016[41]	USA: New Jersey. 2014	CS	3,909 students from 41 schools	High-school students	E-cigarettes	Ego-centric buffers	Number of tobacco retailers that sell e-cigarettes within a 0.5 mile circular buffer around schools	N/A	Lifetime use, past 30-day use	Individual-level: grade, sex, race, tobacco use history, peer tobacco use, tobacco use in home, ad exposure. School level: % students receiving free/reduced price lunch (proxy for economic disadvantage)	Density positively associated with lifetime use (aPR=1.03; 95% CI: 1.00, 1.05; p<0.05) and past 30-day use (aPR=1.04; 95% CI: 1.01, 1.08; p<0.05).
Lipperman-Kreda et al., 2020[48]	USA: California. 2017-2018	CS	100 smokers and non-smokers from 8 cities	16-20 y/o	Cigarettes	Ego-centric buffers	Number of outlets within 100 m of activity space polylines	N/A	Smoking on a given day, number of cigarettes smoked on a given day	Individual-level: age, sex, race/ethnicity, perceived SES, past month tobacco use	Density positively associated with the number of cigarettes smoked on a given day. IRR=1.04; CI: 1.01, 1.06; p<=0.05. No association with smoking (vs. not

											smoking) on a given day.
Lipperman-Kreda et al., 2016[54]	USA: California. 2010-2012	L	1,061 youths from 50 cities	13-16 y/o	Cigarettes	Cities (n=50)	Number of outlets per 10,000 persons in each city	N/A	Lifetime smoking	Individual-level: age, sex, ethnicity, perceived availability of cigarettes, perceived enforcement of underage tobacco law City-level: population density, % youth, ethnicity, race, SES	Density was positively associated with lifetime smoking. OR=1.12; CI: 1.04, 1.22; p<0.01.
Lipperman-Kreda et al., 2014[49]	USA: California. Not reported.	CS	832 youths from 45 cities	13-18 y/o	Cigarettes	Ego-centric buffers	Number of tobacco outlets within 0.75 and 1.0 mile radius of home and school location	Straight-line distance in miles to the closest outlet from home and school	Past 30-day smoking frequency	Individual-level: age, sex, ethnicity. City-level and buffer level: population density, % youth, household income, % African-Americans, % Hispanic, % college education, %	Positive for higher density within 0.75 mile (β = 0.293; SE = 0.069; p<=0.05) and 1.0 mile (β = 0.340; SE = 0.082; p<=0.05) radius d around home. No association with density around school.

										unemployment	No association with proximity from home or school.
Lipperman-Kreda et al., 2012[53]	USA: California. Not reported.	CS	1,491 youths from 50 cities	13-16 y/o	Cigarettes	City	Number of outlets per 10,000 persons	N/A	Lifetime smoking, past 30-days smoking, past 12-months smoking	Individual-level: Age, sex, race, frequency of smoking City-level: population density, % whites, % single moms, % unemployment, education, local tobacco policies	Density positively associated with lifetime smoking (OR=1.312; 95% CI: 1.041; 1.655, p<=0.05) and past 12-months smoking (β =0.010; SE=0.003; p<=0.005)). None for past 30-day smoking.
Loomis et al., 2012[9]	USA: New York. 2000-2008	CS	70,427 students	9-17 y/o	Cigarettes	County	Number of outlets per 1,000 youth aged 17 and younger in each county	N/A	Smoking susceptibility, current smoking (past 30-days), cigarettes per day	Individual-level: Age, sex, race, weekly personal income, living with a smoker, exposure to ads school-level smoking prevalence	No association
Marsh et al., 2016[33]	New Zealand. 2012	CS	27,238 students from 298 schools	14-15 y/o	Cigarettes	Polygons around schools	Median number of outlets within: a) 500m	N/A	Current smoking, experimental smoking, susceptibili	Individual-level: Sex, age, ethnicity, smoking status of family members and	Higher density positively associated with susceptibility to smoking within 500m (OR=1.09;

							and b) 1km road network polygons around schools, categorized into none, <=median, >median		ty to smoking	peers. School-level: SES and rurality	95%CI: 1.03, 1.14) and 1-km (OR=1.07; 95%CI: 1.01, 1.16) of schools. Higher density negatively associated with current smoking within 500m (OR=0.75; 95%CI=0.65, 0.87) and 1-km (OR=0.80; 95%CI=0.67, 0.96). No association with experimental smoking.
McCarthy et al., 2009[50]	USA: California. 2003-2004	CS	19,306 students from 245 schools	Youth (middle and high school students)	Cigarettes	Ego-centric buffers around schools (n=245)	Number of tobacco outlets within 1-mile radius around schools	Average straight-line distance from school's address to each retailer in feet	Established smoking (past 30-day smoking and >100 cigarettes in lifetime), experimental smoking (past 30-day smoking and <100 cigarettes	Individual-level: age, gender, race, school grades, peer tobacco use, perception of tobacco use prevalence, depressive symptoms. School-level: school rurality, parental education	Density positively associated with experimental smoking only in high-school (vs. middle school) students in urban areas (vs. rural). OR=1.11; 95% CI =1.02, 1.21. None for density and established smoking.

