# Application of the Social Ecological Model to Reduce Tobacco Use Among Adolescents

Dissertation

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Abstract

**Background.** Tobacco use remains the leading preventable cause of death in the United States. Adolescence presents a critical window for preventing tobacco use, as most adults started using tobacco before reaching age 18. One framework that is useful for understanding adolescent tobacco use is the social ecological model, which defines risk and protective factors for health behaviors, like tobacco use, at multiple levels of influence. This research studied risk factors for tobacco use at the individual, community, and policy levels. In a cohort of adolescent boys, we evaluated whether e-cigarette use increased risk of initiating cigarette or smokeless tobacco (SLT) use (individual level) and whether perceived neighborhood quality was associated with initiation of emerging and traditional tobacco products (community level). In a sample of Columbus, Ohio, tobacco retailers, we evaluated whether implementation of Tobacco 21 (T21) policy was associated with a change in trajectories of tobacco marketing practices (policy level).

**Methods.** The adolescent cohort included N=1220 boys who were 11- to 16-years-old at enrollment and were followed every six months for two years. All boys lived in urban Franklin County, Ohio, or one of nine Appalachia Ohio counties. On each survey, boys reported their use of tobacco products, as well as risk and protective factors for tobacco use. The sample of tobacco retailers included N=74 to N=103 stores that held a cigarette dealer license. Stores were audited by trained fieldworkers in 2014, 2016,

2017, 2018, and 2019 (T21 enforcement began between the 2017 and 2018 audits). Fieldworkers recorded the prices of cigarette packs, availability of flavored products, count of products advertised outside stores, and count of products with interior or exterior price promotions.

To estimate risk of initiating cigarette and SLT use after using e-cigarettes, we conducted a propensity score match in 25 multiple imputation datasets. Risk ratios (RRs) and standard errors were estimated in each dataset and results were combined. To estimate risk of initiating emerging (i.e., e-cigarettes and hookah) and traditional (i.e., cigarettes, cigars, and SLT) tobacco products, we ran Cox proportional hazards regression models that included indicators of perceived safety, social disorder, physical disorder, and cohesion for youths' neighborhoods at age 10 in five multiple imputation datasets. To evaluate whether trajectories of retailer marketing practices changed post-T21 implementation, we used mixed effects regression models.

**Results.** In our analysis of tobacco use risk factors at the individual level, e-cigarette use more than doubled the risk of starting to smoke cigarettes (RR=2.71; 95% CI: 1.89, 3.87) and use SLT (RR=2.42; 95% CI:1.73, 3.38) among adolescent boys. At the community level, living in a physically disordered neighborhood at age 10 was associated with greater risk of initiating traditional tobacco products (hazard ratio = 2.01; 95% CI: 1.09, 3.79). At the policy level, implementation of T21 was associated with a change in the trajectories of the price of Marlboro Reds (per-year price increase of $0.25 pre-T21 vs. $0.08 post-T21; p=0.008) and count of price-promoted tobacco products (21% decrease per year pre-T21 vs. 29% increase per year post-T21; p=0.004).

**Discussion.** At a time when the landscape of tobacco products used by adolescents is changing rapidly, this research advanced our understanding of risk factors for tobacco use at the individual, community, and policy levels of the social ecological model. Findings can be used to support interventions and policies to reduce tobacco use among adolescents. Results also provide directions for future research that would improve understanding of the associations we observed.

Dedication

Dedicated to my parents.

Acknowledgments

I want to thank my parents for teaching me, over and over again, that the only thing I can control is how hard I work. So, thank you, Dad, for hitting grounders to me for hours when I never wanted to go to the field for extra practice, and thank you for teaching me to take studying seriously. Thank you, Mom, for sitting with me every night while I trudged through math homework, and thank you for showing me how to work my way through any problem.

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Vita

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Publications

Muralidharan, N., **Keller-Hamilton, B.,** Ferketich, A.K., & Roberts, M.E. (2019). Tobacco Advertising and ID Checks in Columbus, OH in Advance of Tobacco 21. *American Journal of Health Promotion*, in press. doi: 10.1177/0890117119850751.

**Keller-Hamilton, B.**, Moe, A., Breitborde, J.K., Lee, A., & Ferketich, A.K. (2019). Reasons for smoking and barriers to cessation among adults with serious mental illness: A qualitative study. *Journal of Community Psychology*, 47: 1462-1475. doi:10.1002/jcop.22197.

**Keller-Hamilton, B.,** Roberts, M.E., Slater, M.D., & Ferketich, A.K. (2019). Memorability of Cigarette Advertisements Making "Natural" Claims Among Adolescents. *Tobacco Regulatory Science*, 5(4): 326-331. doi: 10.18001/TRS.5.4.2.

**Keller-Hamilton, B.**, Roberts, M.E., Slater, M.D., Berman, M., & Ferketich, A.K. (2019). Adolescent males' responses to blu's fake warnings. *Tobacco Control*, in press. doi:10.1136/tobaccocontrol-2018-054805

Burgoon, M.L., Albani, T., **Keller-Hamilton, B.,** Lu, B., Roberts, M.E., Craigmile, P.F., Browning, C., Xi, W., Ferketich, A.K. (2019). Exposures to the Tobacco Retail Environment among Adolescent Boys in Urban and Rural Environments. *The American Journal of Drug and Alcohol Abuse*, *45*(2): 217-26. doi: 10.1080/00952990.2018.1549562.

Roberts, M.E., **Keller-Hamilton, B.**, Hinton, A., Browning, C.R., Slater, M.D., Xi, W.,

Ferketich, A.K. (2019). The magnitude and impact of tobacco marketing exposure in adolescents' day-to-day lives: An ecological momentary assessment (EMA) study. *Addictive Behaviors, 88*: 144-9. doi: 10.1016/j.addbeh.2018.08.035.

**Keller-Hamilton, B.,** Muff, J., Blue, T., Lu, B., Slater, M. D., Roberts, M.E., and Ferketich, A.K. (2018). Tobacco and alcohol on television: A content analysis of male adolescents' favorite shows. *Preventing Chronic Disease, 15*: E134. doi: 10.5888/pcd15.180062.

