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Alternative Tobacco Product Use among Adolescents and Young Adults

by

Hoda Samir Abdel Magid

A dissertation submitted in partial satisfaction of the

requirements for the degree of

Doctor of Philosophy

in

Epidemiology

in the

Graduate Division

of the

University of California, Berkeley

Committee in charge:

Assistant Professor Patrick T. Bradshaw, Chair
Professor Bonnie Halpern-Felsher
Professor Pamela Ling
Professor Mahasin Mujahid
Professor Ronald Dahl

Fall 2018

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Abstract

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University of California, Berkeley

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There is a changing landscape of tobacco use among adolescents and young adults in the United States. Non-cigarette, alternative tobacco product (ATP) use such as such as electronic cigarettes (e-cigarettes), smokeless tobacco (chewing tobacco, dissolvable or dipping tobacco, moist snuff, and snus), tobacco pipes, cigars (traditional, filtered, and cigarillos or little cigars), and hookah (water pipes) has increased in the past decade among AYAs. This changing tobacco landscape threatens decades of public health campaigns and gains in tobacco control dedicated to denomormilize smoking and lowering rates of tobacco use. Research shows positive relationships among marketing receptivity through ownership of tobacco promotional items, tobacco retail environment, and risk and benefit perceptions with cigarette use among adults. Limited studies have assessed these relationships with ATP use among adolescents and young adults.

This dissertation aims to illustrate the relationships between marketing receptivity and ATP initiation, identify a hierarchical relationship between individual-level, neighborhood-level, and school-level covariates and ATP initiation; and assess the relationship between risk and benefit perceptions with cigarette or ATP switching. These aims were examined using a prospective longitudinal cohort study of adolescents and young adults from California designed to assess adolescents' use and perceptions of a variety of tobacco products. This dissertation further analyzes data from this longitudinal cohort, linked with the Census Bureau's American Community Survey, the state retailer-licensing database maintained by California's Board of Equalization, and school-level data from the California Department of Education.

These findings suggest marketing receptivity, tobacco retail environment, and risk and benefit perceptions may predict individual ATP use among adolescents and young adults. Results of this dissertation indicate adolescents and young adults with increased marketing receptivity, who reside in neighborhoods with increased retail access to ATPs, and who have lower ATP risk perceptions and greater benefit perceptions exhibit greater ATP initiation, product switching, and use over time. These findings may help inform the Food and Drug Administration's regulations of new and emerging tobacco products by regulating marketing efforts, informing health campaigns, and regulating the tobacco retail environment.

Dedication

To Samir, Hanan, Salma, and Maryam.

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Chapter 1

Introduction

1.1 Motivation

There is growing concern about the use of alternative tobacco products (ATPs) such as electronic cigarettes (e-cigarettes), smokeless tobacco (chewing tobacco, dissolvable or dipping tobacco, moist snuff, and snus), tobacco pipes, cigars (traditional, filtered, and cigarillos or little cigars), and hookah (water pipes) among adolescents and young adults (AYAs) in the United States. Cigarettes are no longer the most commonly used tobacco product among AYAs. Although rates of cigarette and other combustible tobacco use has declined among AYAs in the U.S., ATP use has increased.[1,2] This change in tobacco use is a rising public health issue in the U.S., with increasing rates of use of tobacco among all age groups over the past four years, especially among AYAs.

Trends in Tobacco and Alternative Tobacco Product Use among Adolescents and Young Adults

Adolescents and young adults are a high priority population of tobacco and alternative tobacco users.[3] According to the 2018 National Youth Tobacco Survey (NYTS), approximately 19.6% (2.95 million) of high school students (grades 9-12) reported past 30-day use (using any tobacco product in the past 30 days) including 9.2% (1.38 million) who reported past 30-day use of ≥2 tobacco products, and 12.9% (1.94 million) who reported use of any combustible tobacco product.[2] From 2011 to 2015, e-cigarette use increased from 3.9% to 5.3% among middle school students (grades 6-8) and from 1.5% to 16.0% among high school students (grades 9-12).[2] According to the 2017 Monitoring the Future (MTF) study, more teens used e-cigarettes in the past 30 days than traditional tobacco cigarettes or any other tobacco product. Among high school students, e-cigarettes were the most commonly used tobacco product among high school students (16.0%), followed by combustible cigarettes (hereafter called cigarettes) (9.3%), cigars/cigarillos/little cigars (8.6%), hookah (7.2%), smokeless tobacco (chewing tobacco, snuff, dip, snus) (6.0%), and pipe tobacco (1.0).[1] Use of ATPs was highest among young adults (ages 18-23) with e-cigarettes (5.2%), cigars/cigarillos (4.2%), and hookah (3.4%) being the most commonly used ATPs among this group.[4]

Alternative Tobacco Product Use and Progression to Traditional Cigarette Use

It is important to note that cigarette use among adolescents has decreased significantly from 2001 to 2018.[2,4,5] This is thought to be due mainly to decades of tobacco control interventions and campaigns resulting in increased perceived risk and decreased acceptability of cigarettes.[6] Nevertheless, for adolescents and young adults alike, ATPs, such as e-cigarettes and smokeless tobacco may act as a gateway to smoking conventional tobacco cigarettes. In a recent analysis of 1,300 adolescents from the Population Assessment of Tobacco and Health (PATH) survey, among adolescent cigarette experimenters, using e-cigarettes was positively and independently associated with progression to current established smoking.[7] Teens who reported e-cigarette use in addition to their cigarette use were twice as likely to have become established smokers (i.e.

report ever smoking 100 or more cigarettes in their lifetime) and were 1.5 to 2 times more likely to have smoked cigarettes in the past 30 days in follow-up surveys. Adolescents who reported never smoking a conventional cigarette at baseline, and subsequently reported use of e-cigarettes, smokeless tobacco or tobacco water pipes were more likely to start smoking conventional cigarettes within a year of follow-up.[8] Specifically, compared to those who never used e-cigarettes, those who ever used e-cigarettes were more likely to progress to become an established cigarette smoker (19.3% vs 9.7%), past 30-day smoking (38.8% vs 26.6%), and established smoking (15.6% vs 7.1%). Similar to the evidence for e-cigarettes, a recent systematic review of longitudinal studies shows AYAs who initiate with smokeless tobacco use are more likely to initiate cigarette use.[9-15] Not every adolescent who experiments with ATPs will go on to smoke cigarettes, and some who do go on to smoke might have done so regardless. However, convincing evidence shows that ATP use is a strong predictor of subsequent cigarette initiation and increases the odds of becoming an established smoker—even for youth who have an otherwise low risk for cigarette smoking.[3,8,16-18]

Marketing Receptivity

This shifting landscape of tobacco use from cigarette use to ATP use likely has multiple contributing factors. One is the increase in marketing of these ATP products. Tobacco companies are marketing ATPs using promotional strategies including promoting flavors, aspirational imagery using fashion and celebrities, and messages emphasizing pleasure online, in newspapers/magazines, retail stores, TV, movies, sports, music event sponsorships, and advertisements placed at children's eye-level.[1,19-23] Tobacco companies have been found to use marketing tactics to market ATPs such as online banner/video advertising, many with unproven claims about the benefits of ATPs such as e-cigarettes.[19] These tactics include using messages that appeal to young adults and advertised on websites with large young adult audiences.[24,25] While restrictions are enforced for cigarette marketing by the 1998 Master Settlement Agreement (MSA) legally restricting tobacco company advertisements that would be seen by youth,[7] and the Family Smoking Prevention and Tobacco Control Act (FSPTCA) which delegated regulatory power over tobacco products to the US Food and Drug Administration (FDA); most of these restrictions currently do not extend to ATPs. For example, even though the FDA currently restricts e-cigarette sales to minors over the internet, AYAs are still exposed to ATP marketing across various online mediums including social media channels.[19]

These marketing tactics are thought to cause increased awareness of ATPs among adolescents and young adults. Approximately 32% to 50% of adolescents report awareness of ATPs such as e-cigarettes, hookah, and snus.[17] Moreover, more than 60% of young adults report awareness of ATPs.[26] Though the long-term health effects of ATPs are not yet well understood, evidence shows that contrary to the marketing claims made by tobacco companies, ATPs do not help smokers cease tobacco use and are expanding the tobacco epidemic by attracting low-risk youth. Given the reach and accessibility of marketing to vulnerable populations such as AYAs and the potential for health claims such as ATPs being harmless tobacco products or effective smoking cessation tools to be misinterpreted, further research is needed to explore the influence of ATP marketing on ATP use among AYAs. Findings may provide guidance for the regulation of ATP marketing to prevent deceptive marketing tactics and ensure consumer safety.[25]

Tobacco marketing plays a causal role in uptake of cigarette smoking, and it is believed ATP marketing may have a similar role in the uptake of ATP use among AYAs. Tobacco companies have increased their investments in marketing of ATPs in recent years, with a majority of marketing expenditures spent on ATP marketing.[19] Recent national data show that AYAs' receptivity to ATP marketing, an operationalized measure of tobacco marketing, has increased substantially in recent years, and that this is an important predictor of tobacco uptake.[27,28] Tobacco marketing receptivity has been measured by examining individuals' (1) exposure and effective response to advertisements and/or (2) ownership of tobacco promotional materials.[27,29] Cross-sectional studies have examined the role of marketing receptivity of tobacco products measured by receipt of coupons, samples, or promotional items on cigarette use among adolescents[30-32] and young adults[33] in the U.S. For example, tobacco marketing receptivity was found to be associated with ATP use among high risk young adults in the US, where young adult bar patrons reporting marketing receptivity were approximately twice as likely to have used ATPs including e-cigarettes and hookah compared to those not reporting marketing receptivity.[21]

Tobacco marketing strategies shape consumer risk perceptions, which in turn increase social acceptability and use of tobacco products.[27,34,35] Understanding how tobacco companies have profiled, targeted, and marketed to adolescent and young adult tobacco users will provide a valuable context for understanding current marketing activities for this study. Emerging tobacco products and marketing platforms including social media further facilitate these marketing strategies, and increase the reach, relevance, and opportunities to interact with young consumers, resulting in perceptions of reduced risk, greater benefits, and greater social acceptability of tobacco products. Moreover, exposure to ATP marketing is associated with subsequent cigarette smoking, even when the promoted products are not cigarettes.[36]

Little data exist on how ATP marketing influences perceptions and subsequent use of traditional and emerging products among AYAs. This study will address this gap by examining the relationship between marketing receptivity, with ATP initiation as measured by alternative tobacco product switching.

Tobacco Retail Environment

The shifting pattern of tobacco use in the U.S. may also be due to an increase in retail availability of ATP products.[37,38] Aspects of the built environment such as retail access to tobacco products have been consistently identified as important social determinants of health. Specifically, tobacco retailers have been found to concentrate in socially disadvantaged neighborhoods,[39] such as school neighborhoods with higher proportions of Hispanic and low-income students.[40] For example, cigar availability, advertising, and price in the point-of-sale environment has been shown to be associated with neighborhood demographics, with higher availability of these products found in African American communities and lower prices and greater outdoor advertising in minority and young adult neighborhoods.[41]

Increased tobacco availability, including the density (number of retailers per area/population) and proximity (distance to the nearest retailer) from one's home have been found to be associated with earlier smoking initiation, increased current smoking, cigarette purchasing, and reduced smoking cessation over time.[38,40,42-44] There are approximately 375,000 tobacco outlets

in the United States, approximately seven for every 1,000 school-age youth.[43] Neighborhoods with higher retailer densities have increased exposure to tobacco marketing, which can hinder smokers' quit attempts by increasing cues to smoke, provoking cravings, and triggering impulse purchases.[38,40,42-44] Moreover, living or going to school in areas with higher density of tobacco outlets may serve to increase smoking by normalizing tobacco use. Some studies have shown positive associations between increased tobacco retailer density in school neighborhoods with 1) higher odds of teens' ever smoking, 2) current smoking, 3) susceptibility to future smoking, and 3) greater school-level smoking prevalence.[45,46]

Though several studies have suggested associations of tobacco retailer density and proximity with cigarette use, few have examined this relationship with alternative tobacco products specifically. This study examines whether the proximity and density of tobacco retailers near students' home is associated with a higher likelihood of initiating ATP use over time. Therefore, this study fills an important gap in the literature and our understanding of environmental risk factors on AYA's ATP use.

Tobacco and Alternative Tobacco Risk and Benefit Perceptions

Another hypothesized contributing factor for increased ATP use among adolescents and young adults is the potential influence of decreased risk perceptions and increased benefit perceptions of these products. Adolescents' perceptions of risky behavior, including cigarette use, have been shown to be key drivers of adolescents "high risk behaviors." [47] Empirical research suggests that ATP use among adolescents and young adults is associated with increased benefit perceptions and lower risk perceptions such as perceptions of social benefits and health risks from using tobacco prodcuts.[48-54]Adolescents reporting lower risk and benefit perceptions have been found to have higher risk for tobacco use.[48-53] Adolescents' misperceptions of ATPs including widespread beliefs that ATPs are less harmful than cigarettes, are smoking-cessation tools, and are not addictive have been found to be significant predictors of tobacco use.[48-54] For example, in a study utilizing the 2015 NYTS, 23.8% of youth were open to using e-cigarettes and that youth who perceived e-cigarettes cause a lot of harm had lower odds of openness to use e-cigarettes and cigarettes.[51]

Changes in youth ATP use may occur in part because of changes in risk and benefit perceptions of these products. The identification of current cigarette and ATP product switching behaviors AYAs is critical for understanding trends and determining targets for interventions. Despite the importance of risk and benefit perceptions on youth tobacco use, most research has been cross-sectional, focused on adolescents (as opposed to young adults) or limited to cigarette use. The presented study will fill this gap by prospectively examining the relationship between perceptions and patterns of ATP use behaviors in both adolescents and young adults.

Summary

This changing tobacco landscape threatens decades of public health campaigns and gains in tobacco control dedicated to de-normalizing smoking and lowering rates of tobacco use. Potential contributing factors to this changing landscape of tobacco use include increased marketing receptivity, increased retail access to ATP products, and decreased risk perceptions

and increased benefit perceptions. These potential underlying causes of ATP use have previously been linked to cigarette use in adolescents and young adults. Therefore, it is plausible that similar relationships exist for ATPs.

In this dissertation, I assess three research aims that attempt to improve our understanding of the factors that contribute to adolescents' and young adults' tobacco related perceptions and risk behavior. To my knowledge, this will be the first study to collectively examine the relationship of marketing receptivity, tobacco retailer density and proximity, and risk and benefit perceptions with use of tobacco and alternative tobacco products among adolescents and young adults. This research is also a novel and cost-effective use of an existing longitudinal dataset. Results of these studies may potentially inform regulations of alternative tobacco products in the United States.

