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Tobacco Retail Density and Initiation of Alternative Tobacco Product Use Among Teens

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A B S T R A C T

Purpose: The rise of noncigarette, alternative tobacco product (ATP) use among adolescents may be due in part to an increase in retail availability of ATPs. We examined whether proximity and density of tobacco retailers near students' homes are associated with a higher likelihood of initiating ATP use over time.
Methods: Using data from 728 adolescents (aged 13–19 years at baseline) residing in 191 different neighborhoods and attending 10 different California high schools, longitudinal multilevel and cross-classified random effect models evaluated individual-level, neighborhood-level, and school-level risk factors for ATP initiation after 1 year. Covariates were obtained from the American Community Survey and the California Department of Education.
Results: The sample was predominantly female (63.5%) and was racially and ethnically diverse. Approximately one third of participants (32.5%) reported ever ATP use at baseline, with 106 (14.5%) initiating ATP use within 1 year. The mean number of tobacco retailers per square mile within a tract was 5.66 (standard deviation = 6.3), and the average distance from each participant's residence to the nearest tobacco retailer was .61 miles (standard deviation = .4). Living in neighborhoods with greater tobacco retailer density at baseline was associated with higher odds of ATP initiation (odds ratio = 1.22, 95% confidence interval = 1.07–2.12), controlling for individual and school factors.
Conclusions: Tobacco retailers clustered in students' home neighborhood may be an environmental influence on adolescents' ATP use. Policy efforts to reduce adolescent ATP use should aim to

IMPLICATIONS AND CONTRIBUTION

This longitudinal study suggests that living in areas with greater retail availability is a risk factor for initiating tobacco use for a variety of noncigarette tobacco products. Implications for improving adolescent health are to better regulate the tobacco retail environment in school and residential neighborhoods.

Conflicts of interest: The authors declare no conflicts of interest.
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reduce the density of tobacco retailers and limit the proximity of tobacco retailers near adolescents' homes and schools.

Declines in cigarette smoking by U.S. high school students are offset by increases in alternative tobacco product (ATP) use including electronic cigarettes (e-cigarettes/vapes), smokeless tobacco (chewing tobacco and snus), tobacco pipes, cigars (large cigars, cigarillos, or little filtered cigars), and hookah (water pipes) [1], posing a threat to decades of public health campaigns focused on denormalizing smoking and reducing nicotine use [1,2]. For example, in 2018, e-cigarettes were the most commonly used tobacco product among high school students (11.7%), followed by cigars (7.7%), cigarettes (7.6%), smokeless tobacco (5.5%), hookah (3.3%), pipe tobacco (.8%), and bidis (.7%) [3]. In California, where this study was conducted, prevalence of current tobacco use among high school students in academic year (AY) 2017–2018 was highest for e-cigarettes (10.9%), followed by little cigars and cigarillos (2.0%) and hookah (1.5%) [4].

The rise of noncigarette, ATP use among adolescents may be due in part to an increase in retail availability of ATP products. For example, in California, the odds that a convenience store sold e-cigarettes tripled between 2011 and 2014 [5]. In addition, 47.5% of U.S. adolescents reported at least weekly visits to convenience stores, where other ATPs are likely widely available [6]. Adolescents who visited convenience stores at least weekly were more than twice as likely to report ever or past-month cigarette smoking, but ATP use was not studied [7].

U.S. studies that examined the role of the tobacco retail environment in relation to adolescent tobacco use have been cross-sectional and predominately focused on cigarette smoking [8–16]. Findings have been mixed. Some studies have found that greater retail availability of cigarettes, as measured by the density and proximity of tobacco retailers to adolescents' home and/or school, was associated with higher odds of ever trying cigarette smoking, past-month smoking, and attempting to purchase cigarettes [11,13]. In other studies, higher density but not proximity was found to be a significant predictor of adolescent cigarette smoking [9–12,14–16]. Moreover, in a recently published systematic review including the aforementioned studies assessing the association between tobacco outlet density and proximity and tobacco use among youth, researchers found these studies to be susceptible to primary sources of biases including over and under adjustment of mediators and confounders, respectively, poor statistical model fit, selection bias, and misclassification of exposure measurements [17].

The few studies that assess tobacco retail density and adolescent ATP use focus on e-cigarettes only. Two studies showed positive geospatial associations between the presence of tobacco retailers around schools and e-cigarette use among students, but these associations were not consistent across all neighborhoods [18,19].

The present study fills two gaps in the literature: a dearth of longitudinal research and assessment of a comprehensive set of ATPs. This is the first longitudinal study to examine the relationship of tobacco retailer density and proximity to adolescent initiation of tobacco use, using data from a cohort with a broad assessment of all ATPs. Based on the existing literature, we tested the following hypotheses: controlling for covariates, (1) the probability of ATP initiation will be higher among adolescents living in neighborhoods with greater tobacco retailer density; and (2) the probability of ATP initiation will be higher among adolescents who live in closer proximity to a tobacco retailer.

We implemented a geospatial analysis, accounting for the unique nesting structure in our sample. Following the analytical approach that Dunn et al. used to assess smoking behaviors among adolescents in the National Longitudinal Study of Adolescent Health (Add Health) [20], we used Cross-Classified Multilevel Models (CCMM) allowing us to account for nonhierarchical nesting structures, which is appropriate for our sample in which students who live in the same neighborhoods attended different schools. This application of CCMM enables us to simultaneously examine the fixed and random effects corresponding to the students' home neighborhoods and school settings. This is important because both settings can influence ATP use through multiple pathways, including policies, normative behaviors, and access to resources.