Evans, A., Peters, E., **Keller-Hamilton, B.,** Loiewski, C., Slater, M., Lu, B., Roberts, M., and Ferketich, A.K. (2018). Warning size affects what adolescents recall from tobacco advertisements. *Tobacco Regulatory Science, 4*(3):79-87. doi: 10.18001/TRS.4.3.7.

Friedman, K.L., Roberts, M.E., **Keller-Hamilton, B.,** Yates, K.A., Paskett, E.D., Berman, M.L., Slater, M.D., Lu, B., & Ferketich, A.K. (2018). Attitudes toward tobacco, alcohol, and non-alcoholic beverage advertisement themes among adolescent boys. *Subst Use Misuse, 53*(10):1707-1714. doi: 10.1080/10826084.2018.1429473.

Holtzen, H., Klein, E.G., **Keller, B.,** & Hood, N. (2016). Perceptions of physical inspections as a tool to protect housing quality and promote health equity. *Journal of Health Care for the Poor and Underserved, 27*(2):549-59. doi: 10.1353/hpu.2016.0082

Klein, E.G, **Keller, B.,** Hood, N., & Holtzen, H. (2015). Affordable housing and health: A health impact assessment on physical inspection frequency. *J Public Health*

*Manag Pract, 21*(4), 368-74. doi: 10.1097/PHH.0000000000000138.

Katz, M.L., **Keller, B.,** Tatum, C.M., Fickle, D.K., Midkiff, C., Carver, S., Krieger, J.L., Slater, M.D., & Paskett, E.D. (2015). Community members' input into cancer prevention campaign development and experience being featured in the campaign. *Progress in Community Health Partnerships: Research, Education, and Action, 9*(2):149-56. doi: 10.1353/cpr.2015.0043.

## Fields of Study

Major Field: Public Health

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# Chapter 1. Introduction

Tobacco use remains the leading preventable cause of death in the United States (U.S.), with 480,000 people dying from causes attributable to cigarette smoking each year.[1] The prevalence of current use[a] of any tobacco product among U.S. adults was 19.3% in 2017.[2] Among youth,[b] the prevalence of current use of any tobacco product was 19.6% for high school students and 7.5% for middle school students in 2017.[3] Prevalence of current tobacco use differs across states, and the burden of use of cigarette smoking is particularly high in states with large Appalachian populations, like Ohio. In 2017, 8.5% of Ohio youth smoked cigarettes, and 21.1% of adults smoked cigarettes (ranking 8$^{th}$ in the U.S.).[5]

The prevalence of current use of any tobacco product among youth in the U.S. declined from 2011 to 2017.[3] Over the same period, however, declines in prevalence of use were not observed for all tobacco products. In particular, the use of novel and novel-to-the-U.S. products like electronic cigarettes (e-cigarettes) and hookah did not decrease. Among high school students, the prevalence of current e-cigarette use increased from

[a] For adults, current use of cigarettes is defined as having smoked at least 100 cigarettes in one's life and now smoking every day or some days; current use of other tobacco products is defined as having ever used the product and now using the product every day or some days.[2] For youth, current use is defined as use of a tobacco product at least once in the past 30 days.[3]

[b] "Youth" will be used to refer to all people who are younger than 18-years-old. "Adult" will refer to all people who are at least 18-years-old. "Adolescents" will be used to specifically refer to youth who are 11- to 17-years old. "Young adults" will be used to specifically refer to adults who are 18- to 25-years-old.[4]

1.5% in 2011 to 11.7% in 2017.[3] Among middle school students, the prevalence of current e-cigarette use increased from 0.6% to 3.3%, and the prevalence of current hookah use increased from 1.0% to 1.4%.[3] The most recent national estimates of youth e-cigarette use, however, signal an alarming trend: 20.8% of high school students and 4.9% of middle school students were estimated to be current e-cigarette users in 2018.[6] In both age groups, e-cigarettes have become the most common tobacco product used among U.S. adolescents.[3]

Adolescents who use e-cigarettes may be at increased risk of future cigarette use due to renormalization of smoking behavior, nicotine addiction and dependence, positive expectancies about cigarette smoking, or increased association with peers who are tobacco users.[7] Although youth who use e-cigarettes are more likely than nonusers to initiate cigarette smoking,[7] whether these e-cigarette users would have been cigarette smokers in the absence of e-cigarettes is unknown. There are both shared and distinct risk factors for e-cigarette and cigarette use,[8,9] which suggests that 1) some of this shift between products at the population level is due to youth using e-cigarettes instead of cigarettes (i.e., "product-replacement"), and 2) that some youth are using e-cigarettes when they would not have otherwise used tobacco products (i.e., a "gateway" to tobacco use). The numerous observational studies reporting that adolescents who used e-cigarettes at baseline were more likely to initiate cigarette use at follow-up than never users of e-cigarettes[7] support both product-replacement and gateway hypotheses due to the overlap in risk factors for use of both products. Whether youth e-cigarette use primarily acts as a product-replacement or a gateway to tobacco use has important

consequences for population health. The former could be viewed as a method of harm reduction due to reduced health consequences of e-cigarette use compared to cigarette use,[10] and the latter would ultimately lead to increased burden of tobacco-related illness.