1.2 Specific Aims

In this dissertation, I examined the association between marketing receptivity, tobacco retail environment, and risk and benefit perceptions with ATP use among adolescents and young adults. I utilized methods to estimate relationships using observational data and apply spatial analysis to examine potential neighborhood characteristics underlying the relationship between social contextual factors and individual ATP use. The central hypothesis is that adolescents and young adults with increased marketing receptivity and who reside in neighborhoods with increased retail access to ATPs will be more likely to have decreased ATP risk perceptions and exhibit greater ATP initiation and use over time. My specific aims are as follows:

1. To examine the relationship between marketing receptivity and alternative tobacco product initiation (Chapter 2).
2. To examine the relationship of the tobacco retail environment (tobacco retail density and proximity) with individual alternative tobacco product initiation. (Chapter 3)
3. To explore the relationship between risk and benefit perceptions with alternative tobacco product or cigarette switching. (Chapter 4)

These aims were examined using a prospective longitudinal cohort study of adolescents and young adults from California designed to assess adolescents' use and perceptions of a variety of tobacco products. Specifically, in Aims 1 through 3, I analyzed data from the University of California, San Francisco (UCSF) Tobacco Centers of Regulatory Science (TCORS) grant "Improved Models to Inform Tobacco Product Regulation" (P50CA-180890 Center PI: Dr. Stan Glantz) collected under Project 2: "The Role of Risk and Benefit Perceptions in Tobacco Control and Product Usage" (Dr. Bonnie Halpern-Felsher Project 2 Lead/PI). Additionally, in the second aim, I analyzed data from the longitudinal cohort in conjunction with the Census Bureau's American Community Survey (ACS), the state retailer-licensing database maintained by California's Board of Equalization, and school-level data from the California Department of Education to account for clustering and utilizes multiple data sources. The final chapter concludes the dissertation by reviewing findings and implications of the three studies conducted and proposes suggestions for future research.

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Chapter 2

Ownership of Promotional Materials Predicts Initiation of Alternative Tobacco Products among Adolescents and Young Adults

2.1 Background

Although rates of cigarette and other combustible tobacco use has declined among adolescents and young adults in the United States, use of alternative tobacco products (ATP) including electronic cigarettes (e-cigarettes/vapes), smokeless tobacco (chewing tobacco, dissolvable or dipping tobacco, moist snuff, and snus), tobacco pipes, cigars (traditional, filtered, and cigarillos or little cigars), and hookah (water pipes) has increased.[1,2] For example, according to the 2018 National Youth Tobacco Survey (NYTS), past 30-day e-cigarette use increased among high school students from 1.5% in 2011 to 11.7% in 2017.[3] Among high school participants, e-cigarettes were the most commonly used tobacco product (11.7%), followed by cigars (7.7%), cigarettes (7.6%), smokeless tobacco (5.5%), hookah (3.3%), pipe tobacco (0.8%), and bidis (0.7%). Among adults, past 30-day use of ATPs was highest among young adults (ages 18-23), with e-cigarettes (5.2%), cigars/cigarillos (4.2%), and hookah (3.4%) being the most commonly used ATPs.[4]

This changing landscape of tobacco use may be due in part to the marketing of these ATPs, including in online, in newspapers/magazines, retail stores, TV, movies, sports, music event sponsorships, and advertisements placed at children's eye-level.[5-9] The 1998 Master Settlement Agreement (MSA) and the Family Smoking Prevention and Tobacco Control Act (FSPCTA) delegated regulatory authority over tobacco products to the US Food and Drug Administration (FDA) to implement restrictions on tobacco marketing including cigarette marketing to adolescents on traditional mediums such as TV and Radio and online . These regulations include restrictions on the distribution of promotional materials to adolescents during public events such as instructional seminars and music and sporting events, and through postal mail and loyalty programs.[10-14]Though some of these marketing strategies including the distribution of free samples are regulated for select ATPs such as e-cigarettes, many of these marketing restrictions currently do not extend to ATPs, especially online.[6,15]

Promotional materials include but are not limited to t-shirts, hats, keychains, posters, and other items with tobacco companies' insignia and logos. Even though some regulations on ATPs are currently implemented such as the FDA's Youth Tobacco Prevention Plan prohibiting e-cigarette sales to minors, ATPs are still widely marketed including the distribution of ATP samples and coupons via postal mail.[10] According to a recent analysis of the National Youth Tobacco Survey, approximately 13% of middle and high school students reported ownership of e-cigarette coupons in the past 30 days received through digital communications or postal mail.[16]

Tobacco marketing receptivity, has been measured by examining individuals' (1) exposure and affective response to advertisements and/or (2) ownership of tobacco promotional materials.[17,18] Most studies on marketing receptivity among adolescents have focused primarily on the former measurement of marketing receptivity rather than the latter. In general studies have found, marketing receptivity as measured by affective responses to advertisements to be predictive of subsequent initiation of ATPs in adolescents and young adults.[17,19]

Four cross-sectional studies examined the role of marketing receptivity of tobacco products measured by receipt of coupons, samples, or promotional items on cigarette use

among adolescents[16,20,21] and young adults[22] in the U.S., and one study in the U.K.[23] These studies showed positive associations between current cigarette smoking, awareness of coupons,[23] and receipt of coupons among adolescents and young adults.[16,20-22] Receipt of tobacco coupons was also associated with increased positive smoking-related beliefs, higher susceptibility to smoking, lower likelihood of confidence in quitting smoking, and higher likelihood of intentions to purchase tobacco in the future.[20]

We know of no study that has longitudinally examined how ownership of ATP promotional items relates to subsequent initiation of ATPs in adolescents and young adults. The change in alternative use among adolescents and young adults in the United States poses a threat to decades of public health campaigns aimed at reducing tobacco use (Fairchild) by renormalizing smoking, decreasing risk perceptions, and increasing benefit perceptions of tobacco products. [24-26]

In this longitudinal study, we explore the relationship of ATP marketing receptivity and initiation of different alternative tobacco products including e-cigarettes, chewing tobacco or moist snuff (smokeless tobacco), tobacco pipes, cigars, cigarillos or little cigars, and hookah in a California cohort of adolescents and young adults. We assess marketing receptivity defined as both ownership of (1) ATP promotional items and (2) ATP or cigarette promotional items. These promotional items include samples, coupons, and branded material (e.g., caps, t-shirts, or posters) self-reported in wave 1. We examine the relationship of marketing receptivity with both (1) ATP initiation and (2) ATP or cigarette initiation in wave 2 of follow-up. We hypothesize that adolescents who own promotional materials are more likely to initiate ATP and cigarette use.

2.2 Methods

Data and Study Design

The data presented in this analysis are from wave 1 (July 2014 – October 2015) and wave 2 (July 2015 – March 2016) of a prospective longitudinal study of adolescents in 9th and in 12th grade. Students were recruited from ten California high schools with diverse student populations. Assent forms were signed by the student and consent forms were signed by their parent or guardian. Students 18 years or older provided their own consent.

Roughly 4000 students received materials about the study, with 1299 (32%) returning signed consent forms. Of these students, 31.1% (n=405) of the participants were disqualified from the study for either providing invalid contact information, being ineligible (e.g., being in the wrong grade), or unable to be reached by the researchers. Overall, 772 (86.4%) of eligible consented participants completed the survey in wave 1 and 578 in wave 2. with consent were sent an email with a link to the online survey, administered through Qualtrics, which participants completed at home or at school. Data for this analysis (n=757) represent all individuals with complete data on exposure, covariates (wave 1), and outcome variables (wave 2). Participants received $10.00 for participating in wave 1 and $15.00 for wave 2. This study was approved by Stanford University and University of California, San Francisco's (UCSF) institutional review boards. Study details have been previously published.[26]

Measures

All items listed below were asked for the following products: e-cigarettes, cigarettes, smokeless tobacco (chewing tobacco or moist snuff), cigars, cigarillos or little cigars, and

hookah. With the exception of cigarettes, we refer to these products as "Alternative Tobacco Products" (ATP).

Alternative Tobacco Product and Cigarette Ever and Past 30-Day Use

In each wave, participants were asked about ever use of cigarettes and ATPs. Participants were asked, "During your entire life, how many times have you ever used [product]?" Two variables were created from this set of questions: 1) "ATP Ever Use" and 2) "ATP or Cigarette Ever Use." ATP ever use was dichotomized yes/no, indicating whether the participant reported any ever use of at least one ATP. ATP or Cigarettes ever use was dichotomized to indicate if participants reported any lifetime use of any tobacco product (including cigarettes).

In each wave, participants were asked, "During the last 30-days, on about how many days did you use [product]?" Two variables were created from this set of questions: 1) "ATP Past 30-Day Use" and 2) "ATP or Cigarettes Past 30-Day Use." ATP Past 30-Day use was dichotomized yes/no if participant reported any past 30-day use of at least one ATP. ATP or Cigarettes past 30-day use was dichotomized yes/no if participants reported any past 30-day use of any tobacco product (including cigarettes).

ATP Initiation

Our primary outcome of interest was ATP initiation between wave 1 and wave 2 of follow-up. Individuals were categorized as having initiated ATP between waves 1 and 2 if they (1) reported no ever or past 30 day ATP use (defined above) in wave 1, and (2) reported either ever or past 30-day ATP use during wave 2. Our secondary outcome of interest was similarly defined for ATP or cigarette initiation.

Ownership of Promotional Materials:

Participants were asked, "Do you or your friends own any promotional materials (such as: caps, t-shirts, posters) for the products listed below [e-cigarettes, chewing or dipping tobacco or moist snuff, tobacco pipes, cigars, cigarillos or little cigars, and hookahs]?" Response options included "No, neither I nor my friends own items;" "Yes, I own items;" and "Yes, my friends own items." Individuals were categorized as owning promotional material if they responded, "Yes, I own items," coded as yes/no.

Receipt of Product Coupons and Samples: Participants were asked, "Have you received coupons for any of the products listed below [e-cigarettes, chewing or dipping tobacco or moist snuff, tobacco pipes, cigars, cigarillos or little cigars, and hookahs]?" coded as yes/no; and (2) "Have you received samples for any of the products listed below?" coded as yes/no.

We characterized individual exposure to marketing in two ways. First, we defined ownership of ATP-specific promotional materials (yes/no) if students reported at least one of the following: receipt of ATP product samples, receipt of ATP product coupons, or ownership of ATP product promotional material for any ATP including e-cigarettes, chewing or dipping tobacco or moist snuff, tobacco pipes, cigars, cigarillos or little cigars, and hookahs. Second, we defined ownership of ATP or cigarette promotional materials (yes/no) if students reported at least one of the following: receipt of any product samples, receipt of any product coupons, or ownership of any product promotional material from cigarettes or any ATP product. These measures are based on established literature showing ownership of promotional materials as an indicator of tobacco marketing receptivity.[17,18]

Demographics

Participants self-reported age at wave 1 in years, sex, race/ethnicity, and mothers' education. Age was dichotomized into ages 13-15 and 16-19 to distinguish between younger adolescents and older adolescents and young adults in our sample. Race/ethnicity was measured in eleven categories and recoded into five categories (non-Hispanic White, non-Hispanic Asian/Pacific Islander, Latino, and non-Hispanic Other), representing the most prevalent demographic makeup of the schools in California.

Statistical Analysis

We estimated odds ratios between ownership of (1) ATP promotional materials and (2) ATP or cigarette promotional materials reported in wave 1 with (1) ATP initiation and (2) ATP or cigarette initiation in wave 2. Generalized estimating equation (GEE) logistic regression models were used in all analyses to account for potential clustering by school and to estimate population-averaged parameter estimates with robust standard errors with assumed exchangeable working correlation matrix.[27-29] We present parameter estimates (odds ratios (OR) and corresponding 95% confidence intervals (CI)) for the relationship of ownership of ATP promotional materials with (1) ATP initiation and (2) ATP and cigarette initiation.

Individual demographic and socioeconomic characteristics *a priori* determined to be related to our exposure and outcome based on prior literature were considered as confounders in the multivariate analysis.[16,17,19-23] We adjusted for two covariate sets to separately assess the influence of demographic, socioeconomic, and behavioral factors in our analysis. Model 1 adjusts for baseline age, gender, race/ethnicity, and mother's education; model 2 adjusts for model 1 covariates plus ever cigarette use, and ever alcohol use at baseline. Data analysis was conducted using R 3.2.1 (R Foundation for Statistical Computing, Vienna, Austria).

2.3 Results

In wave 1, adolescents on average were 16 years old mean (SD): 16.1 (1.13) female, and Latino. More than 20% of participants of adolescents in this sample self-identified as Asian/Pacific Islander and approximately 36% were Latino. Of 757 participants, approximately 17% (n=129) subsequently initiated ATP use and 18.6% (n=141) initiated either ATP or cigarette use in wave 2. A full description of the sample by initiation status is provided in *Table 1*. Among the 81 adolescents and young adults in the who reported ownership of any cigarette or ATP promotional item, the majority reported ownership of cigarette, e-cigarette, or hookah-specific promotional items. Table 2 further describes marketing receptivity from cigarettes and ATPs among the analytic sample.

Table 2 presents the results of our analysis. In the unadjusted models (Model 1), adolescents reporting ownership of ATP promotional materials were more were more than twice as likely to have initiated ATP use one year later (OR (95% CI): 2.23 1.26, 3.97). Adjusting for individual demographic factors (Model 2) including age, gender, and race/ethnicity, adolescents owning ATP promotional items at baseline were more likely to initiate ATP use one year later compared to individuals not owning ATP promotional material (OR=2.31; 95% CI: 1.28, 4.18). After adjustment for all covariates (Model 3) including mothers' education, baseline ever alcohol use and cigarette use, the relations between ownership of ATP promotional material and ATP initiation in wave 2 was slightly attenuated with greater odds of ATP initiation in wave 2 among individuals owning ATP promotional material compared to individuals not owning ATP promotional material (OR

(95% CI): 2.13 (1.16, 3.91)). In unadjusted models, ATP or cigarette initiation was significantly associated with ownership of ATP or cigarette product promotional material. When covariates were considered, however, results were attenuated and not statistically significant. Specifically, adjusted models assessing the combined predictor of owning ATP or cigarette promotions on the combined outcome of ATP or cigarette initiation produced positive odds ratios that were not statistically significant (OR (95% CI): 1.62 (0.91, 2.91)).

2.4 Discussion

To our knowledge, this is the first study to examine the relationship of marketing receptivity as defined by ownership of ATP promotional items with subsequent initiation of ATP use including e-cigarettes, smokeless tobacco, tobacco pipes, cigars, cigarillos or little cigars, and hookah among adolescents and young adults. In this study, among a sample of California adolescents and young adults, self-reported ownership of ATP promotional material and self-reported ownership of ATP or cigarette-specific promotional material at baseline were longitudinally associated with ATP initiation one year later.