Methods

Data and study design

This longitudinal analysis combined data from multiple sources: a cohort survey of adolescents from 10 California high schools, licensing data about the location of tobacco retailers near students' home addresses, census tract data to characterize students' home neighborhood, and data from the California Department of Education to characterize sociodemographic factors of each high school.

The cohort study consists of participants recruited from 9th- and 12th-grade from 10 California high schools and followed over 4 years. Details about the online survey and cohort have been published elsewhere [21]; but the administrative data from the California Department of Education, California's Department of Tax and Fee Administration, as well as census tract data are unique to this analysis. The data presented in this analysis were from wave 1 (July 2014 to October 2015) and wave 2 (July 2015 to March 2016). Overall, 786 (87.9%) of eligible consented students completed the wave 1 survey, and 728 of these participants had completed covariate, exposure, and outcome data. In wave 2, 578 participants completed the survey (retention rate = 75%). Thus, cross-sectional analyses use 728 participants with complete covariate, exposure, and outcome data, whereas the longitudinal analysis uses wave 1 and wave 2 participants with complete covariate, exposure, and outcome data. We tested for differences between participants who completed wave 2 and those lost to follow-up and found no significant differences in terms of demographic characteristics (data not shown). In addition, study participants' demographics were compared with the overall student bodies at each school, with no significant differences found [21–23].

Participants received $10.00 for participating in wave 1 and $15.00 for wave 2. This study was approved by Stanford University's Institutional Review Board.

ATP initiation

In each wave, participants were asked about their lifetime and past 30-day use of cigarettes and ATPs, using the following question: "During your entire life, how many times have you ever used [product]?" Ever users were asked, "During the last 30 days, on about how many days did you use [product]?" Both items assessed the following products: cigarettes, e-cigarettes, chewing or dipping tobacco or moist snuff, cigars, cigarillos or little cigars, and hookah. In cross-sectional analysis, participants were categorized as having used an ATP if they reported (1) ever ATP use at baseline or (2) past 30-day ATP use at baseline. In longitudinal analysis, participants were categorized as having initiated ATP use if they reported (1) never using ATP at baseline and (2) either ever or past 30-day ATP use during wave 2.

Tobacco retailer density and proximity

Participants provided their home address on a pre-wave 1 survey intake form, and these data were geocoded to latitude/longitude and census tract using ArcGIS 10.5.1 and StreetMap Premium 2017 Release No.3 linked to the 2010 Census Block Map (latitude/longitude mapping rate = 98.6%). Supplementary Figure 1 provides details on the geoprocessing conducted for this study. Furthermore, we compared participants' home addresses during wave 1 to wave 2 and found that none of the participants reported a different home address from wave 1 to wave 2. Although it is recommended to use egocentric neighborhood definitions in studies of youth access to tobacco retailers [24], this was not possible because most participants lived within one mile of each other. Instead, we used census tract as the primary spatial unit for each student's home neighborhood as in other studies [25].

We linked the data for students' home address and census tract to address data for tobacco retailers that we geocoded from the state tobacco retail licensing for 2014 (mapping rate = 98.6%), which was maintained by California's State Board of Equalization, now the California Department of Tax and Fee Administration. Two common measures of tobacco retailer density were computed for each census tract: density per square mile (number of tobacco retailers divided by land area) and density per 1,000 persons (number of tobacco retailers divided by total population). Based on previous work [26], we categorized census tracts according to tertiles of tobacco retail density: none, low (.02–8.0), and high ($\geq$8.10) retailers per square mile in the present study. Proximity measured the distance from each participant's home address to the nearest tobacco retailer in roadway miles, irrespective of census tract. Thus, proximity was included with other individual-level baseline measures, and density was included with other tract-level baseline measures. We computed distance to a participant's home to any nearest retailer, regardless of Census tract, as the use of larger administrative neighborhood definitions has been shown to bias exposure estimates for tobacco retailer proximity [24].

Neighborhood-level covariates

For 191 unique census tracts, we acquired data from the American Community Survey estimates (2012–2016) to characterize students' home neighborhood. These tract-level covariates were percent non-Hispanic white, median household income, and population density because these are common covariates in other studies [10,16]. Detailed tract-level characteristics of this sample are available in Supplementary Table 5.

School-level covariates

Data for the 10 high schools were obtained from the California Department of Education [21]. Data for AY 2014–2015 were school demographics (school size, average class size, and race/ethnicity), socioeconomic demographics (percent socioeconomically disadvantaged youth, percent homeless youth, percent foster youth, percent English learners, percent scoring $\geq$1,500 on Standardized Admissions Test, and percent of students eligible for free or reduced-price meals). Percent of female students was obtained for AY 2016–2017 because AY 2014–2015 was not available [21]. Detailed characteristics for the 10 high schools are summarized in Supplementary Table 4.