Youth who use tobacco products are at increased risk for negative health consequences, both during their youth and in adulthood. Exposure to nicotine during adolescence can alter brain development through abnormal activation of nicotinic acetylcholine receptors,[11] which are involved in regulating brain maturation through adolescence.[12] Such exposures can affect adolescents' cognition and emotional regulation, as well as addiction potential.[11] Moreover, youth who smoke cigarettes are at increased risk of abnormal cardiac symptoms, including early atherosclerosis[4] and decreased regulation of heart rate by the vagus nerve,[13] as well as respiratory symptoms, such as chronic cough,[14] reduced lung function, wheezing, and limited lung growth[4] during adolescence. Use of smokeless tobacco (SLT) is further associated with increased risk of oral mucosal lesions among adolescents.[15] The health consequences of smoking cigarettes for adults are well-known and growing. For instance, smoking causes several cancers, including (but not limited to) cancers of the lung, head and neck, bladder, and cervix; cardiovascular diseases including coronary heart disease, abdominal aortic aneurysm, peripheral vascular disease, atherosclerosis, and cerebrovascular disease; and respiratory diseases like chronic obstructive pulmonary disease (COPD).[1] Importantly, nearly 90% of adult smokers initiated use by the end of adolescence—thus, adolescence presents a critical window for preventing initiation of tobacco use.[1]

The social ecological model describes how multiple levels of influence affect specific health behaviors[16] and can be used to better understand tobacco use during adolescence. For example, low socioeconomic status (SES)[17,18] and personality traits[19–21] contribute to the risk of adolescent tobacco use at the individual level. Peer[22–26] and parental[24,25,27] tobacco use similarly increase risk of tobacco use among adolescents at the interpersonal level. Additionally, growing up in a socioeconomically disadvantaged neighborhood further increases risk of cigarette and e-cigarette use at the community level.[28]

The tobacco industry is partly responsible for these neighborhood-level disparities. Examination of industry documents has demonstrated that low SES, high racial minority neighborhoods have been targeted by the tobacco industry.[29] This has manifested in lower tobacco prices[30] and increased density of tobacco retailers,[31,32] availability of tobacco products,[33] and amount of tobacco advertising[34] in census tracts with a high proportion of minority and low-income people. Importantly, exposure to a high density of tobacco retailers and point-of-sale marketing increases risk of tobacco use among adolescents.[35–37] These targeted activities by the tobacco industry are hypothesized to influence adolescents' tobacco use behaviors by increasing perceived tobacco availability,[38] influencing norms regarding tobacco use,[39,40] and portraying role models via advertising who have characteristics that are especially appealing to adolescents, such as independence and sex appeal.[41,42] Additionally, adolescent tobacco purchasing behaviors are price-sensitive,[43] with high prices being associated with reduced

odds of ever and current smoking, reduced intensity of smoking,[44] and wanting to quit smoking.[45]

Policy-level approaches to reduce youth and adult tobacco use have been implemented at the national, state, and local levels. At the national level, policy efforts include excise taxes on cigarette purchases[46] and requiring warning labels on all packages of and advertisements for cigarettes,[47] SLT,[48] cigars, e-cigarettes, hookah, roll-your-own, and pipe tobacco.[49] The 2009 Family Smoking Prevention and Tobacco Control Act (TCA) additionally banned non-menthol cigarette flavors, sales to minors, selling fewer than 20 cigarettes per pack, free cigarette giveaways, and tobacco-brand sponsorship of sporting or entertainment events.[48] States and localities also apply excise taxes to packs of cigarettes, ranging from $0.17 in Missouri to a combined state and local excise tax of $6.16 in Chicago, IL.[50] Other policy approaches that can be or are implemented by states and localities include raising the minimum age for purchasing tobacco products to 21 (i.e., "Tobacco 21"), clean indoor air laws, banning the sale of tobacco products in pharmacies, raising the price of tobacco products through non-tax approaches (i.e., minimum price laws), retailer licensing laws, zoning laws, and limiting the proximity of tobacco retailers to each other or to schools.

The long-term goal of this research is to reduce adolescent initiation of tobacco products. With the tobacco industry continuing to evolve, we must understand how the emergence of new products affects risk of using traditional products. With the tobacco industry's historical targeting of poorer communities, we must understand whether adolescents who lived in those communities are at increased risk of using traditional and

emerging tobacco products. With the implementation of Tobacco 21 policies spreading across the U.S., we must understand how the tobacco industry adapts their marketing practices in response to a reduced market. Together, answering our proposed research questions will provide evidence in support of tobacco regulations and targeted interventions to reduce adolescent tobacco use.

This research will use data collected from a cohort of adolescent males and their families who reside in Franklin County or Appalachian Ohio. Briefly, males were followed for two years to measure their tobacco use behaviors and risk factors for tobacco use. Their parents provided additional information about the boys' neighborhood and home environments. Although the study of only males limits our generalizability, it gives us greater power to estimate risk factors for SLT—an understudied area of the literature. This research will also use data collected from five years of central Ohio tobacco retailer audits which occurred before and after implementation of Tobacco 21 policy. Information about tobacco prices, availability of flavors, and price promotions were collected from each retailer.

## Specific Aims

Toward our long-term goal, this research had the following specific aims:

1. **Evaluate whether e-cigarette use acts as a "gateway" to initiation of cigarette and SLT use among adolescent males.**

   For our individual-level analyses, we used a propensity score analysis to create groups that were exchangeable on individual- and interpersonal-level risk

factors for e-cigarette use, then evaluated whether e-cigarette users were at increased risk of initiating 1) ever and 2) current cigarette smoking or SLT use. We hypothesized that youth who had ever used e-cigarettes would have increased risk of initiating cigarette and SLT use.

2. **Describe how parent-reported measures of perceived neighborhood quality at age 10 relate to adolescents' short-term risk of ever use of traditional and emerging tobacco products.**

For our community-level analyses, survival analysis was used to model the short-term risk of initiating emerging (i.e., e-cigarettes and hookah) and traditional (i.e., cigarettes, SLT, and cigar) tobacco products according to perceived safety, social disorder, physical disorder, and cohesion in youths' neighborhoods at age 10. We hypothesized that youth who lived in neighborhoods perceived to be more dangerous, more disordered, and less cohesive would have greater risk of initiating tobacco products

3. **Evaluate whether the trajectories of tobacco product prices, availability of flavored products, exterior advertising for tobacco products, and amount of price promotions in retailers changed post-implementation of Tobacco 21 policy.**

For our policy-level analyses, data from audits of a stratified random sample of retailers with cigarette dealer licenses were used to evaluate whether

trajectories of the price of tobacco products, availability of flavored products, exterior advertisements for flavored and unflavored tobacco products, and amount of price promotions within and outside of retailers changed post-implementation of Tobacco 21 policy in Columbus, Ohio. Cigarette and e-cigarette prices and count of flavored tobacco products available were recorded on the same sample of retailers in 2014, 2016, 2017, 2018, and 2019. From 2016 to 2019, the count of products with exterior advertisements and count of products with interior or exterior price promotions were also recorded. These procedures allowed us to evaluate temporal trends in marketing practices. This exploratory aim will describe whether the tobacco retail environment changed post-implementation of Tobacco 21.