This study provides evidence for the longitudinal relationship of marketing receptivity and subsequent ATP initiation that is consistent with the literature showing ownership of cigarette-related promotional-material is a risk factor for cigarette use among adolescents and young adults.[16,20,21] In an analysis of 24,658 middle and high school participants from the 2012 National Youth Tobacco Survey, exposure to tobacco coupons was found to be associated with higher likelihood to intend to purchase cigarettes in the next 30 days, revealing potential relationships of promotional materials and adolescent cigarette use.[20] Moreover, exposure to these marketing strategies is associated with increases in rates of cigarette use among nonsmokers, translating to faster escalation of cigarette use and lower smoking reduction.[21] Similarly, ATP-specific promotional materials may serve as risk factors for ATP use among adolescents and young adults and this is likely due to tobacco companies using similar marketing strategies as traditional cigarettes to now market ATPs.

This study's findings are important given previous research showing (1) marketing receptivity predicting ATP use,[8,17] and (2) ATP use predicting subsequent cigarette initiation.[12,30-34] ATP use is a strong predictor of subsequent cigarette initiation and increases the odds of becoming an established smoker—even for adolescents and young adults who have an otherwise low risk for cigarette smoking.[30,31] This shift to cigarette use after ATP use is likely due to altered perceptions of cigarettes through increased ATP advertisement and marketing exposure.[35,36] For example, exposure to marketing for ATPs such as e-cigarettes has been found to be associated with subsequent cigarette smoking, even when the promoted products are not cigarettes.[19]

Our study's findings are also important given the restrictions currently implemented for tobacco advertising. AYAs in our study are not only reporting marketing receptivity to unregulated ATPs, but also marketing receptivity to cigarettes. Despite restrictions on the distribution of promotional materials for cigarettes, AYAs still report owning tobacco promotional items. Thus, we believe the significant findings of ATP marketing receptivity predicting ATP initiation found in this study have important public health implications: increased ATP receptivity may not only increase the uptake of ATPs in adolescents, but it may simultaneously contribute to the renormalization of smoking and increase the uptake of

cigarette smoking following ATP initiation. These results suggest the importance of regulating the distribution of all types of tobacco promotional materials to adolescents and young adults.

Our results should be interpreted in light of a few limitations. First, our study does not account for selection or attrition bias whereby adolescents and young adults who were differentially at higher risk for ATP initiation may have been more likely to participate in this study or be lost to follow up. In addition, although we measured and adjusted for all the confounders we identified based on the literature, the potential influence of unmeasured confounders is another limitation of this study. This study was under powered to test effect modification by age and other covariates. Future studies should aim to assess these potential interactions. Moreover, no causal relationships can be established between ownership of promotional material and ATP use, though previous research has made a strong case for causal effect of tobacco marketing and initiation of cigarette use among adolescents and young adults.[2,14] In addition, past 30-day ATP use was defined as any ATP use in the past 30-days, but since many of these ATPs are relatively new products, this measure may only be reflecting recent use of these products and not established use. Moreover, all measures in this study were self-reported, and our study does not account for information bias including potential measurement error. Furthermore, our results may not be generalizable to adolescents and young adults throughout and outside of California; use rates of tobacco and ATPs in our study are consistent with national rates for youth. California's tobacco control regulations may not be generalizable to regulations outside of California. For example, the California Health and Safety Code prohibits the distribution of free or nominal-cost tobacco products (such as coupons, rebate offers, gift certificates, or "other similar offers" for such products) on public grounds or on private grounds that are open to the public.[37] Nevertheless, this law applies only to cigarettes and smokeless tobacco products.[37]

Conclusion

Our results suggest that regulating the distribution of promotional materials for ATP products would likely result in a significant reduction in ATP use. This study fills gaps in the literature by simultaneously assessing a wide variety of ATPs used by adolescents and young adults. Identifying factors associated with ATP use can help inform tobacco control campaigns and ATP regulations such as restrictions for materials distributed to adolescents. The results of this study may inform the FDA's approach to regulating alternative tobacco products and their corresponding marketing efforts. Current restrictions of cigarette samples, coupons, and other promotional material distributed to adolescents and young adults should extend to alternative tobacco products.

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2.6 Tables and Figures

Table 1. Descriptive baseline (wave 1) characteristics of participants, Overall and by Alternative Tobacco Product (ATP) and ATP and Cigarette Initiation Status at wave 2.[a,b]

	Total Sample (n=757)	Never Used Alternative Tobacco Products or Cigarettes (n=628)	Alternative Tobacco Product Initiation (n=129)	ATP or Cigarette Initiation (n=141)
Age				
13-15	304 (40.2)	274 (43.6)	30 (23.2)	32 (22.7)
16-19	453 (59.8)	354 (56.3)	99 (76.7)	109 (77.3)
Gender				
Male	276 (36.5)	234 (37.2)	42 (32.5)	45 (31.9)
Female	481 (63.5)	394 (62.7)	87 (67.4)	96 (68.1)
Race/Ethnicity				
White	202 (26.7)	174 (27.7)	28 (21.7)	30 (21.2)
Asian/Pacific Islander	166 (21.9)	139 (22.1)	27 (20.9)	25 (17.7)
Latino	276 (36.4)	227 (36.1)	49 (37.9)	57 (40.4)
Other	113 (14.9)	88 (14.01)	25 (19.4)	29 (20.5)
Mother's Education				
Don't know	73 (9.6)	60 (9.5)	13 (10.1)	13 (9.2)
Elementary/Junior High school	68 (8.9)	57 (9.0)	11 (8.5)	18 (12.7)
Some high school	68 (8.9)	54 (8.6)	14 (10.8)	15 (10.6)
High school graduate/GED	131 (17.3)	86 (15.3)	35 (27.1)	38 (26.9)
Some college	127 (16.8)	111 (17.7)	16 (12.4)	22 (15.6)
2-year college degree	75 (9.9)	58 (9.2)	17 (13.1)	17 (12.0)
4-year college degree	123 (16.2)	112 (17.8)	11 (8.5)	10 (7.1)
Graduate or professional degree	92 (12.1)	80 (12.7)	12 (9.3)	8 (5.6)
Ever Cigarette Use	95 (12.5)	78 (12.4)	17 (13.1)	19 (13.5)
Ever Alcohol Use	370 (48.8)	281 (44.7)	89 (68.9)	93 (65.9)
Ownership of ATP promotional item	64 (8.4)	45 (7.1)	19 (14.7)	16 (11.3)
Ownership any cigarette or ATP promotional item	81 (10.7)	58 (9.2)	23 (17.8)	22 (15.6)

a) Alternative tobacco products (ATP) including e-cigarettes, chewing or dipping tobacco or moist snuff, tobacco pipes, cigars, cigarillos or little cigars, and hookahs
b) ATP and cigarette initiation includes initiation of alternative tobacco products or cigarettes.

Table 2. Ownership of Cigarette and Alternative Tobacco Product Promotional Items by Cigarette and Alternative Tobacco Product Use among adolescents and young adults (n=757).

	Cigarettes	E-cigarettes	Chewing, Dipping Tobacco, or Moist Snuff	Tobacco Pipes	Cigars, Cigarillos, or Little Cigars	Hookah
Samples	6	11	1	0	2	13
Coupons	25	24	5	1	7	12
Other promotional items[a]	9	52	5	6	0	11

a) Other promotional items include but are not limited to t-shirts, hats, keychains, posters, and other items with tobacco companies' insignia and logos

Table 3. Generalized estimating equation (GEE) logistic regression models of ownership of ATP-specific promotional materials (wave 1) with subsequent ATP initiation (wave 2) and any tobacco initiation among adolescents and young adults in the (n=757).

	Model 1[a]				Model 2[b]				Model 3[c]			
	Alternative Tobacco Product Initiation[d]		ATP or Cigarette Initiation [e]		Alternative Tobacco Product Initiation		ATP or Cigarette Initiation		Alternative Tobacco Product Initiation		ATP or Cigarette Initiation	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Ownership of alternative tobacco product promotional material	2.23	(1.26, 3.97)	1.51	(0.83, 2.75)	2.31	(1.28, 4.18)	1.54	(0.82, 2.87)	2.13	(1.16, 3.91)	1.42	(0.75, 2.71)
Ownership of ATP or cigarette product promotional material	2.13	(1.26, 3.60)	1.74	(1.02, 2.96)	2.09	(1.21, 3.60)	1.69	(0.97, 2.94)	1.99	(1.11, 3.56)	1.62	(0.91, 2.91)

a) Model 1 is unadjusted for any covariate. b) Model 2 presents a model adjusting for baseline age, gender, race/ethnicity. c) Model 3 presents a model adjusting for model 2 covariates plus mother's education, ever alcohol use and ever cigarette use at baseline. d) Wave 2 Alternative tobacco product initiation analysis: n=129 e) Wave 2 ATP and Cigarette Initiation: n=141.

Chapter 3

Tobacco Retail Environment and Alternative Tobacco Product Use Among Teens

3.1 Background

The rise of non-cigarette or alternative tobacco product (ATP) use among adolescents poses a threat to decades of public health campaigns focused on denormalizing smoking and reducing nicotine use.[1,2] This changing pattern of tobacco use may be due to an increase in retail availability of ATP products.[3,4] Little is known about the effect of the tobacco retail environment on adolescent ATP use. Data from a longitudinal survey of 728 adolescents (ages 13-19) nested in 191 neighborhoods nested in 10 California high schools were used to examine whether greater tobacco retailer density and proximity predicts ATP initiation. To account for partial and complete nesting, two- and three-level multilevel and cross-classified random effect logistic regression models evaluated individual-level, school-level, and neighborhood-level risk factors for ATP initiation. Adjusting for covariates at multiple levels, tobacco retailer density (but not proximity) was associated with ATP initiation, suggesting that tobacco retailers clustered around students' home neighborhood may be an important environmental influence on adolescents' ATP use. This suggests that retail density policies to reduce adolescent ATP use should focus not only on limiting the number of tobacco retailers with close proximity to schools, but also on reducing the density of tobacco retailers where students live.

Declines in cigarette smoking by US high school students are offset by increases in ATP use which includes e-cigarettes and other "vaping" products, smokeless tobacco (chewing tobacco, dipping tobacco, moist snuff, and snus), tobacco pipes, cigars (traditional, filtered, and cigarillos or little cigars), and hookah (water pipes). [2] For example, according to the 2017 National Youth Tobacco Survey (NYTS), e-cigarette use among high school students increased from 2011–2017 (1.5% to 11.7%).[5] Moreover, according to the 2017 Monitoring the Future Study, more teens used e-cigarettes in the past 30 days than traditional tobacco cigarettes or any other tobacco product.[5] A total of 3.9 million middle (grades 6-8) and high school (grades 9-12) participants reported current use of at least one tobacco product, and over 1.8 million reported poly-tobacco use, defined as past 30-day use of 2 or more tobacco products.[6] Similarly to middle school students, 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 (0.8%), and bidis (0.7%).[7]

The rise of non-cigarette, alternative tobacco product (ATP) use among adolescents may be due to an increase in retail availability of ATP products. For example, in California where this study was conducted, the odds that a convenience store sold e-cigarettes tripled between 2011 and 2014 (cite report on CTCP website). Additionally, in a survey of a nationally representative sample of adolescents, 47.5% of adolescents reported visiting convenience stores at least weekly including retailers with documented evidence of selling unhealthy products including tobacco and alternative tobacco products.[8] 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.

While youth substance use is known to be spatially clustered, the underlying reasons for this pattern are not well understood.[9] 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 would decrease purchase costs for ATP.[10] 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.[11] 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.[12]

US studies that examined the role of the tobacco retail environment in relation to adolescent tobacco use are predominately cross-sectional and focus on cigarette smoking.[11,13-20] Findings have been mixed. Some studies have found that greater retail availability of cigarettes, as measured by the density and proximity of tobacco retailers from adolescents' home and/or school, to be associated with higher odds of ever trying cigarette smoking, past-month smoking, and attempting to purchase cigarettes. At the same time, among studies assessing the relationship of density and proximity with cigarette use, higher density but not proximity was found to be significant predictor of cigarette use among adolescents.[11,14-17,19,20] To our knowledge only two cross-sectional studies have assessed the relationship of the tobacco retail environment and ATP use (specifically e-cigarettes only) among adolescents. Using data from the 2014 New Jersey Youth Tobacco Survey and adolescents in four counties in Texas, researchers observed positive geospatial associations between the presence of tobacco retailers around some schools and cigarette/e-cigarette among some students, but these associations were cross-sectional and not consistent across all neighborhoods.[4,21]

Two longitudinal studies have suggested higher odds of initiating tobacco and ATP use among participants who live in areas with higher tobacco retailer density.[17,22] In a sample of youth aged 13-16 from 50 mid-sized noncontiguous cities in California, researchers found outlet density was associated positively with life-time cigarette smoking and perceived availability of tobacco products and negatively associated with perceived enforcement of tobacco sales laws.[17] While this study assessed the relationship between tobacco retailer density and tobacco use among adolescents, only cigarette smoking was assessed. In the Legacy Young Adult Cohort Study, a 2013 nationally representative sample of young adults aged 18–34 in the United States, researchers found higher tobacco retailer density was significantly associated with a higher likelihood of initiating cigarette use among adults aged 25–34, and of initiating non-cigarette combustible use among adults ages 18–24 years including cigars, little cigars/cigarillos/bidis, hookah/shisha, pipe, e-cigarettes, dip/snuff, chewing tobacco, snus and dissolvables.[22] While this study assessed the relationship between tobacco retailer density and ATP use, this study was conducted among young adults only.

The current study fills two main gaps in the literature. This is the first longitudinal study to examine the relationship of tobacco retailer density and proximity to ATP initiation among adolescents. Although several studies have suggested associations of tobacco retailer density and proximity with cigarette use, few have examined alternative tobacco products specifically, and none to our knowledge have assessed a comprehensive list of ATPs. To address these gaps, we conducted secondary analyses of data from a longitudinal cohort to understand potential environmental influences including tobacco retail density and proximity on adolescent initiation of ATP use. To assess the relationships between tobacco retailer density and proximity with ATP initiation, we performed two sets of analyses: 1) cross-sectional and 2) longitudinal. This study aims to answer the question "What is the relationship between living in neighborhood tobacco retail density and proximity with individual ATP initiation among adolescents"? 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 living in neighborhoods with greater tobacco retailer proximity. To test these hypothesis, we implemented a geospatial analysis approach, accounting for the unique nesting structure in our sample. Specifically, we utilized Cross-Classified Multilevel Models (CCMM) allow us to account for non-hierarchical nesting structures, which is appropriate for a sample in which students who live in the same neighborhoods attended different schools. This application of a 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. This research aims to contribute to the literature to evaluate the underlying reasons behind spatial clustering of youth substance use by examining the association between tobacco retailer density and proximity in high-school students' home neighborhood with subsequent ATP initiation.

3.2 Methods

Data and Study Design

This longitudinal analysis combined data from multiple sources: a cohort survey of adolescents from ten 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.