Individual-level covariates

Baseline demographics were self-reported age, gender, race/ethnicity, and mother's education. Age was dichotomized to distinguish between adolescents who were not yet old enough to drive (age 13–15 years) from older adolescents. Race/ethnicity was coded to compare non-Hispanic white (reference) to non-Hispanic Asian, non-Hispanic Pacific Islander, Hispanic, and Other. Because of a small sample of non-Hispanic African Americans in our study, these participants were recoded into "Other." As in previous studies [20], mother's education was dichotomized to compare students whose mother completed less high school with those whose mothers continued their education past high school.

Statistical analysis

Following the analytical approach of Dunn et al., we conducted longitudinal CCMM controlling for individual-level, neighborhood-level, and school-level sociodemographic factors and potential confounders [20]. This application of a CCMM enables us to simultaneously examine the fixed and random effects corresponding to the students' home neighborhoods and school settings. Thus, in addition to modeling the effect of either school or neighborhood setting, as conducted using a traditional logistic multilevel regression approach [27], we also used logistic cross-classified random effect models to disentangle the role of schools and neighborhoods on participants' subsequent ATP initiation. We began by fitting a two-level, school-only multilevel model adjusting for individual-level and school-level covariates. Second, we ran a two-level neighborhood-only model adjusting for individual-level and neighborhood-level covariates. Finally, we fitted a cross-classified model to account for the fact that some students who lived in the same census tracts attended different high schools.

All analyses were repeated for retailer density defined as count per 1,000 persons and wave 1 any tobacco product ever and past 30-day use, including cigarettes. All data analysis was conducted using Stata SE 14.1 (StataCorp, College Station, TX) and R 3.2.1 (R Foundation for Statistical Computing, Vienna, Austria).

Table 1
Baseline characteristics of participants (n = 728), neighborhoods (census tracts, n = 191), and high schools (n = 10) in California: overall and for ATP ever users and initiators at 12-month follow-up [1]

Wave 1 demographics	Total sample (n = 728)	Ever ATP [2] users, wave 1 (n = 237)	ATP initiation, wave 2 (n = 106)
	n (%) or M (SD)	n (%) or M (SD)	n (%) or M (SD)
Individual-level demographics (level 1, n = 728)			
Age (y)			
13–15	433 (59.4%)	47 (19.8%)	26 (24.5%)
16–19	295 (40.5%)	190 (80.2%)	80 (75.5%)
Gender			
Male	266 (36.5%)	97 (40.9%)	33 (31.1%)
Female	462 (63.5%)	140 (59.1%)	73 (68.8%)
Race/ethnicity			
White	195 (26.8%)	72 (26.2%)	23 (21.7%)
Asian/Pacific Islander	164 (22.5%)	39 (16.5%)	25 (23.5%)
Latino	259 (35.6%)	102 (43.0%)	36 (33.9%)
Other	110 (15.1%)	34 (14.3%)	22 (20.7%)
Mother's education (less than high school degree)	193 (26.5%)	67 (28.3%)	26 (24.5%)
Ever cigarette use	95 (13.0%)	81 (34.2%)	13 (12.2%)
Ever alcohol use	359 (49.3%)	205 (86.5%)	68 (64.1%)
Tobacco retailer proximity			
Distance to nearest retailer (mi.)	.60 (.5)	.61 (.7)	.72 (1.04)
Neighborhood-level demographics (level 2, n = 191)			
Percent white	33.34 (20.6)	41.18 (18.3)	40.12 (18.5)
Median household income	68,365 (37,184)	70,262 (36,102)	78,760 (42,491)
Population density (per square mile)	8,879 (7,338)	6,803 (5,060)	6,729 (4,499)
Tobacco retailer density			
Tobacco retailers per square mile	7.21 (6.5)	7.39 (6.42)	7.15 (5.49)
Density categories			
None (0 retailers)	143 (19.6%)	45 (18.9%)	20 (18.8%)
Low (.02–8.0 retailers/square mile)	356 (48.9%)	110 (46.4%)	54 (50.9%)
High (≥8.1 retailers/square mile)	229 (31.5%)	82 (34.6%)	32 (30.2%)
School-level demographics (level 3, n = 10)			
Percent white	26.65 (14.9)	25.95 (14.5)	28.37 (14.9)
Average class size	26.90 (3.9)	28.00 (3.1)	27.5 (3.2)
Percent reduced price lunch	54.83 (21.7)	56.98 (21.0)	55.82 (21.7)

ATP = alternative tobacco products including e-cigarettes, chewing or dipping tobacco or moist snuff, tobacco pipes, cigars, cigarillos or little cigars, and hookah; M = mean; SD = standard deviation.

Results

Table 1 shows individual-level, neighborhood-level, and school-level demographics for the overall sample, separately by ATP use at wave 1 and ATP initiation at wave 2 among baseline nonusers. The sample was predominately female (63.5%) and represented major racial/ethnic groups in California. Half of all students (54.8%) were eligible for their high school's reduced-price or free lunch program, and the median household income across all participants' neighborhoods was $68,365, which was consistent with the California median household income. Approximately one third of participants (32.5%) reported ever ATP use at wave 1, and 106 (14.5% of total and 21.5% of baseline nonusers) initiated ATP use within 1 year (wave 2). The mean number of tobacco retailers per square mile within a tract was 7.21 (standard deviation = 6.5), and the average distance from each participant's residence to the nearest tobacco retailer was .60 miles (standard deviation = .5).