## Literature Review

### *Overview of Youth Tobacco Use in the U.S. and Ohio*

After reaching a peak of 28% in 1997,[51] the prevalence of current cigarette smoking among high school students in the U.S. declined to 8.1% in 2018; among middle school students the prevalence of current cigarette smoking was 1.8%.[6] The prevalence of current SLT use among high school students has similarly declined after peaking in 1995 at 12.2% among twelfth graders and in 1994 at 7.1% among eighth graders.[51] In 2018, an estimated 5.9% of high school students and 1.8% of middle school students were current SLT users.[6] While the prevalence of use of these traditional tobacco products has been

steadily declining among youth in the U.S., the prevalence of use of emerging tobacco products has increased. The largest increases have been observed for e-cigarettes, which have become the most commonly-used tobacco product among middle and high school students.[3] In 2011, an estimated 1.5% of high school students and 0.6% of middle school students were current users of e-cigarettes.[52] By 2018, 20.8% of high school students and 4.9% of middle school students were current e-cigarette users, which represented 1.5 million new youth e-cigarette users from the previous year.[6] This switching of product popularity has resulted in no net decrease in current use of tobacco products among high school students in the U.S. from 2011-2018.[3,6]

The prevalence of youth cigarette smoking in Ohio is higher than the national average. In 2017, an estimated 8.5% of high school students were current cigarette smokers.[5] As in the rest of the U.S., e-cigarettes have also become the most common tobacco product used among Ohio youth. An estimated 10.5% of Ohio high school students were current e-cigarette users, and 37.8% were susceptible to e-cigarette use, in 2016.[53]

*Health Consequences of Youth Tobacco Use*

Preventing tobacco use during youth is important, not only to reduce the risk of negative health consequences in adulthood,[1] but also to protect youths' health. For youth who use tobacco, the negative health consequences of tobacco use start to emerge prior to reaching adulthood.[4] Relative to other tobacco products, the health effects of cigarette smoking among youth have been the most studied. Regarding the pulmonary system,

cigarette smoking among youth has been associated with increased risk of chronic cough,[14,54] nocturnal cough,[55] chronic phlegm,[14] wheeze,[54,56–59] exercise-induced wheeze[59] and bronchospasm,[55] and asthma.[54,56] Cigarette smoking also impairs lung function among youth and young adults.[56,60]

Youth and young adult cigarette smoking also affects their risk of developing cardiovascular complications prior to adulthood, such as early atherosclerosis.[61–63] Another indicator of cardiovascular health is respiratory sinus arrhythmia (RSA), or the degree to which the vagus nerve mediates fluctuation in heart rate during the respiratory cycle, with a higher RSA indicating better control over rhythm.[64] In addition to increased risk for later cardiovascular disease,[65] low RSA is associated with increased allostatic load, reduced immune system functioning,[66] and difficulty regulating emotions.[67] Thus, the effects of decreased RSA extend beyond cardiovascular consequences. Smoking a single cigarette is associated with lower RSA and higher mean heart rate among adolescents with low levels of nicotine dependence, and this effect is strongest among youth who started smoking prior to age 10.[13]

In addition to respiratory and cardiovascular health outcomes, tobacco use during adolescence affects brain development and mental health outcomes. Regular functioning of nicotinic acetylcholine receptors (nAChRs)—which regulate components of adolescent brain maturation including emotional regulation, executive function, and reward processing—is disturbed by tobacco use.[11,12] One of the neurotransmitters most affected by chronic exposure to nicotine is serotonin,[11,68,69] and reduced serotonin pathway activity increases risk of depression.[70] Longitudinal studies have reported increased risk

of developing depression,[71–74] anxiety,[72] parasuicide,[72] suicide,[75] and drug abuse and dependence[76] among adolescent cigarette smokers. However, the relationship between tobacco use and poor mental health outcomes is complex, as there is evidence that the association may be bi-directional[77] and they share common causes. For example, a nationally representative cross-sectional study of youth and young adults (ages 14-22 years) identified that active smoking was associated with increased odds of suicidal ideation, but only among participants whose parents did not smoke. This association could therefore be due to personality traits (e.g., impulsivity[78–80] or sensation seeking [19–21,81]) or other underlying mental health conditions that affect both the risk of smoking and of suicidality.[82]

Finally, youths' susceptibility to nicotine dependence is another reason to prevent smoking initiation. Although most symptoms of nicotine dependence are strongest among adolescents who have more established cigarette smoking behaviors (e.g., daily smoking or more than 100 lifetime cigarettes), some—particularly symptoms of nicotine tolerance[83]—begin to emerge during earlier stages of smoking initiation. For instance, a longitudinal study of adolescent cigarette smokers found that 58.8% of youth who had smoked fewer than 100 cigarettes escalated their frequency of cigarette smoking, 47.1% smoked to relieve restlessness or irritability, and 45.9% reported having to smoke more to be satisfied compared to when they began smoking.[83] Importantly, nicotine dependence among youth who are not yet established smokers increases their risk of daily smoking by young adulthood.[84]

The age at which adolescents start smoking affects their risk of developing nicotine dependence. Those who initiate daily cigarette smoking around age 10 are at the highest risk for nicotine dependence in adulthood, and the risk remains elevated for those who initiate daily smoking prior to 20-years-old.[85] Within that developmental period, there are critical ages during which youth experience different trajectories of nicotine dependence. For youth who have smoked cigarettes and experience some level of nicotine dependence, symptoms increase rapidly between ages 12 and 15 years. From ages 16 to 19, while some youth demonstrate stabilization in nicotine dependence, others experience a further increase or even a decrease in nicotine dependence symptoms. By age 20, nicotine dependence becomes relatively stable among most users.[86]