This analysis uses baseline and 12-month follow-up data from a prospective longitudinal study of adolescents recruited followed at roughly one-year intervals. Details about the online cohort survey have been published elsewhere. [23] The baseline survey (Wave 1) was completed in 2014 and the mean length of follow-up was 12.1 months (SD=2.4). Overall, 786 (87.9%) of eligible consented students completed the survey in wave 1, and 728 of wave 1 participants were used in this analysis with complete covariate, exposure, and outcome data. In wave 2, 578 participants completed the survey (retention rate=75%). Cross-sectional analyses utilizes 728 participants with complete covariate, exposure and outcome data while the longitudinal analysis utilizes wave 2 participants with complete covariate, exposure, and outcome data. Participants received $10.00 for participating in wave 1 and $15.00 for wave 2. The survey included 125 questions and took participants between 30 and 60 minutes to complete. The study was approved by institutional review boards at Stanford University School of Medicine and the University of California, San Francisco.

Alternative Tobacco Product Initiation

Our primary outcome of interest was ATP initiation between baseline and Wave 2 of follow-up. In each wave, participants were asked about their lifetime and past-30 day use of cigarettes and alternative tobacco products. At baseline and Wave 2, participants were asked, "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 were asked for the following products: cigarettes and separately for each ATP, including e-cigarettes, chewing or dipping tobacco or moist snuff, cigars, cigarillos or little cigars, and hookah. In cross-sectional analysis, participants were categorizes as having used 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) reported never using ATP at baseline and (2) reported either ever or past 30-day ATP use during wave 2.

Tobacco Retailer Density and Proximity

Participants provided their home address on pre-Wave 1 survey intake form and these data were geocoded to latitude/longitude and census tract using ArcGIS 10.5.1 and Street Map Premium 2017 Release No.3 linked to the 2010 Census Block Map. Data for this analysis (n=728) represents all geographically mapped individuals with complete data on exposure, outcome, and covariate data. *Supplementary Figure* 1 provides details about 42 participants who were excluded for missing data. Although it is recommended to use egocentric neighborhood definitions in studies of youth access to tobacco retailers,[9] this was impossible because the majority of participants in the study sample lived within ½ mile and 1mile buffers of each other. Instead, we used census tract as the primary spatial unit for each student's home neighborhood as in other studies.[22]

We linked the data for students' home address and census tract to address data for tobacco retailers that we geocoded from the California Board of Equalization's 2014 state tobacco retail licensing (mapping rate=98.6%). 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). For descriptive purposes, we also categorized census tracts according to tertiles of tobacco retail density: none, low (0.02-4.2), and high (≥8.10) retailers per square mile. Proximity measured as the distance from each participant's home address to the nearest tobacco retailer in roadway miles. Thus, proximity was included with other individual-level variables measured at baseline and density was included with other tract-level variables measured at baseline.

Neighborhood-level Covariates

Using census tract to define students' home neighborhood, we acquired tract-level data for 191 unique Census tracts from the American Community Survey estimates for 2012-2016. We acquired data on a range of tract-level covariates including population demographic factors, household composition factors, socioeconomic factors, and residential environment factors. Final analyses controlled for percent non-Hispanic White, median household income, and population density because these are common covariates in other studies.[11,15] 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.[24] These 2014-2015 academic year data include school demographics (school size, average class size, percent female, race/ethnicity), socioeconomic demographics (percent socioeconomically disadvantaged youth, percent homeless youth, percent foster youth, percent English learners, percent scoring ≥ 1500 on Standardized Admissions Test (SAT), percent of students eligible for free or reduced-price meals). Health assessment data was obtained for the 2014-2015 academic year but percent of female students was obtained for the 2016-2017 academic year as 2014-2015 data was not available.[24] Detailed characteristics for the 10 high schools are summarized in *Supplementary Table 4*.

Individual-level Covariates

Demographics were all measured at baseline, including self-reported age in years, sex, race/ethnicity, and mothers' education. Age was dichotomized into ages 13-15 and 16-19 to distinguish between adolescents who were not yet old enough to drive from older adolescents. Race/ethnicity coded to include non-Hispanic White, Asian, Pacific Islander, Hispanic, and Other. As in previous studies, mother's education was dichotomized to compare students whose mother completed high school with others.[25]

Statistical Analysis

We conducted longitudinal cross-classified multilevel modeling (CCMM) and controlled for individual-level, neighborhood-level and school-level sociodemographic factors and potential confounders, following the analytical approach of Dunn and colleagues.[25] Thus, in addition to modeling the effect of either school or neighborhood setting, as conducted using a traditional logistic multi-level regression approach,[26] we also used logistic cross-classified random effect models to disentangle the role of schools and neighborhoods on participants' subsequent ATP initiation. We fit three sets of models in the current analysis. The first two models used a traditional two-level multilevel model, assuming observations are that all individuals are completely nested within neighborhoods within schools. 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 fit a cross-classified model to account for the fact that some students who lived in the same census tracts attended different high schools.

We also conducted our analyses cross-sectionally, evaluating the relationship between tobacco retailer density and proximity with ATP ever use at baseline. Parameter estimates (adjusted odds ratios, OR) and 95% confidence intervals (CI) are presented for fixed parameter estimates and random effect parameter estimates are presented as variance estimates and standard deviations. Descriptive statistics and residual plots were used to explore and describe the analytic sample, test model assumptions, detect outliers and influence points on model fit. Detailed description of the models used in our analysis appears in *Supplementary Table 1.*

All analyses were repeated for secondary exposures and outcomes, including tobacco retailer density defined as count per 1000 persons, 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, Texas 77845 USA) and R 3.2.1 (R Foundation for Statistical Computing, Vienna, Austria).

Sensitivity Analyses

We repeated our analyses, assessing the inclusion of blunts (marijuana wrapped in a tobacco leaf) in our definition of ATP ever-use because cigar wraps are non-cigarette tobacco products. Finally, we further adjusted models including an indicator variable for participant neighborhoods with only one respondent (0=tract included more than 1 respondent; 1=tract has only one respondent) All sensitivity analyses yielded similar results to the main analyses (data not shown).

3.3 Results

Table 1 shows individual-level, neighborhood-level, and school-level exposure, outcome, and covariate information for the sample overall and stratified by ATP use status (ever ATP users in wave 1, ATP initiation in wave 2). The sample was predominantly 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 baseline and 106 (14.5%) initiated ATP use within one year (Wave 2). The mean number of tobacco retailers per square mile within a tract was 7.21 (SD=6.5), and the average distance from each participant's residence to the nearest tobacco retailer was 0.60 miles (SD=0.5). Approximately 31% of students (n=229) lived in a census tract with high tobacco retailer density (≥8.1 retailers/square mile).

Figure 1 illustrates partial and overlapping clustering of students from two of the 10 high schools in the sample. Note that some students living in the same census tracts attended different high schools, which illustrates the importance of accounting for partial, non-hierarchical nesting in our modeling. In addition, Figure 1 also illustrates simultaneous variation in tobacco retail density across census tracts near two of the 10 high schools in this sample.

In unadjusted cross-sectional analyses (*Supplementary Table 1*), results indicated that adolescents were 1.21 (95% CI: 1.14, 1.66) times more likely to have ever used ATPs with every one-unit increase in tobacco retailer density (tobacco retailers per square mile) after adjusting for individual-level covariates. Results slightly increased after adjusting for individual-level with neighborhood-level covariates (OR=1.26, 95% CI: 1.12, 1.19) and school-level covariates (OR=1.11, 95% CI: 1.03, 1.34). In a fully adjusted cross-classified model accounting for individual-level, school-level, and neighborhood-level covariates, results were further attenuated with an odds ratio of 1.03 (95% CI: 1.02, 1.15).

Table 2 and *Table 3* present the results of a series of models for the neighborhood-only, school-only multilevel model, neighborhood and school multilevel model, and the cross classified multilevel model predicting ATP initiation as a function of tobacco retailer density and covariates. In the null model (*Table 2, Model 1*) the variance of the random effects for the school-only and neighborhood-only and school-only model were 55% and 23% respectively, and remain unchanged in both the traditional MLM with both neighborhood and school and the corresponding cross-classified multilevel model. When individual-level covariates were added (*Table 2 Model 2*), significant declines relative to model 1 were observed for neighborhood (43%) and school (10%) random effects. A similar decline was observed in the cross classified multilevel model (*Table 2 Model 3*), with the variance only slightly more driven by school (10%) than neighborhood (8%). Smaller declines were seen when neighborhood-level and school-level covariates were considered. This decline suggests that the between-level variation in ATP initiation was due largely to the observed school-level and neighborhood-level characteristics across schools and neighborhoods.

After adjusting for school-level and neighborhood-level covariates (*Table 3 Models 3 and 4*), the estimated odds (95% Confidence Interval (CI)) of ATP initiation after one year of follow-up was 1.34 (1.21, 3.81) and 1.08 (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 non-hierarchical nesting in our fully adjusted CCMM model (*Table 3 Model*

5), including individual-level, neighborhood-level, and school-level covariates, the estimated odds of subsequent ATP initiation was 1.22 (1.07, 2.12). In this full adjusted cross classified multilevel model, neighborhood-level and school-level variation was 4% and 3%, respectively.

Results for tobacco retailer proximity (distance to nearest tobacco retailer (mile)) and covariates are shown in *Supplementary Table 2 and Supplementary Table 3*. While results were similar in inference (increasing 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. Sensitivity analyses yielded similar results to the main analyses (data not shown).

3.4 Discussion

To our knowledge, this is the first longitudinal study to provide a longitudinal examination of aspects of the retail environment for ATP in relation to adolescents individual ATP use patterns. In a sample of California adolescents, 14.5% of never users at baseline had initiated ATP use at one-year follow-up. However, odds of initiation were higher for students who lived in census tracts with greater retail availability of ATP, as measured by tobacco retailer density. These findings suggest that the increased retail availability of ATP products in 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.

This study's findings are consistent with that extant literature examining the influence of the tobacco retail environment on cigarette use among adolescents.[11,13-20,22] For example, our study's findings are consistent with a recent analysis examining the impact of tobacco retailer density on tobacco and alternative tobacco use in a national sample of adults ages 18-34 which found tobacco retailer density to have a significant positive impact on initiation of cigarettes and other combustible tobacco products.[22] This is further plausible for ATPs, as relative to adults, adolescents have been shown to be particularly vulnerable to marketing and promotion of tobacco products.[15]

As with studies assessing cigarette smoking, our findings for ATP initiation suggest that the tobacco retail environment may have a direct effect on experimenting with ATP products or willingness to use ATP products, which is known to predict future smoking.[27] Our study presents results suggesting tobacco retailer density may predict ATP initiation, which we hypothesize occurs in part through increased retail availability and increased marketing of ATPs at the point-of-sale. It is also possible tobacco retailer density and proximity may directly impact ATP initiation by influencing ATP access behaviors through non-compliant retailers or other social sources from which they may access ATPs. Researchers have shown tobacco retailer density, coupled with school smoking rates, were related to underage youth buying their own cigarettes or finding someone to buy cigarettes on their behalf. [16] Future research will consider these alternative relationships further.

Strengths of this study include its longitudinal design, the availability of geocoded data allowing us to examine multi-level data to capture environmental risk factors for ATP use. Measures of tobacco retailer density and proximity were created with data from a state tobacco retailer licensing database. Moreover, the inclusion of objective measures of the tobacco retail environment in this study serve as more valid measures of exposure to retail marketing than survey data on marketing, as studies have shown adolescents self-reporting their exposure may

not be a valid measure due to recall bias, which has been shown in studies on cigarette marketing,[29] and more recently with e-cigarette marketing.[4]

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, we did not obtain data about what alternative tobacco products were sold in each store. Although rare, the exposure measure may have included stores that only sold cigarettes and not ATP. More likely, the exposure measure underestimated retail availability of ATP because it excludes vape shops that were not required to have a state tobacco retailer license until 2017. Of course, census tracts may not accurately capture adolescents' exposure to tobacco retail environments as they travel from home to school to leisure activities, etc. The use of larger administrative neighborhood definitions has been shown to bias exposure estimates for tobacco retailer proximity, and thus may explain null findings for proximity in this study.[9] Unfortunately, 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 and school neighborhoods defined by road network buffers or activity spaces, utilize other geographical sampling techniques, and define neighborhoods using other methods rather than administrative units.

Other limitations of this study are typical of survey research. For example, the study does not account for 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 or be lost to follow-up. Although we measured and adjusted for many confounders that we identified based in the literature, the potential influence of unmeasured confounders is another limitation. In addition, all outcome measures were self-reported, with an overall response rate typical of Internet panels among adolescent respondents. Finally, results may not be generalizable to adolescents and young adults throughout and outside of California.

Other limitations include data sparseness and buffer definitions used in our geo-processing. In our study, some neighborhoods had only one respondent and several participants lived within ½ mile and 1 mile of each other. While it is possible our findings may 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 adjusting for neighborhoods with one respondent produced similar results to main analyses and while we did not observe statistically significant results for tobacco retailer proximity, we did observe meaningful cross-classification of neighborhoods and schools.

This research provides the first longitudinal evidence of that higher tobacco retailer density near adolescents' home predicts greater odds of initiating ATP use. Regulation of these non-cigarette tobacco products is a public health priority, especially for tobacco use prevention. 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 alternative tobacco products in retailers around the United States, coupled with a growing body of evidence that the impact of tobacco retail availability on cigarette smoking behavior among adolescents suggest that the current tobacco retail environment may be contributing factor in promoting ATP experimentation and initiation. Moreover, these findings suggest the importance school-centric regulations are expanded to also include regulations of the tobacco retail environment in residential neighborhoods. Policy efforts to reduce adolescent ATP use should limit and the reduce the density of tobacco retailers.

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3.6 Tables and Figures

Figure 1. Cross-classification example: Students reside in the same census tracts but attend different high schools, 2014.