Figure 1 illustrates the presence of cross-classification for two high schools in the study. Some students living in the same census tracts attended different high schools, which illustrate the importance of accounting for partial, nonhierarchical nesting in our modeling. Other schools in our study presented with similar levels of cross-classification. In unadjusted cross-sectional analyses (Supplementary Table 1), results indicated that adolescents were 1.21 (95% confidence interval [CI]: 1.14–1.66) times more likely to have ever used ATPs with every 1-unit increase in tobacco retailer density (tobacco retailers per square mile) after adjusting for individual-level covariates. This association persisted after adjusting for neighborhood-level covariates (odds ratio [OR] = 1.26, 95% CI: 1.12–1.19) and school-level covariates (OR = 1.11, 95% CI: 1.03–1.34), respectively. In a fully adjusted cross-classified model accounting for individual-level, school-level, and neighborhood-level covariates, results were further attenuated with an OR of 1.03 (95% CI: 1.02–1.15).

Tables 2 and 3 present the results of a series of models for the neighborhood-only, school-only multilevel model, neighborhood and school multilevel model, and the CCMM predicting ATP initiation as a function of tobacco retailer density and covariates. In the null model (Table 2, *Model 1*), random effect coefficients for the school-only and neighborhood-only models were .23 and .55, respectively, and remained unchanged in both the traditional multilevel models with both neighborhood and school and the corresponding CCMM. When individual-level covariates were added (Table 2, *Model 2*), declines relative to model 1 were observed for neighborhood (.43) and school (.10) random effect estimates, meaning that the variation in the outcome at the neighborhood level was larger than at the school level. A similar decline was observed in the CCMM (Table 2, *Model 3*), with the random effects only slightly larger at the school level (.10) than at the neighborhood level (.08). Similar declines were seen when neighborhood-level and school-level covariates were considered.

After adjusting for school-level and neighborhood-level covariates (Table 3, *Models 3 and 4*), the estimated odds of ATP

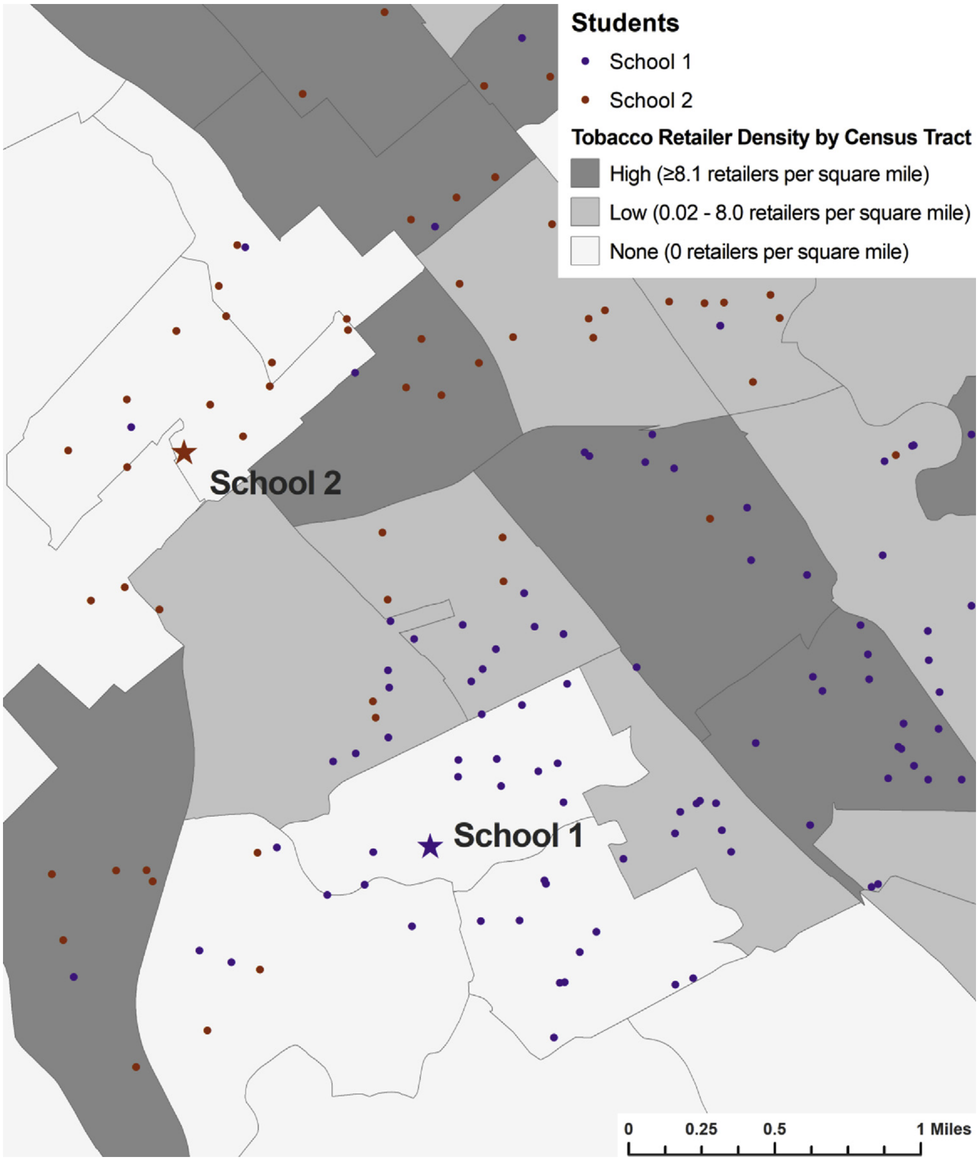

Figure 1. Cross-classification example: students reside in the same census tracts but attend different high schools.