									in lifetime)		No associations with proximity.
Novak et al., 2006[4]	USA: Illinois. 1995-1999	CS	2,116 (smokers and non-smokers)	11-23 y/o	Cigarettes	Census tract (80 neighborhood clusters and 178 census tracts)	Number of census block faces with at least 1 outlet/total number of block faces per census tract (divided into quartiles)	N/A	Past 30-day smoking	Individual-level: age, race, sex, parental education Census tract level: % race, % poor, % foreign born, % >= 5 y in household, % unemployed, % aged >25 with at least Associates degree.	High (vs. low) density positively associated with past- 30 day smoking. OR=1.20; 95% CI=1.01, 1.44; p=0.49.
Pokorny et al., 2003[55]	USA: Illinois. 1999	CS	6,370 students from 23 schools	6^{th}-8^{th} graders	Cigarettes	Community level (n=11)	Number of retailers per 1,000 youth population within each community	N/A	Smoking initiation, past 30-day smoking	Individual-level: age, sex, race, family and peer tobacco use, perceived access to tobacco, ability to purchase tobacco. Community-level: youth population, median income (as a proxy for SES)	No association.

Schleicher et al., 2016[8]	USA. 2011-2012	CS	2,771 students	13-16	Cigarettes	Ego-centric buffers	Number of tobacco outlets per 0.5 street-network buffers around home and school	1)Roadway distance from school to nearest outlet in miles 2) Presence of any outlet within 1000 ft. of school	Ever smoking	Individual-level: age, sex, race, school grades, peer smokers, parent smokers, household income. Neighborhood-level: race, ethnicity, poverty	Higher residential density was positively associated with ever smoking. OR = 1.01, 95% CI: 1.00, 1.02; p<0.05. No association with density around schools. No association with school proximity. .
Scully et al., 2013[37]	Australia: Victoria. 2008	CS	2,044 students from 35 schools	12-17	Cigarettes	Ego-centric buffers around schools (n=35)	Number of outlets in 500-m radius around school	N/A	Past 30-day smoking	Individual-level: age, sex, pocket money, smoking status of parents, perceived ease of purchasing cigarettes. Areal-level: neighborhood SES, outlet cigarette prices	No association
Shortt et al., 2016[39]	Scotland. 2010-2011	CS	20,446 adolescents	13-15	Cigarettes	Postcodes (n=50,466)	Number of proximity-weighted tobacco	N/A	Ever smoking, smoking “at all	Individual-level: age, sex, ethnicity, parental	Highest residential density (vs. no outlets) positively associated with ever

							outlets per square kilometer for every postcode (categorized into quartiles)		nowadays" (current smoking)	smoking, free school meals, self-perceived family wealth, family structure Area-level: deprivation, rurality.	smoking (OR= 1.53; 95% CI: 1.27, 1.85; p<0.001) and current smoking (OR= 1.47, 95% CI: 1.13, 1.91; p<0.01). Highest density around schools negatively associated with ever smoking (OR=0.66; 95% CI: 0.50, 0.86; p<0.01) and current smoking (OR=0.75; 95% CI: 0.59, 0.95; p<0.05).
Trapl et al, 2020[42]	USA: Ohio. 2016	CS	3,778 students from 63 schools	$7^{th}/8^{th}$ graders	Cigarettes, E-cigarettes	Kernel density for each school (n=63)	Number of retailers per square miles	Roadway distance from school to the nearest tobacco outlet	Current (past 30-day) use	Individual-level: Sex, grade, race/ ethnicity, Family Affluence Scale (proxy for SES), walking to or from school, self- reported retail exposure, age of first tobacco use	No associations

ATP= Alternative tobacco products. SES= Socioeconomic status. N/A= Not applicable. CS= Cross-sectional, L=Longitudinal. OR= Odds ratio. CI= Confidence interval. SE= Standard error.

Table 3. Measures of Tobacco Retailer Density/Proximity across Included Studies

Study	Density in ego-centric neighborhoods around homes	Proximity from home to outlet	Density in administrative units	Proximity from census area centroid to tobacco outlet	Density in ego-centric neighbourhoods around schools	Proximity from school to tobacco outlet	Density in ego-centric neighborhoods of activity spaces	Proximity from active spaces to tobacco outlet
Adults								
Current smoking								
Barnes et al., 2016 [36]	x							
Shareck et al., 2016[29]	x	x					x	x
Pearce et al., 2016[38]			x					
Pearce et al., 2009[32]				x				
Marashi-Pour et al., 2015[3]			x					
Kirst et al, 2019[27]			x					
Chuang et al., 2005*[46]	x	x	x					
Smoking initiation								
Cantrell et al., 2016[43]			x					
Thirty-day abstinence								
Cantrell et al. 2015[45]	x	x						
Fleischer et al., 2019[26]	x	x						
Six-months quit intentions/quit attempts								
Kirchner et al., 2017[51]			x					
Chaiton et al., 2018[25]	x	x						
Smoking cessation								
Shareck et al, 2018[28]	x	x					x	x
Halonen et al., 2014[35]	x	x						
Pulakka et al.,2016[34]		x						
Former smoker status								
Pearce et al., 2016[38]			x					
Relapse								
Pulakka et		x						

* Level of smoking (number of cigarettes smoked per day) used as an outcome