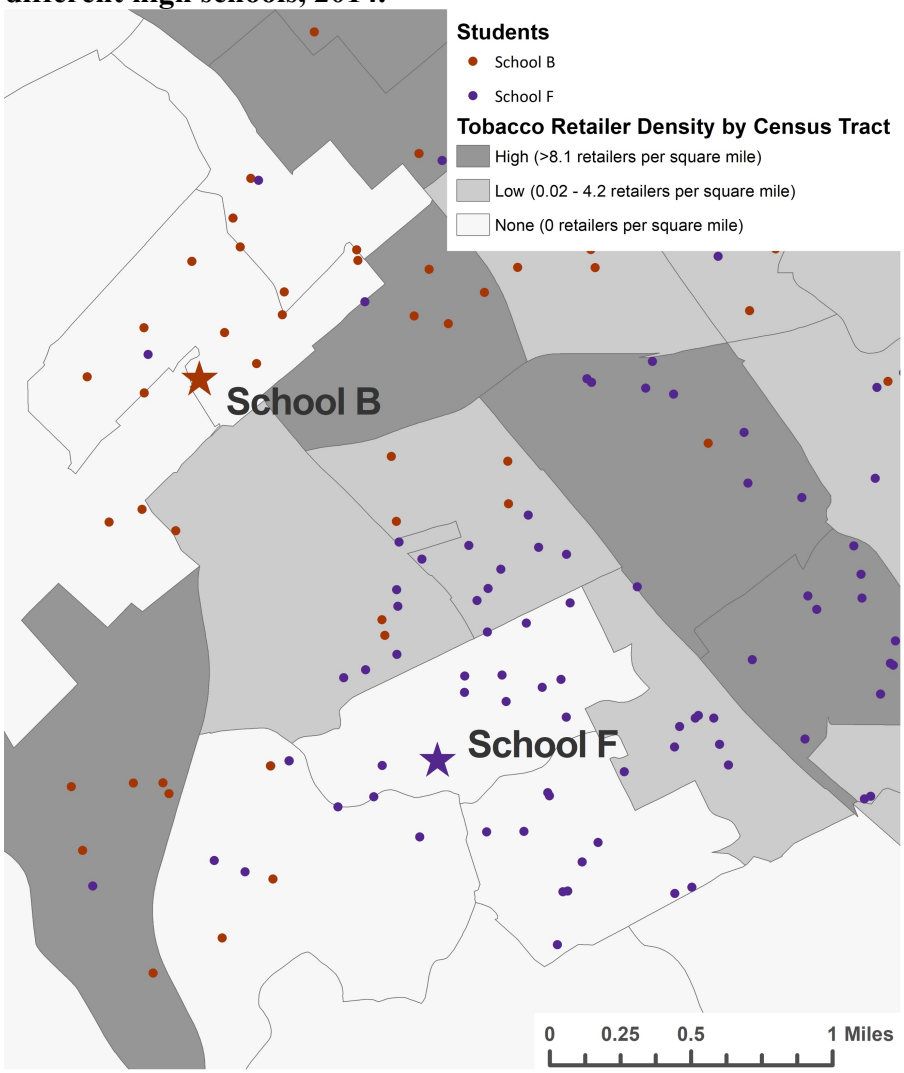


Table 1. Baseline descriptive characteristics of participants (n=728) nested in neighborhoods (n=191) nested in schools (n=10), Overall and by Alternative Tobacco Smoking Status in Wave 1 and Wave 2 of follow-up.[1]

Wave 1 Demographics	Total Sample (n=728)	Ever ATP[2] Users, Wave 1 (n=237)	ATP Initiation, Wave 2 (n=106)
Participant Demographics (Level 1, n=728)	**N (%)**	**N (%)**	**N (%)**
Age			
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.) mean (sd)	0.60 (0.5)	0.61 (0.7)	0.72 (1.04)
Neighborhood Demographics (Level 2, n=191)			
Percent white mean (sd)	33.34 (20.6)	41.18 (18.3)	40.12 (18.5)
Median household income mean (sd)	68,365 (37,184)	70,262 (36,102)	78,760 (42,491)
Population density (per sq. mile) mean (sd)	8,879 (7,338)	6,803 (5,060)	6,729 (4,499)
Tobacco retailer density			
Tobacco retailers per square mile mean (sd)	7.21 (6.5)	7.39 (6.42)	7.15 (5.49)
Density tertiles			
None (0 Retailers)	143 (19.6)	45 (18.9)	20 (18.8)
Low (0.02-4.2 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 Demographics (Level 3, n=10)			
Percent white mean (sd)	26.65 (14.9)	25.95 (14.5)	28.37 (14.9)
Average class Size mean (sd)	26.90 (3.9)	28.00 (3.1)	27.5 (3.2)
Reduced lunch mean (sd)	54.83 (21.7)	56.98 (21.0)	55.82 (21.7)

- [1]ATP = Alternative Tobacco Products including e-cigarettes, chewing or dipping tobacco or moist snuff, tobacco pipes, cigars, cigarillos or little cigars, and hookahs.

Table 2. Associations between tobacco retailer density, baseline individual-level covariates, and Alternative Tobacco Product (ATP) initiation at 12-month follow-up, excluding neighborhood and school-level covariates

	Model 1				Model 2			
Fixed Effect Odds Ratios	**School -Only**	**Neighborhood-Only**	**Neighborhood & School**	**Cross-Classified**	**School-Only**	**Neighborhood-Only**	**Neighborhood & School**	**Cross-Classified**
Tobacco retailer density (retailers per square mile)	1.25 (1.04, 1.87)	1.24 (1.05, 1.81)	1.24 (0.87, 1.73)	1.23 (1.03, 1.78)	1.33 (0.98, 2.03)	1.28 (1.04, 1.88)	1.33 (0.98, 2.03)	1.33 (1.02, 2.03)
Individuals (Level 1, n=728)								
Age								
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					0.76 (0.48, 1.19)	0.76 (0.48, 1.19)	0.76 (0.48, 1.19)	0.76 (0.48, 1.19)
Race/Ethnicity								
White					Ref	Ref	Ref	Ref
Asian/Pacific Islander					1.60 (0.85, 3.02)	1.26 (0.69, 2.28)	1.60 (0.85, 3.01)	1.60 (0.85, 3.01)
Latino					1.26 (0.69, 2.28)	1.26 (0.69, 2.28)	1.26 (0.69, 2.28)	1.26 (0.69, 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)					0.76 (0.46, 1.29)	0.76 (0.46, 1.28)	0.76 (0.46, 1.27)	0.77 (0.45, 1.29)
Random Effect Estimates								
Neighborhood	--	0.55 (0.32)	0.55 (0.32)	0.55 (0.32)	--	0.43 (0.28)	0.43 (0.28)	0.08 (0.10)
School	0.23 (0.62)	--	0.23 (0.62)	0.23 (0.62)	0.10 (0.61)	--	0.10 (0.60)	0.10 (0.60)

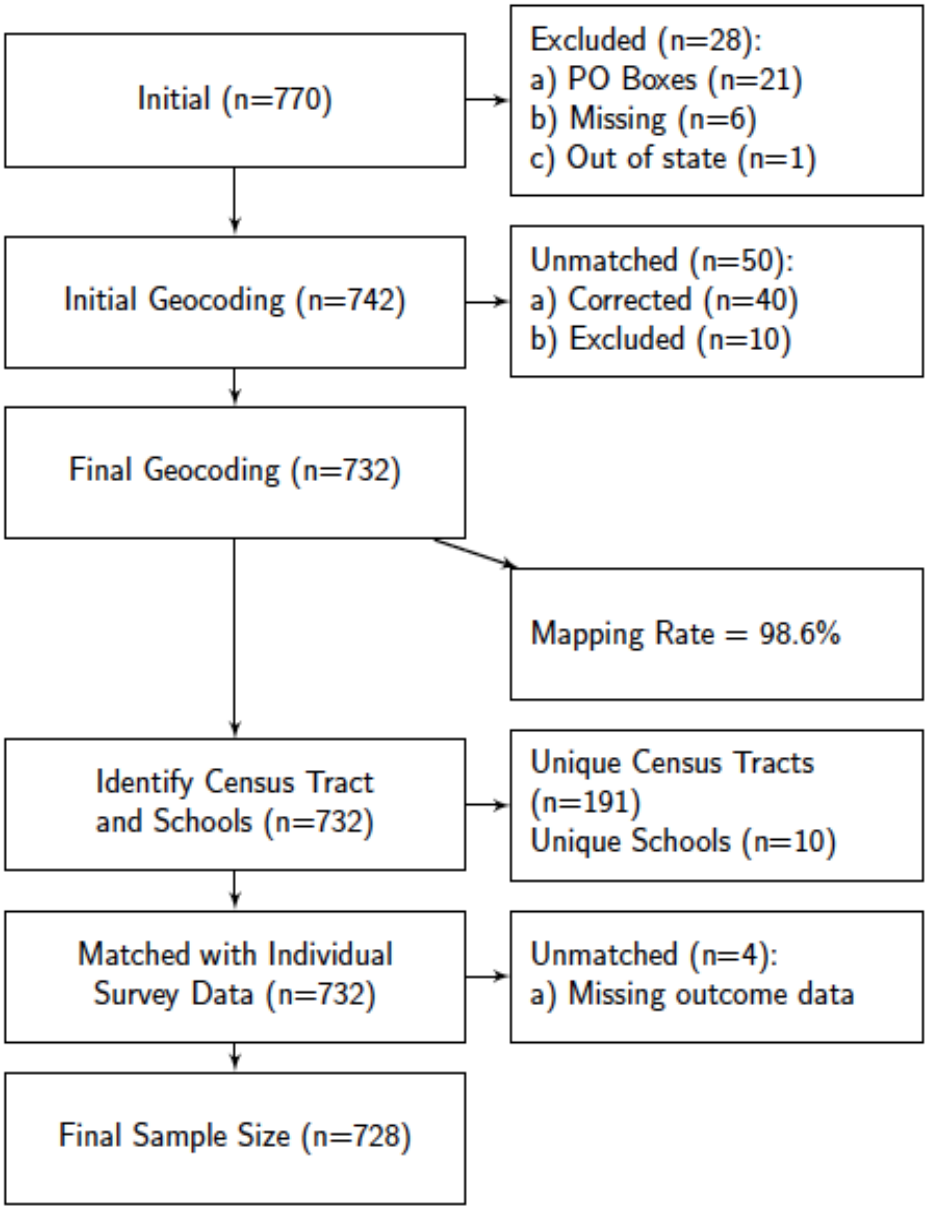
- Cell entries are fixed effects parameter estimates (adjusted odds ratios, OR) and 95% confidence intervals (CI) from multi-level and cross-classified random effects logistic regression models.
- Model 1 presents the results for a null model (i.e., no covariates) for each model type: school-only multilevel 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 estimate and standard deviations.

Table 3. Associations between tobacco retailer density, baseline individual-level covariates, and Alternative Tobacco Product (ATP) initiation at 12-month follow-up, excluding neighborhood and school-level covariates, adjusting for

	Model 3		Model 4		Model 5
Fixed Effect Odds Ratios	**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					
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	0.75 (0.47, 1.18)	0.75 (0.47, 1.18)	0.75 (0.47, 1.18)	0.75 (0.47, 1.18)	0.74 (0.47, 1.17)
Race/Ethnicity					
White	Ref	Ref	Ref	Ref	Ref
Asian/Pacific Islander	1.45 (0.73, 2.87)	1.45 (0.73, 2.87)	1.51 (0.77, 2.97)	1.51 (0.77, 2.97)	1.54 (0.77, 3.06)
Latino	1.32 (0.72, 2.41)	1.32 (0.72, 2.41)	1.21 (0.66, 2.19)	1.21 (0.66, 2.19)	1.29 (0.70, 2.38)
Other	2.07 (1.06, 4.06)	2.07 (1.06, 4.06)	1.93 (0.99, 3.76)	1.93 (0.99, 3.76)	2.02 (1.03, 3.98)
Mother's Education (Less than a high school degree)	0.82 (0.48, 1.39)	0.82 (0.48, 1.39)	0.77 (0.46, 1.29)	0.77 (0.46, 1.29)	0.82 (0.48, 1.41)
Neighborhoods (Level 2, n=191)					
Percent non-Hispanic White	1.01 (0.99, 1.02)	1.01 (0.99, 1.02)			1.01 (1.00, 1.03)
Median Household Income ($10K)	0.98 (0.94, 1.04)	0.97 (0.91, 1.04)			0.94 (0.87, 1.02)
Population Density (Per 1000 Persons)	1.03 (0.99, 1.07)	1.02 (0.98, 1.07)			1.03 (0.99, 1.07)
Schools (Level 3, n=10)					
Percent non-Hispanic White			4.89 (0.82, 29.30)	4.89 (0.81, 29.29)	8.81 (0.98, 78.80)
Percent eligible for free or reduced meals			1.79 (0.79, 4.02)	1.79 (0.79, 4.02)	1.19 (0.46, 3.10)
Average class size			1.04 (0.95, 1.13)	1.03 (0.96, 1.13)	1.01 (0.93, 1.11)
Random Effect Estimates					
Neighborhood	0.07 (0.26)	0.04 (0.21)	--	--	0.04 (0.21)
School	--	--	0.05 (0.17)	0.05 (0.17)	0.03 (0.08)

- Cell entries are fixed effects parameter estimates (adjusted odds ratios, OR) and 95% confidence intervals (CI) from multi-level 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-level 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 estimate and standard deviations.
- Median household income and population density were rescaled for the model

Supplementary Figure 1. Geoprocessing.



Supplementary Table 1. Cross-sectional associations between tobacco retailer density (retailers per square mile), individual-level covariates, and Alternative Tobacco Product (ATP) at baseline, adjusting for neighborhood and school-level covariates.

Fixed effect Odds Ratios: Tobacco retailer density (retailers per square mile)	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
School-Only	1.44 (1.07, 2.52)	1.42 (1.08, 4.56)	--	1.11 (1.03, 1.34)	--
Neighborhood-Only	1.34 (1.04, 1.73)	1.26 (1.06, 1.82)	1.26 (1.12, 1.19)	--	--
Neighborhood & School	1.63 (1.26, 2.12)	1.23 (1.06, 1.73)	--	--	--
Cross-Classified	1.76 (1.37, 2.26)	1.21 (1.14, 1.66)	1.20 (1.13, 1.48)	1.10 (1.03, 1.31)	1.03 (1.02, 1.15)

- 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.
- 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-level covariates.
- Model 5 presents the results of a CCMM containing all individual, neighborhood-, and school-level covariates.
- Cell entries are parameter (Odds Ratios) estimates and confidence intervals calculated using the Wald approximation.

Supplementary Table 2. Associations between tobacco retailer proximity (distance to nearest tobacco retailer (mile), baseline individual-level covariates, and Alternative Tobacco Product (ATP) initiation at 12-month follow-up, excluding neighborhood and school-level covariates, excluding neighborhood and school-level covariates.

	Model 1				Model 2			
Fixed Effect Odds Ratios	**School-Only**	**Neighborhood-Only**	**Neighborhood & School**	**Cross-Classified**	**School-Only**	**Neighborhood-Only**	**Neighborhood & School**	**Cross-Classified**
Tobacco retailer proximity (distance to nearest tobacco retailer (mile))	0.89 (0.63, 1.27)	0.86 (0.62, 1.19)	0.86 (0.63, 1.27)	0.89 (0.63, 1.27)	0.87 (0.60, 1.27)	0.82 (0.58, 1.15)	0.82 (0.58, 1.15)	0.89 (0.63, 1.27)
Individuals (Level 1, n=728)								
Age								
13-15					Ref	Ref	Ref	Ref
16-19					2.48 (1.52, 4.04)	2.43 (1.50, 3.93)	2.43 (1.51, 3.93)	2.48 (1.52, 4.04)
Gender								
Male					0.75 (0.48, 1.18)	0.75 (0.48, 1.19)	0.75 (0.48, 1.19)	0.75 (0.48, 1.18)
Race/Ethnicity								
White					Ref	Ref	Ref	Ref
Asian/Pacific Islander					1.69 (0.88, 3.23)	1.70 (0.89, 3.22)	1.70 (0.89, 3.22)	1.69 (0.88, 3.23)
Latino					1.31 (0.72, 2.39)	1.70 (0.89, 3.22)	1.70 (0.89, 3.22)	1.31 (0.72, 2.39)
Other					2.13 (1.09, 4.16)	1.70 (0.89, 3.22)	1.70 (0.89, 3.22)	2.13 (1.09, 4.16)
Mother's Education (Less than a high school degree)					0.81 (0.48, 1.36)	0.79 (0.47, 1.32)	0.79 (0.47, 1.32)	0.81 (0.48, 1.36)
Random Effect Estimates								
Neighborhood	--	<0.0001	<0.0001	<0.0001	--	<0.0001	<0.0001	<0.0001
School	0.15 (0.38)	--	<0.0001	<0.0001	0.04 (0.19)	--	<0.0001	<0.0001

- Cell entries are fixed effects parameter estimates (adjusted odds ratios, OR) and 95% confidence intervals (CI) from multi-level 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 estimate and standard deviations.