initiation after 1 year of follow-up was 1.34 (95% CI: 1.21–3.81) and 1.08 (95% CI: 1.03, 1.92) times higher for each unit increase in tobacco retailer density in fully adjusted neighborhood-only and school-only models, respectively. Accounting for the nonhierarchical nesting in the fully adjusted CCMM (Table 3, *Model 5*), the estimated odds of subsequent ATP initiation was 1.22 (95% CI: 1.07–2.12). In this fully adjusted CCMM, neighborhood-level and school-level random effect estimates were .04 and .03, respectively.

Results for tobacco retailer proximity (distance in miles) and covariates are shown in Supplementary Tables 2 and 3. Although results were similar in inference (increasing tobacco retailer proximity positively associated with increasing ATP initiation) to the results for retailer density, the results for proximity were not statistically significant, and the random effect estimates were substantially smaller.

Discussion

To our knowledge, this is the first longitudinal study to show that initiation of any ATP use is more common for high-school students who live in neighborhoods with higher tobacco retailer density. In a sample of California adolescents, 14.5% of never users at baseline had initiated ATP use at 1-year follow-up. Notably, odds of initiation were higher for students who lived in census tracts with greater retail availability of ATP, as measured by tobacco retailer density. Consistent with much of the literature about cigarette smoking [8–16,25] and e-cigarettes [5], the findings from the present study suggest that the increased retail availability of ATP products in an adolescent's home neighborhood may increase youth experimentation with ATPs. Contrary to expectation, the proximity of tobacco retailers was not a significant predictor of ATP use by adolescents.

Table 2
Associations between tobacco retailer density, baseline individual-level covariates, and alternative tobacco product initiation at 12-month follow-up, excluding neighborhood- and school-level covariates

Fixed effect odds ratios	Model 1				Model 2			
	School only	Neighborhood only	Neighborhood and school	Cross-classified	School only	Neighborhood only	Neighborhood and school	Cross-classified
Tobacco retailer density (retailers per square mile)	1.25 (1.04–1.87)	1.24 (1.05–1.81)	1.24 (.87–1.73)	1.23 (1.03–1.78)	1.33 (.98–2.03)	1.28 (1.04–1.88)	1.33 (.98–2.03)	1.33 (1.02–2.03)
Individuals (level 1, n = 728)								
Age (y)								
13–15					Ref	Ref	Ref	Ref
16–19					2.44 (1.50–3.96)	2.43 (1.51–3.93)	2.43 (1.51–3.93)	2.44 (1.50–3.96)
Gender								
Male					.76 (.48–1.19)	.76 (.48–1.19)	.76 (.48–1.19)	.76 (.48–1.19)
Race/ethnicity								
White					Ref	Ref	Ref	Ref
Asian/Pacific Islander					1.60 (.85–3.02)	1.26 (.69–2.28)	1.60 (.85–3.01)	1.60 (.85–3.01)
Latino					1.26 (.69–2.28)	1.26 (.69–2.28)	1.26 (.69–2.28)	1.26 (.69–2.28)
Other					2.05 (1.05–3.97)	2.05 (1.05–3.97)	2.05 (1.05–3.97)	2.05 (1.05–3.97)
Mother's education (less than a high school degree)					.76 (.46–1.29)	.76 (.46–1.28)	.76 (.46–1.27)	.77 (.45–1.29)
Random effect estimates								
Neighborhood	—	.55 (.32)	.55 (.32)	.55 (.32)	—	.43 (.28)	.43 (.28)	.08 (.10)
School	.23 (.62)	—	.23 (.62)	.23 (.62)	.10 (.61)	—	.10 (.60)	.10 (.60)

Cell entries are fixed effects parameter estimates (adjusted odds ratios) and 95% confidence intervals (CI) from multilevel and cross-classified random effects logistic regression models.
Model 1 presents the results for a null model (i.e., no covariates) for each model type: school-only multilevel model, neighborhood-only multilevel model, neighborhood and school model, and the cross-classified multilevel model.
Model 2 presents the same models as Model 1, except Model 2 includes individual-level predictors and covariates: age, gender, and race/ethnicity.
For the fixed effect estimates, cell entries are parameter (odds ratios) estimates and confidence intervals calculated using the Wald approximation.
Random effects are presented as variance estimates and standard deviations.

As with studies assessing cigarette smoking, our findings for ATP initiation suggest that the tobacco retail density may have a direct effect on experimenting with ATP products, which is known to predict future smoking [28]. In previous research, tobacco retailer density, coupled with school smoking rates, was related to underage youth buying their own cigarettes or finding someone to buy cigarettes on their behalf [11]. Findings assessing adolescents' access patterns to ATPs in this cohort show that adolescents were significantly more likely to obtain an e-cigarette and hookah from a smoke shop than a gas station, liquor store, drug store, or the Internet [7]. Among the adolescents who reported ever use of any tobacco product, for both those aged older and younger than 18 years at the time of assessment, most (54.9%) reported their friends as the main source of tobacco products. Thus, the influence of retail density is probably not explained entirely by retail accessibility but also likely because of advertising exposure in the retail environment. Future research should consider investigating these explanatory mechanisms for ATPs.