Although less studied, research into the adolescent health effects associated with use of other tobacco products demonstrates that there is no safe tobacco product for youth. As with cigarette smoking, e-cigarette use has been associated with poor respiratory health outcomes among youth, including increased risk of chronic bronchitis symptoms,[87] cough or phlegm for at least three consecutive months,[88] and asthma.[89] Similarly, cigarettes are not the only product that can cause nicotine dependence among adolescents. Adolescents who are current hookah users are at risk of nicotine dependence,[90] and youth who use SLT products, including snus, experience levels of nicotine dependence similar to cigarette smokers.[91,92] As with cigarette smoking, earlier age of onset for e-cigarette[93] or any tobacco product[94] use are associated with increased levels of nicotine dependence among adolescents. Finally, the risk of nicotine

dependence for youth who use two or more tobacco products is elevated compared to youth who use only one product.[92–94]

In summary, a substantial body of literature demonstrates that youth who use tobacco, even at a relatively low frequency, are at risk for tobacco-related health consequences that emerge prior to reaching adulthood. Negative changes to the respiratory system, cardiovascular system, brain development, and mental health begin to manifest among young tobacco users; in many cases, earlier age of tobacco initiation is related to increased risk for health consequences. Further, the emergence of nicotine dependence at even low levels of tobacco use for adolescents puts youth at risk for continued tobacco use as they enter adulthood, when serious consequences of chronic tobacco use emerge.[1] Preventing initiation and escalation of tobacco use among youth is therefore vital to reducing the public health burden of tobacco use.

### *The Social Ecological Model and Adolescent Tobacco Use*

A framework that is often used to examine tobacco use among adolescents and adults is the social ecological model, which describes how multiple levels of influence individually and jointly affect specific health behaviors.[16] Accordingly, risk and protective factors for tobacco use among adolescents occur at the individual, interpersonal, community, and policy levels of influence.[16,95] At the individual level, low SES,[17,18] personality traits like sensation seeking[c19–21] and delay discounting[d],[78,79] and

[c] Sensation seeking, a form of impulsive behavior, is defined as "a personality trait reflecting a tendency to seek out novel, rewarding situations and stimuli, and a willingness to take risks in doing so."[21]
[d] Delay discounting, a form of impulsive behavior, is defined as "the extent to which an individual discounts the value of an outcome because of a delay to its occurrence."[78]

increased exposure to tobacco portrayals on entertainment media[96–100] increase risk of tobacco use among youth. At the interpersonal level, peer[22–26] and family[24,25,27] use of tobacco products increase the probability that an adolescent will use tobacco by modeling the tobacco use behaviors and influencing descriptive and injunctive tobacco use norms.[101,102] At the community level, living in a socioeconomically disadvantaged community for a long duration is associated with increased risk of cigarette and e-cigarette use by age 25 for people who are white non-Hispanic.[28] Furthermore, living in a neighborhood perceived as low quality by youth or their parents (e.g., high disorganization or low social cohesion) increases adolescents' risk of tobacco use.[103,104] The following sections will review the evidence describing how factors at each level are associated with youth tobacco use.

### *Individual- and Interpersonal-Level Risk Factors for Adolescent Tobacco Use*

Understanding the risk factors for tobacco use among youth is necessary to prevent youth initiation of tobacco products. Research has identified differences between youth who use tobacco and those who do not. These differences are related to demographics, personality traits, mental health, use of other substances, and exposure to entertainment media. Other sources of difference between youth tobacco users and non-users are the prevalence of tobacco use among their friends and within their families. Much of the research into these individual and interpersonal-level differences in tobacco use has focused on cigarettes. However, more recent research has identified that there may be some difference in risk factors for tobacco use according to product—especially

for emerging tobacco products like e-cigarettes—related to SES, race, and substance use. An understanding of how these individual- and interpersonal-level risk factors affect adolescent tobacco use is important, not only for tobacco use prevention efforts, but also for studying whether e-cigarette use increases risk of cigarette smoking among adolescents.

### *Demographic Characteristics Associated with Adolescent Tobacco Use*

Decades of research have described demographic differences between adolescents who use tobacco and those who do not. Factors including age, sex, race/ethnicity, and socioeconomic status are associated with risk of tobacco use among adolescents. Starting with age, the overall prevalence of tobacco product use among young adolescents is quite low, but increases quickly as they approach adulthood. For example, the prevalence of regular smoking in a nationally-representative sample of adolescents in the early 2000s was 1.6% for 12-year-olds, compared to 13.1% for 16-year-olds and 30.8% for 18-year-olds.[103] This acceleration of tobacco use initiation during later adolescence may be due to several factors, including increased independence and mobility within their communities[105] (and thus increased exposure to tobacco marketing), desire to mold their identities after tobacco-using role models,[105–107] and more time spent with peers[105] who may use tobacco.

Regarding sex, adolescent males are generally at increased risk of being ever[108] and current tobacco users compared to females,[23,52,109] and this pattern is reinforced with increasing age. By high school, in 2018, males in the U.S. had a higher prevalence of

current use of any tobacco product, dual use of tobacco products, cigarettes, cigars, e-cigarettes, pipes, and SLT.[6] Restricting analyses to high school seniors, males additionally have higher odds of being past-year hookah users than females.[110] Closer investigation of sex-based differences in tobacco product use among U.S. adolescents revealed that the magnitude of difference between the prevalence of current tobacco use by sex increases with age.[109] In other words, whereas the prevalence of tobacco use is higher in males than females during middle school, it increases faster among males as they progress through high school—ultimately approaching the discrepancy in prevalence of tobacco product use observed between adult males and females.

There is evidence that psychosocial differences between adolescent males and females contribute to differences in tobacco use prevalence. One study reported that males who perceived greater health consequences of smoking at age 11 were less likely to initiate smoking by age 15, but the same association did not hold true for females. For females (but not males), positive affect during ninth grade was protective against smoking progression during high school.[111] The theory of planned behavior could be applied to understand male/female differences in adolescent tobacco use.[112] For example, holding positive normative beliefs about smoking increased risk of smoking initiation among females,[113] females perceived greater social approval for tobacco use,[114] and female smokers were surrounded by more smokers in their social environment than males smokers.[115] Notably, however, female smokers also perceived greater social support for cessation and motivation to quit smoking than males.[115] Cultural factors in the U.S. also contribute to differences in tobacco use prevalence between males and females, with SLT

use in particular being closely tied to masculinity among adolescents.[116,117] In addition to psychosocial differences, male high school students are more likely to be asked for identification when purchasing tobacco products than females.[118] These results highlight substantial heterogeneity between males and females with respect to risk factors for tobacco use during adolescence.