Supplementary Table 3. Associations between tobacco retailer proximity (distance to nearest tobacco retailer (mile), baseline individual-level covariates, and Alternative Tobacco Product (ATP) initiation at 12-month follow-up, adjusting for neighborhood and school-level covariates.

	Model 3		Model 4		Model 5
Fixed Effect Odds Ratios	**Neighborhood-Only**	**Cross-Classified**	**School-Only**	**Cross-Classified**	**Cross-Classified**
Tobacco retailer proximity (distance to nearest tobacco retailer (mile))	0.81 (0.56, 1.17)	0.86 (0.56, 1.28)	0.90 (0.63, 1.28)	0.90 (0.63, 1.28)	0.91 (0.62, 1.33)
Individuals (Level 1, n=728)					
Age					
13-15	Ref	Ref	Ref	Ref	Ref
16-19	2.69 (1.64, 4.42)	2.69 (1.64, 4.42)	2.63 (1.59, 4.33)	2.63 (1.59, 4.33)	2.70 (1.63, 4.47)
Gender					
Male	0.75 (0.47, 1.19)	0.75 (0.47, 1.19)	0.74 (0.47, 1.17)	0.74 (0.47, 1.17)	0.83 (0.48, 1.42)
Race/Ethnicity					
White	Ref	Ref	Ref	Ref	Ref
Asian/Pacific Islander	0.78 (0.45, 1.34)	0.79 (0.46, 1.36)	0.69 (0.40, 1.18)	1.23 (0.79, 1.92)	0.76 (0.44, 1.33)
Latino	1.31 (0.84, 2.04)	1.28 (0.82, 2.01)	1.23 (0.79, 1.92)	0.89 (0.51, 1.52)	1.27 (0.81, 1.99)
Other	0.97 (0.56, 1.68)	0.94 (0.54, 1.64)	0.88 (0.51, 1.52)	1.48 (1.05, 2.09	0.94 (0.54, 1.63)
Mother's Education (Less than a high school degree)	0.94 (0.62, 1.42)	0.92 (0.61, 1.41)	0.89 (0.60, 1.34)	0.89 (0.60, 1.34)	0.95 (0.63, 1.45)
Neighborhoods (Level 2, n=191)					
Percent non-Hispanic White	1.01 (0.99, 1.02)	1.01 (0.99, 1.02)			1.02 (1.00, 1.03)
Median Household Income ($10K)	0.98 (0.94, 1.03)	0.98 (0.92, 1.04)			0.95 (0.88, 1.02)
Population Density (Per 1000 Persons)	1.02 (0.98, 1.06)	1.02 (0.98, 1.06)			1.03 (0.99, 1.07)
Schools (Level 3, n=10)					
Percent non-Hispanic White			4.32 (0.69, 27.07)	4.32 (0.69, 27.07)	7.73 (0.84, 71.09)
Percent eligible for free or reduced meals			1.76 (0.78, 3.97)	1.77 (0.78, 3.97)	1.19 (0.46, 3.07)
Average class size			1.03 (0.95, 1.12)	1.04 (0.95, 1.27)	1.01 (0.93, 1.11)
Random Effect Estimates					
Neighborhood	<0.0001	0.03 (0.15)	--	--	<0.0001
School	--	--	0.04 (0.15)	0.03 (0.15)	0.03 (0.17)

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- Model 4 presents the results of the school-only multilevel model and CCMM containing individual-level and school-level 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 estimate and standard deviations.
- Median household income and population density were rescaled for the model

Supplementary Table 4. Descriptive school (n=10) characteristics for participants (n=728) nested in neighborhoods (n=191) nested in schools (n=10), 2014.[1]

	Total	Mean (SD)	A	B	C	D	E	F	G	H	I[6]	J
Cohort	728	--	43 (5.91)	93 (12.77)	51 (7.01)	137 (18.82)	132 (18.13)	91 (12.50)	109 (14.97)	40 (5.49)	25 (3.43)	7 (0.96)
Wave 1 Ever ATP Users N (%)	237	--	14 (5.90)	28 (11.81)	23 (9.70)	40 (16.87)	41 (17.29)	15 (6.33)	45 (18.98)	21 (8.86)	10 (4.21)	0 (0.00)
Wave 1 Never ATP Users N (%)	491	--	29 (5.90)	65 (13.23)	28 (5.70)	97 (19.75)	91 (18.53)	76 (15.47)	64 (13.03)	19 (3.86)	15 (3.05)	7 (1.42)
Wave 1 Past 30-Day ATP Users N (%)	78	--	1 (1.28)	15 (19.23)	6 (7.69)	10 (12.82)	15 (19.23)	5 (6.41)	13 (16.67)	8 (10.25)	5 (6.41)	0 (0.00)
Wave 2 ATP initiation N (%)	106	--	8 (7.55)	13 (12.26)	7 (6.60)	16 (15.09)	25 (23.58)	9 (8.49)	17 (16.04)	6 (5.66)	5 (4.72)	0 (0.00)
School Size 2014-2015 (N)		1722 (773)	1774	1423	1543	3118	2334	1349	1747	1749	90	2093
Average Class Size*		26.90 (3.95)	22.10	27.70	29.50	31.60	26.60	25.10	29.90	29.10	18.70	18.70
Female*[2]		46.29 (6.75)	44.47	49.64	50.39	47.86	48.83	47.11	51.40	48.91	27.96	46.41
Race/Ethnicity												
African American		5.10 (5.68)	20.00	1.20	4.30	2.70	5.50	0.21	3.50	8.10	2.20	3.30
American Indian or Alaska Native		4.40 (2.75)	0.80	0.20	0.70	0.30	0.70	0.10	0.50	0.50	0.00	0.60
Asian		9.50 (12.66)	2.30	23.70	5.60	38.80	1.80	1.50	3.30	2.40	0.00	2.60
Filipino		3.97 (5.35)	3.00	5.60	0.60	1.80	0.90	5.50	0.30	1.80	0.00	4.00
Hispanic or Latino		48.20 (17.85)	47.60	27.20	54.40	35.30	44.30	25.90	63.30	68.20	26.70	79.0
Pacific Islander		1.20 (0.89)	1.40	3.00	1.60	0.50	0.60	1.80	1.50	1.60	0.00	0.30
White		27.01 (16.80)	22.30	29.00	22.90	3.70	43.60	39.70	22.80	16.40	60.00	9.70
Two or More Races		44.30 (37.05)	2.70	10.10	5.60	8.00	2.70	9.80	3.10	1.00	1.10	0.20
Not Reported		6.40 (1.40)	0.00	0.10	4.30	0.00	0.00	0.10	1.80	0.00	0.00	1.10
Reduced Price Lunch[3]		54.83 (21.71)	68.90	18.10	73.80	49.70	68.00	15.90	78.80	56.00	60.00	59.00
Socioeconomically Disadvantaged Youth		59.73 (25.59)	70.57	21.36	98.06	58.94	70.22	13.05	81.68	62.55	65.55	55.28

Homeless Youth	2.73 (4.30)	3.16	0.28	3.04	0.38	0.00	0.67	4.98	0.85	0.00	14.00
Foster Youth	0.60 (0.34)	1.01	0.49	0.45	0.61	0.98	0.07	0.63	0.57	1.11	0.19
English Learners	13.15 (7.73)	13.40	6.50	27.90	17.80	4.70	7.56	14.93	22.64	6.67	9.08
Percent Scoring ≥ 1500 on SAT[4]	0.43 (0.18)	33.58	72.29	25.93	49.33	37.19	59.70	23.57	20.99	--	63.43
4-year Cohort Dropout*	6.30 (4.48)	4.70	1.20	4.10	9.40	4.80	5.50	4.50	2.60	16.70	9.50
Scoring in the Healthy Fitness Zone: Body Composition*[5]	19.52 (4.90)	25.10	10.80	20.60	16.40	21.30	14.50	25.90	21.80	--	19.30

- Cells are percents, unless otherwise noted. Data for school demographics, socioeconomic status subgroup, reduced lunch program, and SAT test scores are from the California Department of Education, 2014-2015 academic year.
- *Data from Education Data Partnership, CDE, EdSource, FCMAT.
- [1]All schools except school I are public high schools. School I is a continuation high school as defined by the California Department of Education.
- [2]Proportion female is based on the 2016-2017 academic year. Proportion female for the 2014-2015 academic year was not available.
- [3]Percent of students eligible for free or reduced price meals.
- [4]Percent of students scoring ≥ 1500 on Standardized Admissions Test data was not available for school I.
- [5]The percent of 9th-grade students who scored in the Healthy Fitness Zone on the California Physical Fitness Test. Students take the California Fitness tests in grades 5, 7, and 9. Students are expected to meet Physical Fitness standards in six areas: Aerobic Capacity, Body Composition, Abdominal Strength, Trunk Extensor.
- [6]SAT scores, aerobic capacity, and body decomposition was not available for school I. The mean was imputed for regression models below.

Supplementary Table 5. Descriptive census tract (n=191) characteristics for participants (n=728) nested in neighborhoods (n=191) nested in schools (n=10), Perceptions Cohort, 2014.[1]

	N=191 (100.00%)	Mean (SD)	Range
No. of students per tract		3.88 (4.33)	[1.00, 25.00]
Tract with one student	88 (46.07)	--	--
Tract with students attending different schools	24 (12.56)	--	--
Tobacco retailers per tract		4.10 (3.55)	[0.00, 14.00]
Tobacco Retailer Density[2]			
Tobacco retailers per square mile		7.21 (6.53)	[0.02, 44.00]
Density Categories[2]			
None (0 Retailers)	35 (18.32)	--	--
Low (0.02-4.2 retailers/square mile)	99 (51.83)	--	--
High (≥8.1 retailers/square mile)	57 (29.84)	--	--
Tobacco Retailer Proximity[2]			
Distance to nearest retailer (mi.)	--	0.61 (0.59)	[0.00, 9.37]
Population Density (Per Sq. Mile)		8879 (7338)	[22.15, 60197.46]
Total Land Area (Sq. Miles)		4.56 (21.58)	[0.08, 248.41]
Population Demographic Factors			
Percent female		50.17 (3.29)	[38.3, 60.55]
Percent aged 10-14		6.84 (2.01)	[2.15, 12.32]
Percent aged 15-17		4.08 (1.51)	[0.61, 8.13]
Percent aged 18-24		9.25 (3.16)	[1.62, 24.1]
Percent aged 18 and 19		2.36 (1.13)	[0.00, 6.53]
Percent under 18		24.65 (5.10)	[9.70, 40.01]
Percent Hispanic		40.81 (24.03)	
Percent non-Hispanic:		58.95 (24.02)	[1.50, 99.04]
White		33.34 (20.60)	[0.10, 81.66]
Black or African American		5.11 (9.44)	[0.00, 80.59]
American Indian and Alaska Native		0.34 (0.67)	[0.00, 6.45]
Asian		16.70 (19.63)	[0.00, 77.23]
Native Hawaiian and Other Pacific Islander		0.54 (1.30)	[0.00, 8.99]
Other Race		0.21 (0.46)	[0.00, 2.72]
Two or More Races		2.93 (2.16)	[34.85, 94.88]
Percent born in the USA		69.15 (15.92)	[0.00, 10.18]
Households Composition Factors			
Average household size		3.16 (0.59)	[1.75, 4.90]
Percent in single-person households		20.56 (9.68)	[4.08, 65.07]
Percent female-headed households		13.92 (6.57)	
Percent in vacant dwellings		5.53 (4.29)	[0.00, 30.19]
Socioeconomic Factors			

Gini Index of Income Inequality (among households)	0.41 (0.05)	[0.31, 0.54]
Median household income (in 2016 inflation adjusted dollars)	68, 365 (37,184)	[19729, 218849]
Percent families living in or below poverty level	14.06 (10.81)	[0.53, 46.17]
Percent under 18 living in or below poverty level	22.15 (17.19)	[0.00, 61.08]
Percent aged 18 to 64 living in or below poverty level	15.72 (10.29)	[1.24, 48.23]
Percent receiving public assistance	4.54 (3.73)	[0.00, 18.85]
Percent aged 25 and older with 4-year college degree	16.56 (10.73)	[0.64, 48.77]
Percent aged 25 and older with 4-year college degree or more	26.35 (20.50)	[0.64, 85.76]
Percent civilian population 16 to 19 not high school graduate, not enrolled (dropout)	3.78 (6.13)	[0.00, 36.84]
Percent aged 16+ unemployed in labor force	6.70 (3.24)	[0.98, 32.6]
Residential Environment Factors		
Average Commute to Work (in Min)	30.75 (6.48)	[20,54]
Percent in same housing versus 1 year ago	85.31 (6.37)	[64.42, 97.76]
Percent under 18 with health insurance coverage (private and public)	95.40 (3.99)	[80.98,100]
Percent aged 18 to 24 with health insurance coverage (private and public)	79.38 (14.08)	[29.33,100]

Supplementary Table 6. Traditional two-level multilevel and three-level cross-classified logistic regression models describing the association between tobacco retailer density and proximity (distance to nearest tobacco retailer or tobacco retailers per census tract square mile), covariates, and subsequent ATP initiation for participants (n=728) nested in neighborhoods (n=191) nested in schools (n=10), 2014.