In addition, it is important to note changes in the tobacco control policy occurring at the time of this study included California's Tobacco 21 law, effective June 9, 2016, and expanded the definition of tobacco to include vape products with nicotine [29]. To our knowledge, studies have not yet been published assessing the effect of Tobacco 21 on (1) tobacco retailer density or (2) tobacco use among California teens. However, even after Tobacco 21, illegal sales to decoys aged 18–19 years persisted, with a violation rate of approximately 20% overall and nearly 50% among vape shops [30].

Although youth substance use is known to be spatially clustered, the underlying reasons for this pattern are not well understood [24]. One explanation is that tobacco use parallels the spatial clustering of tobacco retailers in disadvantaged and racial/ethnic minority neighborhoods. Living in neighborhoods with higher tobacco retailer density may also decrease purchase costs for ATP [31]. It would also increase exposure to retail marketing for ATP, which has been shown to increase youth smoking by increasing cues to smoke, stimulating craving, triggering impulse purchases, and increasing benefit and decreasing tobacco-related risk perceptions [16]. At least one study observed higher rates of cigarette sales to minors in neighborhoods with greater tobacco retailer density, suggesting that greater retail availability could also increase youth access to ATP [32].

Strengths of this study include its longitudinal design and the availability of home address data for a spatial analysis. In addition, measures of tobacco retailer density and proximity were informed by a state tobacco retailer licensing database that we also geocoded.

The main limitation of this study is that we were unable to assess the effect of retail density on initiation of specific ATPs. In addition, not knowing which ATP was sold at which retailers in this sample remains a limitation of our study. Although unlikely, the exposure measure may have included stores that sold cigarettes and not ATP [33]. More likely, the exposure measure underestimated tobacco retail density because vape shops (that did not sell conventional tobacco) were not required to have a state tobacco retailer license until 2017. Although this study found no changes between wave 1 and wave 2 home addresses across study participants, this study did not capture changes in tobacco retailers' address from wave 1 to wave 2 and the potential impact such changes may have on the study findings.

Table 3
Associations between tobacco retailer density, baseline individual-level covariates, and alternative tobacco product initiation at 12-month follow-up, excluding neighborhood- and school-level covariates, adjusting for neighborhood- and school-level covariates

Fixed effect odds ratios	Model 3		Model 4		Model 5
	Neighborhood only	Cross-classified	School only	Cross-classified	Cross-classified
Tobacco retailer density (retailers per square mile)	1.34 (1.21–3.81)	1.32 (1.21–2.67)	1.08 (1.03–1.92)	1.06 (1.03–1.92)	1.22 (1.07–2.12)
Individuals (level 1, n = 728)					
Age (y)					
13–15	Ref	Ref	Ref	Ref	Ref
16–19	2.68 (1.63–4.40)	2.68 (1.63–4.40)	2.58 (1.57–4.24)	2.58 (1.57–4.24)	2.65 (1.61–4.37)
Gender					
Male	.75 (.47–1.18)	.75 (.47–1.18)	.75 (.47–1.18)	.75 (.47–1.18)	.74 (.47–1.17)
Race/ethnicity					
White	Ref	Ref	Ref	Ref	Ref
Asian/Pacific Islander	1.45 (.73–2.87)	1.45 (.73–2.87)	1.51 (.77–2.97)	1.51 (.77–2.97)	1.54 (.77–3.06)
Latino	1.32 (.72–2.41)	1.32 (.72–2.41)	1.21 (.66–2.19)	1.21 (.66–2.19)	1.29 (.70–2.38)
Other	2.07 (1.06–4.06)	2.07 (1.06–4.06)	1.93 (.99–3.76)	1.93 (.99–3.76)	2.02 (1.03–3.98)
Mother's education (less than a high school degree)	.82 (.48–1.39)	.82 (.48–1.39)	.77 (.46–1.29)	.77 (.46–1.29)	.82 (.48–1.41)
Neighborhoods (level 2, n = 191)					
Percent non-Hispanic white	1.01 (.99–1.02)	1.01 (.99–1.02)			1.01 (1.00–1.03)
Median household income ($10K)	.98 (.94–1.04)	.97 (.91–1.04)			.94 (.87–1.02)
Population density (per 1,000 persons)	1.03 (.99–1.07)	1.02 (.98–1.07)			1.03 (.99–1.07)
Schools (level 3, n = 10)					
Percent non-Hispanic white			4.89 (.82–29.30)	4.89 (.81–29.29)	8.81 (.98–78.80)
Percent eligible for free or reduced meals			1.79 (.79–4.02)	1.79 (.79–4.02)	1.19 (.46–3.10)
Average class size			1.04 (.95–1.13)	1.03 (.96–1.13)	1.01 (.93–1.11)
Random effect estimates					
Neighborhood	.07 (.26)	.04 (.21)	—	—	.04 (.21)
School	—	—	.05 (.17)	.05 (.17)	.03 (.08)

Cell entries are fixed effects parameter estimates (adjusted odds ratios) and 95% confidence intervals from multilevel and cross-classified random effects logistic regression models.
Model 3 presents the results of the neighborhood-only multilevel model and CCMM containing individual-level and neighborhood-level covariates.
Model 4 presents the results of the school-only multilevel model and CCMM containing individual-level and school covariates.
Model 5 presents the results of a CCMM containing all individual-, neighborhood-, and school-level covariates.
For the fixed effect estimates, cell entries are parameter (odds ratios) estimates and confidence intervals.
Random effects are presented as variance estimates and standard deviations.
Median household income and population density were rescaled for the model.