Low socioeconomic status has been consistently associated with increased risk of cigarette smoking among adolescents. Most of the research in this area has operationalized adolescents' SES by parental education or household income. Low parental education has been associated with increased risk of smoking a whole cigarette,[119] smoking progression,[120] and becoming an established smoker[121] after controlling for other demographic covariates. Likewise, low household income has been associated with increased risk of cigarette smoking initiation[119] and established cigarette smoking among adolescents.[121] Although the above studies only measured SES at one point in time, research that measured household income from participants' infancy through age 15 reached the same conclusions. Youth who were born into a household with low income were more likely to initiate smoking cigarettes by age 15 than youth who started with higher household income, regardless of whether their household eventually reached an adequate income category.[18] A pathway through which low SES affects adolescent smoking outcomes is parental smoking, which has been identified as a mediator of the association.[121] Additionally, as youth of lower SES are more likely to live in lower SES communities, they are also more likely to be exposed to increased density

of tobacco retailers[32] and adults who smoke,[122] which could also affect their normative beliefs related to tobacco use.

In general, a similar pattern exists for the association between adolescents' SES and use of other tobacco products, although some complexities have emerged. Lower parental education has been associated with increased risk of nicotine dependence symptom progression among adolescent waterpipe smokers[90] and increased probability of being a current e-cigarette user.[123] However, higher parental education has also been associated with increased odds of past-year hookah use among adolescents in a nationally-representative sample of high school seniors.[110] Recent research using the Family Affluence Scale[124] to define adolescents' SES identified that lower SES was associated with higher prevalence of ever e-cigarette, cigar, and SLT use, as well as ever use of any tobacco product and dual use of tobacco products among New England high school students.[125] The same association, however, was not identified in a larger sample of New England high school students when the outcome was current e-cigarette use. Whereas there was no direct association between adolescents' SES and current e-cigarette use, there was a modest but statistically significant pathway from high SES to increased exposure to e-cigarette advertising. Increased exposure to e-cigarette advertising was in turn associated with increased frequency of e-cigarette use in the past 30 days.[126] Thus, there was a mediated association between high SES and frequent e-cigarette use that was directed through increased exposure to e-cigarette advertising. These inconsistencies in the association between SES and use of emerging tobacco

products (i.e., e-cigarettes and hookah) imply that the risk factors for cigarette smoking do not necessarily translate to being risk factors for use of other products.

Finally, the association between adolescents' race/ethnicity and tobacco use behaviors is also complex. There are racial and ethnic differences with respect to the prevalence of use, products used, age of initiation, risk of transition to regular use of tobacco, and risk and protective factors for tobacco use among adolescents. In 2017, the prevalence of current use of any tobacco product among middle school students in the US was highest for Hispanic youth (7.7%) followed by white non-Hispanic youth (5.1%) and black non-Hispanic youth (4.9%).[3] By high school, though, the pattern changed. White non-Hispanic high school students had the highest prevalence of current use of any tobacco product (22.7%), followed by Hispanic youth (16.7%) and black non-Hispanic youth (14.2%).[3] The products used among youth of different races and ethnicities in 2017 and 2018 differed as well; e-cigarettes were the most-used tobacco products among non-Hispanic white and Hispanic youth, while cigars were the most-used tobacco product among non-Hispanic black students.[3,6]

These findings agree with earlier research identifying that black and Hispanic youth initiate smoking earlier than white non-Hispanic youth,[127] although other research has reported earlier initiation for white non-Hispanic youth.[128] Early adolescence racial differences in smoking initiation do not translate to later adolescence differences in more established smoking, however. For black non-Hispanic youth, early initiation of smoking does not significantly increase risk of regular smoking during young adulthood; for white non-Hispanic and Hispanic youth, early initiation of smoking does increase risk of

regular smoking by young adulthood.[127] One factor underlying this discrepancy in tobacco use outcomes is that black non-Hispanic youth who initiated smoking early are more likely than white non-Hispanic youth to quit smoking or to maintain low levels of smoking throughout adolescence.[127] Supporting the latter point is other research identifying that white non-Hispanic youth are more likely to be regular smokers throughout adolescence compared to black non-Hispanic youth.[103,129] Other reasons for this discrepancy may be related to cultural differences between racial groups, again with ties to the norms-related aspect of the theory of planned behavior.[112] African American youth generally have stronger connections to religion[130] and increased parental disapproval of smoking[131,132] compared to white non-Hispanic youth, which may ultimately serve to be protective against escalation to regular smoking. Moreover, white non-Hispanic youth are generally more likely to have friends who smoke and approve of smoking,[132] and there is evidence that they are more susceptible to peer influences than black non-Hispanic youth.[22]

As adolescents mature through adulthood, the discrepancy in prevalence of regular smoking between black non-Hispanics and white non-Hispanics narrows, or even crosses over (i.e., the prevalence of regular smoking among black non-Hispanics catches up to or surpasses that of white non-Hispanics).[128,133] A major weakness in this body of research, however, is that adolescent tobacco use studies rarely follow participants beyond adolescence or young adulthood, and thus it is difficult to explain the reasons for this cross-over. Hypothesized reasons for the cross-over are generally related to the social determinants of health. Although the family and peer context of black non-Hispanic

adolescents appear to offer protection against transition to established smoking behaviors, black non-Hispanic adults are more likely than white non-Hispanic adults to live in contexts promoting regular use of tobacco. For example, a study using a nationally-representative sample of adolescents and adults demonstrated this phenomenon by finding that lower educational attainment and marriage rates among black non-Hispanic adults compared to white non-Hispanic adults explained much of the cross-over effect.[128] Additionally, older age of smoking onset among black non-Hispanic people was associated with increased risk of progression to regular smoking,[128] which is the opposite of how the relationship operates among white non-Hispanic people.[127] Altogether, these findings underscore the complexity of the associations between race and tobacco use outcomes. Although black non-Hispanic youth appear to be at reduced risk for harmful tobacco use behaviors (e.g., regular smoking), the same is not true when they are adults.