Model	Levels	No of Levels	Model Equation	Random Effects (Intercepts)	Fixed Effect Parameters
School-Only Multilevel	Individuals (i) School (j)	2	$Logit\left[Pr\ Pr\left(Y_{ij}=1\right)\right] = \beta_0 + \beta_{xij} + u_{0j} + e_{0ij}$	$u_{0j} \sim N(0,\sigma^2)$ $e_{ij} \sim N(0,\tau^2)$	$\frac{exp\ (\beta_0)}{(1+expexp\ (\beta_0))}$ The log odds of ever ATP use among unexposed students across all schools. "Grand mean" β_{xij} vector of individual and school level covariates (including distance to nearest retailer/count of retailers in student's neighborhood)
Neighborhood-Only Multilevel	Individuals (i) Neighborhood(k)	2	$Logit\left[Pr\ Pr\left(Y_{ik}=1\right)\right] = \beta_0 + \beta_{xik} + u_{0k} + e_{0ik}$	$u_{0k} \sim N(0,\sigma^2)$ $e_{ik} \sim N(0,\tau^2)$	$\frac{exp\ (\beta_0)}{(1+expexp\ (\beta_0))}$ The log odds of ever ATP use among unexposed students across all neighborhoods. "Grand mean" β_{xik} vector of individual and neighborhood level covariates

School and Neighborhood Multilevel (Complete Nesting)	Individuals (i) School (j) Neighborhood(k)	3	$Logit\left[Pr\ Pr\left(Y_{ijk}=1\right)\right]=\beta_0+\beta_{xijk}+u_{0j}+u_{0k}+e_{0ijk}$	$e_{ijk}\sim N(0,\sigma^2)$ individual i in neighborhood j and school k $u_{0jk}\sim N(0,\sigma^2)$ for each school $u_{200k}\sim N(0,\sigma^2$ each neighborhood's random deviation from the grand mean	$\frac{exp\,(\beta_0)}{(1+expexp\,(\beta_0))}$ The log odds of ever ATP use among unexposed students across all neighborhoods and schools. "Grand mean" β_{xik} vector of individual, school, and neighborhood level covariates
Null Cross-Classified (No Covariates)	Individuals (i) School (j) Neighborhood(k)	3	$Logit\left[Pr\ Pr\left(Y_{ijk}=1\right)\right]=\beta_0+u_{0j}+u_{0k}+e_{0i(jk)}$	$u_{0j}\sim N(0,\sigma^2)$ each schools' deviation from the grand mean (this is right for this model only) $u_{0k}\sim N(0,\sigma^2)$ $e_{0i(jk)}\sim N(0,\tau^2$ For the individual with the combination of j school and k neighborhood	$\frac{exp\,(\beta_0)}{(1+expexp\,(\beta_0))}$ The log odds of ever ATP use among unexposed students across all neighborhoods and schools. "Grand mean"
Cross-Classified	Individuals (i) School (j) Neighborhood(k)	3	$Logit\left[Pr\ Pr\left(Y_{ijk}=1\right)\right]=\beta_0+\beta1_{0i(jk)}+\beta2_{0j}+\beta+u_{0j}+u_{0k}+e_{0i(jk)}$	$u_{0j}\sim N(0,\sigma^2)$ $u_{0k}\sim N(0,\sigma^2)$ $e_{0i(jk)}\sim N(0,\tau^2$ for the individual with the combination of j school and k neighborhood	$\beta_0\frac{exp\,(\beta_0)}{(1+expexp\,(\beta_0))}$ The log odds of ever ATP use among unexposed students across all neighborhoods and schools. "Grand mean"

	deviation of each I from the mean of their combination of school and neighborhood.	$\beta 1_{0i(jk)}$ (an individual level measure such as individual level SES) $\beta 2_{0j}$ (school-level predictor i.e. school-level SES) $\beta 3_{0k}$(neighborhood-level predictor i.e. neighborhood level SES)

Chapter 4

Risk and Benefit Perceptions Predict Alternative Tobacco Product and Cigarette Switching among Adolescents and Young Adults

4.1 Background

There is a growing public health concern that adolescents and young adults (AYAs) may be exhibiting significant changes in their tobacco use behavior. The identification of current cigarette and alternative tobacco product (ATP) transition behaviors including product switching among AYAs is critical for understanding patterns in AYAs' tobacco use and determining targets for education campaigns and interventions. Identification of tobacco use patterns unique to AYAs may help focus public health messages targeting the diversity of tobacco products and unique use patterns in this age group.

Cigarettes are no longer the most commonly used tobacco product among all age groups, with ATP use increasing across AYAs.[2,3] ATPs include electronic cigarettes (e-cigarettes), smokeless tobacco (chewing tobacco, dissolvable or dipping tobacco, moist snuff, and snus), tobacco pipes, cigars (traditional, filtered, and cigarillos or little cigars), and hookah (water pipes). ATP use among AYAs is a pressing public health concern, and the shifting tobacco landscape among AYAs in the U.S. poses a threat to decades of public health campaigns aimed at reducing tobacco use.[1] For example, according to the 2018 National Youth Tobacco Survey (NYTS), past 30-day e-cigarette use increased among high school students (grades 9-12) from 1.5% in 2011 to 11.7% in 2017.[2] Additionally, poly tobacco use, defined as using two or more tobacco products has recently been reported at an all-time national high, including roughly 9% (approximately 1.4 million students) of high school tobacco users reporting poly-tobacco use of the following tobacco products: e-cigarettes, cigarettes, cigars, smokeless tobacco, hookah, pipe tobacco, and/or bidis on at least one day in the past 30 days.[2] Moreover, the most prevalent patterns of past 30-day ATP use among adolescents are exclusive e-cigarette use (10.0%), dual use of cigarettes and cigars (6.1%), and exclusive hookah use (5.2%) with similar rates for young adults.[4]

Evidence shows that use of ATPs is a strong predictor of subsequent cigarette initiation and increases the odds of becoming an established smoker—even for AYAs who have an otherwise low risk for cigarette smoking.[4-8] A recent meta-analysis showed a threefold increase in the risk of cigarette smoking initiation when comparing e-cigarette ever users to never users.[8] These studies suggest suggesting e-cigarettes may encourage the uptake of cigarettes among youth. Similarly, a recent systematic review of longitudinal studies shows AYAs who initiate with smokeless tobacco use are more likely to initiate cigarette use.[5,8-13] Though these studies have assessed either exclusive cigarette smoking, exclusive smokeless tobacco use, dual use of both products, and use of neither product; these studies have not examined individual transitions from use of any ATP (including hookah, e-cigarettes, cigars, etc.) or cigarette product to another among AYAs. Furthermore, these studies have not examined potential risk factors for these tobacco and ATP use behavior changes among AYAs.

Changes in youth cigarette and ATP use may occur in part because of AYAs' changes in risk and benefit perceptions of these products. Research suggests cigarette and ATP use among AYAs is associated with increased benefit perceptions and lower risk perceptions.[14-20]Adolescents reporting lower risk and benefit perceptions have been found to have higher risk for tobacco use.[14-20] Adolescents' misperceptions of ATPs including widespread beliefs that ATPs are less harmful

than cigarettes, are smoking-cessation tools, and are not addictive have been found to be associated with ATP and tobacco use.[14-20] Although studies have shown perceptions are important predictors of cigarette and ATP use, perceptions have not been examined as potential predictors for cigarette or ATP switching behaviors among AYAs. Identifying risk and benefit perceptions which explain changes in tobacco use behaviors among AYAs may help guide the development and implementation of public health messages targeting these perceptions.

We do not know of any study assessing the relationship between risk/benefit perceptions and (1) individual cigarette or ATP product switch patterns including complete product switching, dual use, or poly-tobacco use among AYAs and (2) how AYAs' cigarette and ATP perceptions predict individual product switch and use patterns over time. Using data from a longitudinal study of adolescents and young adults, and focusing on those who used cigarettes or ATPs at baseline, the current study assesses the relationship between risk and benefit perceptions with individual cigarette and ATP switching behaviors. We hypothesize that the risk of switching cigarette or ATP use over time will be higher among AYAs with increased benefit perceptions and decreased risk perceptions of these products.

4.2 Methods

Data and Study Design

The data presented in this analysis are from wave 1 (July 2014 – October 2015), wave 2 (July 2015 – March 2016), and wave 3 (June 2016 to September 2016) of a prospective longitudinal study of adolescents who were recruited from 9th and 12th grade. Students were recruited from ten California high schools with diverse student populations. Study details have been previously published.[16] Assent forms were signed by the student and consent forms were signed by their parent or guardian. Students 18 years or older provided their own consent.

Students who consented to participate were sent an email with a link to the online survey, administered through Qualtrics. Overall, 772 (86.4%) of eligible consented participants completed the survey in wave 1, 578 in wave 2, and 508 in wave 3. Among 482 participants with complete data on exposure, covariates (wave 1), and outcome variables (2 and 3), this analysis utilized all 119 participants reporting ever or past 30-day tobacco use during wave 1 and therefore eligible to report the outcome of product switching in our study. Participants received $10.00 for participating in wave 1, $15.00 for wave 2, and $20.00 for wave 3. This study was approved by Stanford University and University of California, San Francisco's (UCSF) institutional review boards.

Measures

In each wave, participants were asked about their ever and past 30-day use of ATPs and cigarettes. All items listed below were asked for the following products: e-cigarettes, cigarettes, smokeless tobacco (chewing tobacco or moist snuff), cigars, cigarillos or little cigars, and hookah. With the exception of cigarettes, we refer to these products as "alternative tobacco products" (ATP). Participants were asked, "During your entire life, how many times have you ever used [product]?" and ""During the last 30-days, on about how many days did you use [product]?" For each product, ever and past 30-day use were dichotomized yes/no, indicating whether the participant reported any lifetime or past 30-day use of the product.

Product Switching

Our primary outcome of interest was product switching from wave 1 to wave 2 or 3. Participants who reported either ever or past 30-day use of cigarettes or ATPs were classified as having switched products if they reported switching from any cigarette or ATP use in wave 1 to any ATP or cigarette use in wave 2 or 3. Switching was dichotomized yes/no if (1) users reported switching products either ever or past 30-day use, and (2) had switched completely from one cigarette or ATP to another, reporting no dual or poly product use. Our secondary outcomes of interest were dual and poly-tobacco use. Dual use was dichotomized yes/no if users reported use of any two products of cigarettes or ATPs in waves 2 or 3. Poly-tobacco use was dichotomized yes/no if users reported use of two or more products in waves 2 or 3.

Risk and Benefit Perceptions

Participants' cigarette and ATP perceptions were assessed during wave 1. Consistent with previous literature of AYAs perceptions of cigarette and ATPs, we categorized risk and benefit perceptions into five categories: short-term health risks, long-term health risks, short-term benefits, addictiveness, and harmfulness.[16,18,19] These measures of adolescents' perceptions are summarized here and validated and detailed elsewhere.[16,18,19] Perceptions of short-term health risks, long-term health risks, short-term benefits, harmfulness, and addictiveness were averaged for each individual across all products.

Short-term and long-term health risks and short-term benefits: Participants rated their estimated chance, from 0% to 100%, of experiencing short- and long-term health risks and benefits from using each ATP, under a hypothetical scenario where they used the product about two or three times a day. Short-term health risks included a bad cough, cold, trouble catching breath, mouth sores, and worse performance in sports. Long-term health risks included developing oral cancer, wrinkles, heart attack, lung cancer, another tobacco-related illness, and die from a tobacco-related illness. Short-term social benefits included: look cool, look more mature, and fit in with your peers[18,19]

Addictiveness and Harmfulness: Participants were asked to rate their estimated chance, from 0% to 100% of becoming addicted to each product. Moreover, participants rated their perceptions of addictiveness of each ATP using a five-point scale from not addictive to extremely addictive. Similarly, participants rated their perceptions of harmfulness of each ATP from harmful to extremely harmful. Participants were also asked to rate the overall harm using this product would cause to a friend's health and to the environment. Responses were made on a five-point scale (1 = not at all harmful to 5 = extremely harmful).

Covariates

Demographics were assessed at baseline. Participants self-reported age in years, sex, race/ethnicity, and mothers' education. Race/ethnicity was coded as White, Asian, Pacific Islander, Hispanic, and Other, representing the most prevalent demographic makeup of the schools in California. Moreover, participants were asked to report to the best of their knowledge their family and friends' use of ATPs or cigarette use. Participants were asked: "As far as you know, has your [mother/female guardian, dad/male guardian, siblings, closest friends] used any of the following [products]. Selected a priori, these variables were included as covariates in our analyses as they have been found to be relevant to tobacco use behavior and perceptions of risks and benefits in previous studies of tobacco and alternative tobacco use in adolescents and young adults.[14-19,21]

Statistical Analysis

We estimated the relationship between individual perceptions of (1) short-term health risks, (2) long-term health risks, (3) short-term benefits, (4) addictiveness, and (5) harmfulness in wave 1 with our primary outcome, product switching from wave 1 to waves 2 or 3 and secondary outcomes (dual and poly-tobacco use). We estimated odds ratios (OR) and 95% confidence intervals (CI) for the relationship of perceptions with cigarette or ATP switching at follow-up. Generalized estimating equation (GEE) logistic regression models were used in all analyses to account for potential clustering by school and to estimate population-averaged parameter estimates with robust standard errors with an assumed exchangeable working correlation matrix.[22-24] Robust standard errors were used to compute 95% CIs. Models adjusted for age, sex, race/ethnicity, mother's education (less than high school degree), family's ATP/cigarette use, friends' ATP/cigarette use. All statistical analyses were conducted using R 3.2.1 (R Foundation for Statistical Computing, Vienna, Austria).

4.3 Results

Table 1 presents data on descriptive characteristics among the overall sample and by switching status using during waves 2 and 3 of follow-up data from the cohort. In wave 1, adolescents on average were 16 years old mean (SD) 16.1 (1.13) and female (67.2%). More than 18% of participants in this study self-identified as Asian/Pacific Islander and approximately 44% were Latino. On average, among all participants in this study, participants believed they had more than a 50% chance of developing long-term health risks including oral cancer, wrinkles, heart attack, lung cancer, and other tobacco-related diseases and death.

Among the 119 adolescents and young adults in the analytic sample who reported either ever or past 30-day cigarette or ATP use at baseline, 66% (n=79) reported switching to another product, 10.1% (n=12) reported dual product use, and 10.9% (n=13) during waves 2 or 3 (Table 2). Table 3 further describes cigarette or ATP switching behaviors among the analytic sample. Overwhelmingly, among AYAs reporting product switching, majority reported switching to cigarettes and e-cigarette use exclusively. Compared to individuals not reporting product switching, participants reporting product switching, had increased benefit perceptions including believing ATP and cigarette use helped them look cool and fit in with their peers. In fully adjusted models, the risk of switching cigarette or ATP use over time was higher among adolescents with decreased short-term (OR=1.10, 95% CI: 1.04, 1.26) and long-term health risks (OR=1.19, 95% CI: 1.15, 1.37) and increased short-term benefits (OR=1.04, 95% CI: 1.02, 1.12) (Table 4). Adolescents' perceptions of both addictiveness and harmfulness were not found to be significant predictors of ATP and cigarette switching behavior at follow-up.

4.4 Discussion

To our knowledge, this is the first study to assess the relationship between decreased risk and increased benefit perceptions with cigarette or ATP switching over time among AYAs. Overall, 66% of study participants switched product use after one to two years of follow-up. Our study shows AYAs switching from one product to another at follow-up, and that their risk and benefit perceptions are significant predictors of this use pattern. In this study, cigarette or ATP product switching was found to be higher among adolescents with increased benefit perceptions and decreased risk perceptions. Individuals perceiving lower

risk and higher benefits of cigarettes and ATPs were more likely to switch from one product to another.