Nevertheless, the 12-month gap between waves minimizes the likely impact of this limitation on study results.

In addition, we acknowledge that census tracts may not accurately capture adolescents' exposure to tobacco retail environments as they travel from home to school and to leisure activities. In our study, some neighborhoods had only one respondent, and several participants lived within half a mile and one mile of each other. Although it is possible our findings reflect the greater number of participants in schools than neighborhoods, our findings suggest that data sparseness was unlikely an issue in this study. Moreover, sensitivity analyses (data not shown) adjusting for neighborhoods with one respondent produced similar results to main analyses, and although we did not observe statistically significant results for tobacco retailer proximity, we did observe meaningful cross-classification of neighborhoods and schools.

Other limitations of this study are typical of survey research, including selection or attrition bias whereby adolescents who were differentially at higher risk for ATP initiation may have been more likely to participate in this study. All outcome measures were self-reported, with an overall response rate typical of Internet panels among adolescent respondents. Although we measured and adjusted for many confounders that we identified from existing literature, the potential influence of unmeasured confounders is another limitation. For example, peer influence may explain reasons for ATP initiation among this cohort of adolescents and young adults but was not specifically included in this analysis because of concerns for overcontrolling [17]. Given that California presents a unique environment, both politically and socially, our results may not be generalizable to adolescents and young adults in other states. Even within California, results may not generalize across all urban, suburban, and rural environments.

Finally, the study was not designed to study school environments, and there were too few schools to compare the effect of school and home neighborhoods. Future studies should describe ATP retailers near home neighborhoods, school neighborhoods, and activity spaces in larger, more representative samples.

This research provides the first longitudinal evidence that higher tobacco retailer density near adolescents' home predicts greater odds of initiating any ATP use. Regulation of these noncigarette tobacco products is a public health priority, especially for tobacco use prevention as ATP initiation and use has been shown to predict cigarette use [34]. Further research is needed to understand the possible reasons for the spatial clustering of adolescent substance use, including ATP use. Examining spatial patterns of ATP use can help researchers and policymakers intervene to regulate ATP retail marketing targeting adolescents. The pervasive availability of ATPs in retail outlets around the U.S., coupled with a growing body of evidence showing the impact of tobacco retail availability has on cigarette smoking behavior among adolescents, suggests that the current tobacco retail environment may be a contributing factor in promoting ATP experimentation and initiation.

Moreover, these findings support the need to expand school-centric regulations to also include regulations of the tobacco retail environment everywhere, including in/near residential neighborhoods. Policy efforts to reduce adolescent ATP use should aim to reduce the density of tobacco retailers and limit the proximity of tobacco retailers near adolescents' homes and schools.

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Supplementary Data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jadohealth.2019.09.004.