### *Personality Traits and Mental Health*

Adolescents' personality traits and mental health status affect their tobacco use behaviors. As is the case with most adolescent tobacco use research, much of the investigation into associations between these factors and tobacco use outcomes has focused on cigarette smoking. A personality trait that has been associated with increased risk of cigarette smoking among adolescents is impulsivity, usually characterized by delay discounting or sensation seeking. Delay discounting is defined as "the extent to which an individual discounts the value of an outcome because of a delay to its

occurrence."[78] Although the association between delay discounting trait and cigarette smoking behavior appears to be strongest for adults,[134] there is evidence that adolescent smokers have higher delay discounting trait than nonsmokers.[78,79,135–137] Furthermore, adolescents who discount more by delay are at greater risk of smoking initiation by age 21 compared to adolescents who discount less, even after controlling for family and peer tobacco use, other substance use, novelty seeking, other impulsivity symptoms, and depression.[138] Sensation seeking, or a tendency to seek novel situations even if it means taking a risk to do so,[139] has been associated with increased risk of ever smoking,[21] current smoking,[21] daily smoking,[140] lifetime nicotine dependence,[140] and reduced likelihood of cessation[141] among adolescents; there is some evidence that associations are strongest for males.[21] Though there has been limited investigation into the effects of sensation seeking on adolescent use of other tobacco products, a longitudinal study reported that sensation seeking measured in eighth grade was associated with use of e-cigarettes, hookah, or little cigars by young adulthood, and that part of this association was mediated through intentions to use cigarettes, alcohol, or marijuana.[19] Another study identified that the path from sensation seeking to ever and current cigarette use was mediated by negative affect and reduced risk perceptions of cigarette smoking.[21] Thus, sensation seeking both makes it more likely that adolescents will start smoking and increases the difficulty of cessation. There may be useful targets for interventions (e.g., increasing risk perceptions related to tobacco use) to reduce the effect of this personality trait on tobacco use outcomes.

Mental health symptoms are also related to tobacco use outcomes among adolescents. Anxiety disorders among adolescents are associated with nicotine dependence,[86,140] and similarly, greater stress has been associated with increased nicotine dependence in adolescent waterpipe smokers.[90] As described earlier, longitudinal studies have provided evidence in support of a bidirectional relationship between depression symptoms and tobacco use.[77,142] Peer use of tobacco products appears to be an important mediator for both directions. For example, youth with increased depression symptoms were more likely to have friends who use tobacco, which predicted later tobacco initiation. At the same time, youth who were tobacco users in early adolescence were more likely to see a decrease in the proportion of their friends who use tobacco over time, which was also associated with a decrease in depression symptoms.[142] Regardless of the direction of the association, an important conclusion is that youth with mental health symptoms are more likely to use tobacco than other youth.

*Use of Other Substances and Adolescent Tobacco Use*

Adolescents who use alcohol and marijuana are more likely than other adolescents to use tobacco[19,119,143,144] or be nicotine dependent.[86] A recent study of a nationally-representative sample of high school students identified that youth who were current users of one or more tobacco products had much higher odds of having used alcohol or marijuana at least once. Dual product users, especially, had increased odds of ever using alcohol or marijuana compared to never tobacco users; they had 29.2 times the odds of ever using alcohol and 21.2 times the odds of ever using marijuana.[144] However,

with emerging tobacco products, it appears that the strength of this association depends on which tobacco products are actually being used. A large study of Hawaiian high school students, for example, found that the association between alcohol or marijuana use and tobacco use was strongest for youth who used both cigarette and e-cigarettes, followed by cigarette-only users, then e-cigarette only users; all groups had a higher prevalence of alcohol and marijuana use than nonusers, however.[143] An earlier study of high school students in the northeastern US, however, identified that current e-cigarette users were more likely than cigarette smokers to have smoked blunts (i.e., marijuana in a cigar) in the past month.[145] These associations may be the result of common liability for using illicit substances among adolescents (i.e., common risk factors that predict use of illicit substances during adolescence). As is the case with tobacco use, sensation seeking,[146] delay discounting,[147] peer substance use,[148,149] and parental substance use[150] affect adolescents' use of alcohol and marijuana.

Cross-sectionally, there is evidence that youth who smoke cigarettes are more likely than nonsmokers to use emerging tobacco products.[151,152] As those early cross-sectional studies were not designed to assess causality, more recent longitudinal research has attempted to determine whether use of emerging tobacco products increases risk of using traditional tobacco products, particularly cigarettes, among adolescents. A 2017 systematic review summarizing the results of these studies concluded that adolescents and young adults who had used e-cigarettes at baseline were at increased risk of initiating cigarette smoking over the follow-up period.[108] Specifically, after adjusting for cigarette smoking risk factors in a pooled analysis of data collected between 2012 and 2016,

adolescents and young adults who were ever e-cigarette users at baseline had 3.6 times the odds of becoming an ever cigarette user at follow-up; current e-cigarette users at baseline had 4.3 times the odds of becoming a current cigarette user at follow-up.[7] Interestingly, e-cigarette-using adolescents who had low intentions to smoke cigarettes were more likely to initiate cigarette smoking than adolescents with higher intentions to smoke cigarettes.[108] Recent longitudinal research has examined whether the path between e-cigarette use and cigarette smoking was bi-directional—that is, in addition to testing whether baseline e-cigarette use increased adolescents' risk of later cigarette initiation, the research evaluated whether baseline cigarette use increased risk of later e-cigarette initiation.[153] Ultimately, findings from these studies were mixed.[153–155]