Our findings are consistent with previous literature assessing the relationship between product perceptions with cigarette and ATP use, and the effect sizes were similar or somewhat larger.[14-20] Literature supports the hypothesis that perceptions of risk and benefits shape adolescents' cigarette or ATP transitions. For example, structural equal modeling of the cross-sectional relationship between cigarette and e-cigarette use with perceptions in a sample of adolescents[20] and a nationally representative sample of adults[25] have shown the relationship to be partly mediated through more positive perceptions of smoking. These findings further support the need to develop and implement communication campaigns focused on negative health effects of cigarette and ATP use, such as the Center for Disease Control's (CDC) Tips From Former Smokers Campaign which have been developed to increase quit attempts and risk perceptions.[26] Results may also potentially inform the Food and Drug Administration's (FDA) approach to regulating ATPs and their corresponding marketing efforts by informing regulations of ATP warning labels and overall health claims. Clearer warning labels, perhaps focusing on short- and long-term risks of ATPs on product packaging are needed. The associations of perceptions of short-term and long-term health risks with ATP and cigarette switching provide additional evidence to use detailed warning labels on ATPs that evoke negative risk perceptions, and subsequently deter ATP product switching, initiation, and experimentation. The results of the present study also provide additional implications for regulations of ATP health claims. Specifically, results of the present study provide minimal support for the promotion of ATPs as harm reduction or smoking cessation tools.

Strengths of our study include the long duration of follow-up, prospective cohort design, and extensive control for confounding. Moreover, this study utilizes clear temporality of the exposure, covariates, and outcome. Our results should be interpreted in light of several limitations. First, our findings between perceptions and product switching may have been different if "recent ATP experimenters" were not included in this measure. For example, results from national studies suggest that past 30-day e-cigarette users significantly differ from established e-cigarette users.[27] Since many of the ATPs examined in our study are relatively new products, this measure may only be reflecting recent use of these products and not established use. Secondly, results may not be generalizable to adolescents throughout and outside of California though use rates of tobacco and ATPs are consistent with national rates for youth. Although we adjusted for major confounders cited in the extant literature including sociodemographic factors, family and friend ATP/cigarette use, and behavioral willingness; our results may still be subject to unmeasured confounding by other socioeconomic factors, community-specific social norms, and availability and access to ATP products. Empirical research suggests adolescents who are at higher risk for ATP use maybe more likely to live in neighborhoods with increased marketing of all products.[28-31] Thus, there may be many pathways from perceptions to cigarette and ATP switching. Other mechanisms proposed that are not assessed here are the potential influence of the tobacco social and retail environment, and assessment the direct and indirect effects of adolescents' school and home neighborhood tobacco retailer environment.

Conclusion

This study fills gaps in the literature by simultaneously assessing a wide variety of ATPs used by AYAs. Our findings reveal several patterns of changes in cigarette or ATP

use over time among AYAs that are unique to this age group. Increased risk and decreased benefit perceptions appear to be important predictors of product switching behaviors among AYAs. These findings may help public health practitioners understand the etiology through which perceptions shape adolescents' tobacco risk behaviors including product switching in a rapidly changing tobacco landscape. This study suggests smoking prevention health campaigns and cessation programs should also include strategies related to product switching, aimed at increasing adolescents' risk perceptions and decreasing benefit perceptions of traditional and emerging tobacco products.

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4.6 Tables and Figures

Table 1. Descriptive baseline (Wave 1) characteristics of study participants, overall and by Alternative Tobacco Product and Cigarette Switching Status during Waves 2 and 3, 2014-2016.

	Total Sample (n=482)	Baseline Users, Wave 1 (n=119)	Product Switch, Waves 2 and 3 (n=79)
Covariates			
Age, Mean (SD)	16.1 (1.1)	16.1 (1.1)	17.2 (1.3)
Age			
13-15	208 (43.1)	26 (21.8)	23 (29.1)
16-19	274 (56.8)	93 (78.2)	56 (70.9)
Gender			
Male	158 (27.1)	34 (31.7)	19 (24.0)
Female	324 (67.2)	85 (68.2)	60 (75.9)
Race/Ethnicity			
White	102 (21.2)	48 (40.3)	21 (26.6)
Asian/Pacific Islander	89 (18.5)	25 (21.0)	26 (32.9)
Latino	214 (44.4)	37 (31.0)	17 (21.5)
Other	77 (15.9)	9 (0.08)	15 (19.0)
Mother's Education			
Don't know	0 (0.0)	0 (0.0)	0 (0.0)
Elementary/Junior High school	17 (3.5)	0 (0.0)	13 (16.5)
Some high school	93 (19.3)	23 (19.3)	12 (15.2)
High school graduate/GED	111 (23.0)	38 (31.9)	26 (32.9)
Some college	86 (17.8)	31 (26.1)	0 (0.0)
2-year college degree	26 (5.4)	17 (14.3)	24 (30.4)
4-year college degree	104 (21.6)	10 (8.4)	4 (5.1)83-0
Graduate or professional degree	45 (9.3)	0 (0.0)	0 (0.0)
Family's Ever ATP/Cigarette Use	73 (15.1)	36 (30.2)	52 (65.8)
Friends' Ever ATP/Cigarette Use	81 (16.8)	64 (53.7)	39 (49.3)
Risk and Benefit Perceptions Mean (SD)[3]			
Short-term health risks			
Bad cough	76.1 (25.1)	54.9 (34.0)	42.9 (31.9)
Cold	54.6 (31.6)	41.5 (32.5)	33.6 (30.1)

Trouble catching breath	77.9 (24.0)	56.3 (32.7)	48.4 (33.4)
Mouth sores	63.3 (29.7)	42.8 (34.0)	36.9 (31.5)
Worse at sports	75.4 (27.1)	58.9 (36.6)	50.6 (36.1)
Short-term benefits			
Look cool	15.3 (27.3)	20.4 (31.1)	15.8 (28.2)
Mature	12.9 (24.8)	15.4 (27.4)	17.3 (29.3)
Fit in	13.4 (25.9)	20.3 (31.6)	13.2 (25.8)
Long-term health risks			
Oral cancer	78.9 (23.9)	15.6 (22.9)	53.4 (34.1)
Wrinkles	83.6 (22.5)	43.7 (35.4)	58.4 (35.9)
Heart attack	74.8 (26.2)	24.3 (23.9)	53.0 (34.9)
Lung cancer	83.6 (21.1)	18.7 (23.3)	57.8 (34.2)
Tobacco-related disease	83.9 (21.4)	11.5 (23.4)	58.5 (36.5)
Tobacco-related death	79.6 (24.1)	10.3 (22.8)	55.7 (35.7)
Addictiveness	79.6 (24.2)	10.2 (22.8)	57.9 (35.7)
Five-point scale			
Addictiveness	1.8 (0.8)	1.5 (0.8)	1.8 (0.7)
Harmfulness	2.8 (1.0)	1.8 (0.9)	2.2 (0.9)

1. ATP = Alternative Tobacco Products including e-cigarettes, chewing or dipping tobacco or moist snuff, tobacco pipes, cigars, cigarillos or little cigars, and hookahs.
2. Response for perceptions of short-term health risks, short-term benefits, and long-term benefits ranged from 0 to 100% and responses for perceptions of addictiveness and harmfulness ranged from to strongly disagree (1) to strongly agree (4).
3. Cells represent N (%) unless otherwise noted.

Table 2. Cigarette and ATP Use Patterns in Wave 2 or 3, among Wave 1 Adolescent and Young Adult Cigarette or ATP Users, 2014-2016 (n=119).

	Wave 2 or 3 Use				
	Product Switching	Dual Use	Poly Use	No Change	Total
Wave 1 Use					
Cigarettes	17	10	7	7	41
E-cigarettes	32	1	4	6	43
Chewing, Dipping Tobacco, or Moist Snuff	7	0	0	0	7
Tobacco Pipes	1	0	0	0	1
Cigars, Cigarillos, or Little Cigars	4	0	0	0	4
Hookah	18	1	2	2	23
Total	79	12	13	15	119

1. Product switching was dichotomized yes/no if wave 1 users had switched completely from one cigarette or ATP to another in waves 2 or 3, reporting no dual or poly product use.
2. Dual use was dichotomized yes/no if wave 1 users reported use of any two products in waves 2 or 3.
3. Poly use was dichotomized yes/no if wave 1 users reported use two or more products in waves 2 or 3.

Table 3. Cigarette and Alternative Tobacco Product (ATP) Switching from Wave 1 to Wave 2 or 3, among Wave 1 Adolescent and Young Adult Cigarette or ATP Users, 2014-2016 (n=119).

	Wave 2 or 3 Product Switch						
	Cigarettes	E-cigarettes	Chewing, Dipping Tobacco, or Moist Snuff	Tobacco Pipes	Cigars, Cigarillos, or Little Cigars	Hookah	Total
Wave 1 Use							
Cigarettes	--	9	0	0	2	6	17
E-cigarettes	24	--	0	0	0	8	32
Chewing, Dipping Tobacco, or Moist Snuff	2	5	--	0	0	0	7
Tobacco Pipes	0	1	0	--	0	0	1
Cigars, Cigarillos, or Little Cigars	0	1	0	0	--	3	4
Hookah	13	5	0	0	0	--	18
Total	39	21	0	0	2	17	79

Table 4. Generalized estimating equation (GEE) logistic regression models of the association between risk and benefit perceptions (wave 1) with subsequent ATP and Cigarette switching (wave 2 or 3) among adolescent and young adult cigarette and ATP users at baseline, 2014-2017 (n=119).

Any Product Switch, Waves 2 and 3	OR	95% CI
Short-term health risks	1.09	1.04, 1.26
Long-term health risks	1.19	1.15, 1.37
Short-term benefits	1.04	1.02, 1.12
Harmfulness	0.95	0.81, 0.99
Addictiveness	0.96	0.93, 1.12

1. Estimates adjusted for: age, sex, race/ethnicity, mother's education (less than high school degree), family's ATP/cigarette use, friends' ATP/cigarette use, and duration of follow-up.
2. Product Switch, Wave 1 to Waves 2 or 3: n=79

Chapter 5

Conclusion

5.1 Summary of Findings

Strong evidence supports the contribution of individual and environmental risk factors for alternative tobacco risk behaviors among adolescents and young adults. This dissertation aimed to (1) examine the relationship between marketing receptivity and ATP initiation; (2) identify a hierarchical relationship between individual-level, neighborhood-level, and school-level covariates and ATP initiation; and (3) assess the relationship between adolescents' risk and benefit perceptions with ATP product switching. Observational data from a longitudinal prospective cohort study of adolescents from 10 California high schools were used for these analyses. Moreover, Aim 2 linked data from the observational cohort with data from the US Census, tobacco retailer licensing data from the California Board of Equalization, and California Department of Education. Results of this dissertation showed adolescents and young adults with increased marketing receptivity exposure, who reside in neighborhoods with increased retail access to ATPs, and who have decreased ATP risk perceptions and increased benefit perceptions exhibit greater ATP initiation, product switching, and use over time.

Findings of Chapter 2: Marketing Receptivity and Alternative Tobacco Use in Adolescents and Young Adults

This chapter examined the relationship between marketing receptivity and ATP initiation. To our knowledge, this is the first study to examine the relationship of marketing receptivity as defined by ownership of ATP promotional items with subsequent initiation of ATP use including e-cigarettes, smokeless tobacco, tobacco pipes, cigars, cigarillos or little cigars, and hookah among adolescents and young adults. In this study, among a sample of California adolescents and young adults, initiation of ATP use was associated with both ownership of ATP promotional material and ownership of ATP or cigarette-specific promotional material. This study provides evidence for the relationship of marketing receptivity and subsequent ATP initiation that is consistent with the literature showing ownership of cigarette-related promotional-material is a risk factor for cigarette use among adolescents and young adults. This study fills gaps in the literature by simultaneously assessing ATPs most currently used by adolescents and young adults, and our results indicate that potentially eliminating distribution of promotional materials for ATP products may result in a reduction in ATP initiation among adolescents. The results of this study suggest that current marketing restrictions for cigarettes including restrictions of samples, coupons, and other promotional material distributed to adolescents and young adults should extend to ATPs.

Findings of Chapter 3: Tobacco Retail Environment and Alternative Tobacco Product Use Among Teens

Results from this chapter presented some of the first evidence of a longitudinal association between tobacco retail environment and ATP initiation among adolescents. In this study, we examined the association between ATP initiation after one year of follow-up with tobacco retailer density and proximity among a sample of 728 adolescents nested in 191 neighborhoods nested in 10 California high schools. Though several studies have suggested associations of tobacco retailer density and proximity with cigarette use, few have examined several alternative tobacco products specifically. Moreover, none of the studies we are aware of

have assessed this relationship longitudinally. Our use of longitudinal multilevel and cross-classified random effect models evaluating individual-level, school-level, and home neighborhood-level ATP use correlates provide support for the robustness of our findings. Adjusting for covariates at multiple levels, tobacco retailer density (but not proximity) was associated with ATP initiation, suggesting that tobacco retailers clustered around students' home neighborhood may be an important environmental influence on adolescents' ATP use. These findings suggest the importance of regulating the tobacco retail environment, in order to reduce the accessibility of ATPs, which can thereby reduce the uptake of ATPs among youth. Moreover, these findings suggest the importance school-centric regulations are expanded to also include regulations of the tobacco retail environment in residential neighborhoods. Findings of this study suggest that policy efforts to reduce adolescent ATP use should limit and reduce the density of tobacco retailers.

Findings of Chapter 4: Risk and Benefit Perceptions Predict Alternative Tobacco Product and Cigarette Switching among Adolescents and Young Adults

This chapter assessed the association of risk and benefit perceptions with ATP and cigarette switch patterns among adolescents and provided insight for public health campaigns aimed at curbing tobacco use. Overall 66% of study participants switched product use after one to two years of follow-up, and results showed an association between perceptions and product switching in this sample of adolescents in California. This study shows adolescents are more likely to progress from one ATP or cigarette product to another in a short period of time, and that risk and benefit perceptions are significant predictors of this use pattern. This study fills gaps in the literature by simultaneously assessing a wide variety of ATPs used by adolescents and young adults. These findings may help public health practitioners understand the etiology through which perceptions shape adolescents' tobacco risk behaviors in a rapidly changing tobacco landscape. Furthermore, these findings provide evidence for focusing tobacco control educational campaigns to increase adolescents' risk perceptions of traditional and emerging tobacco products.

5.2 Conclusions and Future Directions

This dissertation focused on establishing that marketing receptivity and retail access is a risk factor for ATP initiation among a sample of adolescents, with potential evidence for mediation through perceptions of risk and benefits. Findings indicate adolescents and young adults with increased marketing receptivity exposure and who reside in neighborhoods with increased retail access to ATPs will be more likely to have decreased ATP risk perceptions and exhibit greater ATP initiation over time. Further research is needed to understand how these pathways operate to induce ATP initiation by US youth. Taken together, these results indicate that regulating ATP marketing and retail access targeted to adolescents is critically important to reduce ATP initiation and use. Given that tobacco marketing is modifiable, interventions targeted at reducing ATP initiation among adolescents in the United States have the largest tobacco control implication.