References

[1] National Center for Chronic Disease Prevention and Health Promotion (US) Office on Smoking and Health. The health consequences of smoking-50 years of progress: A report of the surgeon general. Atlanta, GA: Centers for Disease Control and Prevention (US); 2014.
[2] Fairchild AL, Bayer R, Colgrove J. The renormalization of smoking? E-Cigarettes and the tobacco "Endgame" 2014;370:293–5.
[3] Wang B, King BA, Corey CG, et al. Awareness and use of non-conventional tobacco products among U.S. students, 2012. Am J Prev Med 2014;47:S36–52.
[4] Vuong TD, Zhang X, Roeseler A. California tobacco facts and figures 2019. (California Department of Public Health, Sacramento, CA: May 2019). Available at: https://www.cdph.ca.gov/Programs/CCDPHP/DCDIC/CTCB/CDPH%20Document%20Library/ResearchandEvaluation/FactsandFigures/CATobaccoFactsandFigures2019.pdf.
[5] Schleicher N JT, Rigdon J, Kaimal R, et al. California Tobacco Retail Surveillance Study (2017). Available at: https://www.cdph.ca.gov/Programs/CCDPHP/DCDIC/CTCB/CDPH%20Document%20Library/ResearchandEvaluation/SurveyInstrumentsTrainingManualsAndProtocols/CaliforniaTobaccoRetailSurveillanceStudt2017-CTRSS%206-4.pdf. Accessed January 2019.
[6] Sanders-Jackson A, Parikh NM, Schleicher NC, et al. Convenience store visits by US adolescents: Rationale for healthier retail environments. Health & place 2015;34:63–6.
[7] Meyers MJ, Delucchi K, Halpern-Felsher B. Access to tobacco among California high school students: The role of family members, peers, and retail venues. The J Adolesc healh 2017;61:385–8.
[8] Adams ML, Jason LA, Pokorny S, Hunt Y. Exploration of the link between tobacco retailers in school neighborhoods and student smoking. The J Sch Health 2013;83:112–8.
[9] Bostean G, Crespi CM, Vorapharuek P, McCarthy WJ. E-cigarette use among students and e-cigarette specialty retailer presence near schools. Health & place 2016;42:129–36.
[10] Henriksen L, Feighery EC, Schleicher NC, et al. Is adolescent smoking related to the density and proximity of tobacco outlets and retail cigarette advertising near schools? Prev Med 2008;47:210–4.
[11] Leatherdale ST, Strath JM. Tobacco retailer density surrounding schools and cigarette access behaviors among underage smoking students. Ann Behav Med 2007;33:105–11.
[12] Lipperman-Kreda S, Mair C, Grube JW, et al. Density and proximity of tobacco outlets to homes and schools: Relations with youth cigarette smoking. Prev Sci 2014;15:738–44.
[13] McCarthy WJ, Mistry R, Lu Y, et al. Density of tobacco retailers near schools: Effects on tobacco use among students. Am J Public Health 2009; 99:2006–13.
[14] Novak SP, Reardon SF, Raudenbush SW, Buka SL. Retail tobacco outlet density and youth cigarette smoking: A propensity-modeling approach. Am J Public Health 2006;96:670–6.
[15] Rodriguez D, Carlos HA, Adachi-Mejia AM, et al. Predictors of tobacco outlet density nationwide: A geographic analysis. Tob Control 2013;22:349–55.
[16] Schleicher NC, Johnson TO, Fortmann SP, Henriksen L. Tobacco outlet density near home and school: Associations with smoking and norms among US teens. Prev Med 2016;91:287–93.
[17] Nuyts PAW, Davies LEM, Kunst AE, Kuipers MAG. The association between tobacco outlet density and smoking among young people: A systematic methodological review. Nicotine Tob Res 2019. https://doi.org/10.1093/ntr/ntz153.
[18] Perez A, Chien LC, Harrell MB, et al. Geospatial associations between tobacco retail outlets and current use of cigarettes and e-cigarettes among youths in Texas. J biometrics biostatistics 2017;8. https://doi.org/10.4172/2155-6180.1000375.
[19] Giovenco DP, Casseus M, Duncan DT, et al. Association between electronic cigarette marketing near schools and E-cigarette use among youth. The J Adolesc Health 2016;59:627–34.
[20] Dunn EC, Richmond TK, Milliren CE, Subramanian SV. Using cross-classified multilevel models to disentangle school and neighborhood effects: An example focusing on smoking behaviors among adolescents in the United States. Health & place 2015;31:224–32.
[21] Gorukanti A, Delucchi K, Ling P, et al. Adolescents' attitudes towards e-cigarette ingredients, safety, addictive properties, social norms, and regulation. Prev Med 2017;94:65–71.
[22] McKelvey K, Halpern-Felsher B. Adolescent cigarette smoking perceptions and behavior: Tobacco control gains and gaps amidst the rapidly expanding tobacco products market from 2001 to 2015. The J Adolesc Health 2017;60:226–8.
[23] Roditis M, Delucchi K, Cash D, Halpern-Felsher B. Adolescents' perceptions of health risks, social risks, and benefits differ across tobacco products. The J Adolesc Health 2016;58:558–66.
[24] Duncan DT, Kawachi I, Subramanian SV, et al. Examination of how neighborhood definition influences measurements of youths' access to tobacco retailers: A methodological note on spatial misclassification. Am J Epidemiol 2014;179:373–81.
[25] Cantrell J, Pearson JL, Anesetti-Rothermel A, et al. Tobacco retail outlet density and young adult tobacco initiation. Nicotine Tob Res 2016;18:130–7.
[26] Henriksen L, Schleicher NC, Feighery EC, Fortmann SP. A longitudinal study of exposure to retail cigarette advertising and smoking initiation. Pediatrics 2010;126:232–8.
[27] Rabe-Hesketh S, Skrondal A. Multilevel and longitudinal modeling using Stata, Volumes I and II, third Edition: Multilevel and longitudinal modeling using Stata. Counts, and Survival, ed, Volume II. Stata Press; 2012.
[28] Chaffee BW, Watkins SL, Glantz SA. Electronic cigarette use and progression from experimentation to established smoking. Pediatrics 2018;141. https://doi.org/10.1542/peds.2017-3594.
[29] Zhang X, Vuong TD, Andersen-Rodgers E, Roeseler A. Evaluation of California's 'Tobacco 21' law. Tob Control 2018;27:656–62.
[30] Roeseler A, Vuong TD, Henriksen L, Zhang X. Assessment of underage sales violations in tobacco stores and vape Shops Assessment of underage sales violations in tobacco stores and vape Shops Letters. JAMA Pediatr 2019; 173:795–7.
[31] Ribisl KM, Luke DA, Bohannon DL, et al. Reducing disparities in tobacco retailer density by banning tobacco product sales near schools. Nicotine Tob Res 2017;19:239–44.
[32] Lipton R, Banerjee A, Levy D, et al. The spatial distribution of underage tobacco sales in Los Angeles. Substance use & misuse 2008;43:1594–614.
[33] Schleicher NJT, Rigdon J, Kaimal R, et al. California Tobacco Retail Surveillance Study. 2017.
[34] Watkins SL, Glantz SA, Chaffee BW. Association of noncigarette tobacco product use with future cigarette smoking among youth in the population assessment of tobacco and health (PATH) study, 2013-2015. JAMA Pediatr 2018;172:181–7.