Although there is a clear association between e-cigarette use and later initiation of cigarette smoking, whether adolescents who use e-cigarettes and progress to using cigarettes would have started smoking cigarettes anyway is less clear. A few studies have attempted to better understand whether youth who use e-cigarettes would have otherwise proceeded to cigarette smoking by using causal inference methods. A propensity score matching analysis using nationally-representative data identified that adolescents who used e-cigarettes had higher intentions to smoke cigarettes in the future.[156] Another study estimated nonsmoking youths' propensity to smoke cigarettes according to baseline risk factors for smoking, then evaluated whether baseline e-cigarette use increased risk of smoking at follow-up homogeneously across these risk groups. Similar to the findings reported above,[108] baseline e-cigarette use had the greatest effect on cigarette initiation among youth who had the lowest propensity to smoke cigarettes at baseline.[157] These

results provide support for the gateway hypothesis that e-cigarettes are attracting youth to tobacco products who would not have used them otherwise. Physiologically, the rewards associated with nicotine in the adolescent brain[11] may encourage them to transition to cigarettes, which deliver nicotine more efficiently than some types of e-cigarettes.[158] Applying social cognitive theory[101] and the theory of planned behavior,[112] e-cigarette use may also increase risk of smoking initiation by teaching adolescents cigarette smoking behavior, increasing positive expectancies related to cigarette smoking, or re-normalizing smoking behaviors.

*Use of Entertainment Media*

Adolescents are particularly susceptible to messages conveyed through the media.[159] Health behavior and communications theories can be used to understand how media exposures affect adolescent health behaviors. One theory, cultivation theory, suggests that media exposures shape how adolescents perceive the real world.[160] Following this theory, frequent exposure to tobacco portrayals through television, movies, and the internet would affect adolescents' perception of the prevalence and acceptability of tobacco use.[160] Recently, media has even been described as a "super peer" to adolescents, as the extent to which adolescents identify with models who use tobacco is associated with their perceived social acceptability of tobacco use.[114] A second theory, social cognitive theory, would argue that media exposures to tobacco use portrayals teach adolescents what (positive or negative) consequences to expect from tobacco use.[101] Again, the extent to which adolescents identify with the models using

tobacco would affect how likely they are to engage in the model's behavior.[161,162] A third theory, the theory of planned behavior,[112] could be used to describe how media exposure to tobacco use portrayals affect adolescents' attitudes and norms related to tobacco use. Attitudes and subjective norms, in turn, affect adolescents' intentions to use tobacco and ultimately affect their tobacco use behaviors.

From substantive research into the associations between media exposures and adolescent tobacco use, we can conclude that media exposures do affect adolescent tobacco use behaviors.[98] Increased exposure to tobacco use portrayals in movies has been associated with increased risk of smoking intentions[163] and initiation[96,99] among adolescents. Frequent television watching has also been associated with increased risk of smoking initiation among adolescents.[164] Lending support to the theories above, there is evidence that the paths from exposure to tobacco use portrayals in movies and television to adolescent tobacco use intentions are mediated through descriptive and injunctive norms.[165] Along those lines, adolescents exposed to tobacco use portrayals or pro-tobacco messaging on social media sites are also at increased risk of tobacco use initiation—potentially with stronger effects than what has been observed for movies or television.[166] Additionally, social media exposures may lead to e-cigarette use, specifically, by affecting positive expectancies of e-cigarette use.[167] With the increased e-cigarette presence on social media over the past few years (particularly related to JUUL),[168] these are concerning findings. In summary, adolescents who are frequent users of entertainment media are at increased risk of using tobacco.

*Peer and Parental Influences on Tobacco Use*

According to primary socialization theory, adolescents generally learn normative behaviors from their peers, family, and school.[169] One behavior that adolescents learn through socialization is tobacco use. In practice, evidence suggests that the association between peer tobacco use and an adolescent's tobacco use actually results from both socialization and peer selection processes (i.e., adolescents choose friends who are most like them).[170] Regardless of the processes involved, it is clear that peer and family use of tobacco are associated with adolescents' tobacco use behaviors. For example, although adolescents who smoke and those who do not smoke tend to have similar social network characteristics and social support, those who smoke also have a higher proportion of friends and family members within their social networks who smoke.[171]

The influence of peers on one's decision-making increases during adolescence.[105] Developmentally, adolescents are working toward establishing their identities; affiliating with peers who help them reach their desired social identity becomes an important goal.[105] This new closeness with friends increases normative pressure to participate in risky behaviors if one's friends are doing so.[170] Accordingly, there is substantial evidence that peer use of cigarettes increases adolescents' risk of ever smoking,[22] current smoking,[22–24] regular smoking,[103] and becoming nicotine dependent;[172] it also increases frequency of smoking.[25,26] Though less studied, peers have a similar influence on adolescent use of other tobacco products, including SLT[23] and e-cigarettes.[93,108] The effect of peer tobacco use on adolescents' smoking behaviors is not stable across adolescence, however. The effects of peer tobacco use appear to be strongest in early

compared to late adolescence (i.e., the effects are generally stronger for middle school compared to high school students).[24,25]

There is also some evidence that the effect of parental tobacco use on adolescent use differs across development, although results are less consistent. One study identified that the effect of parental smoking on the frequency of smoking among adolescents increased over the course of middle school, and then decreased starting in tenth grade.[25] Another study found that the association between parental smoking and current smoking among adolescents was stable from ages 10-17.[24] In general, however, adolescents whose parents smoke cigarettes smoke more frequently themselves[25,26] and are at increased risk of early experimentation with cigarettes,[27] current smoking,[24] regular smoking,[27] and nicotine dependence symptoms.[86,172] Maternal smoking (post-pregnancy) has further been associated with adolescent use of emerging tobacco products, including hookah, e-cigarettes, and cigars.[19] Additionally, adolescents who received their first e-cigarette from a family member have a greater frequency of e-cigarette use than those who received their first e-cigarette from a friend.[93] Several factors are likely to influence parent-to-child transmission of tobacco use behaviors, including genetics,[173] parenting style,[103] parental role modeling,[101] household rules about tobacco use,[174] and increased perceived availability of tobacco products.[119]

*Conclusion*

There are several individual- and interpersonal-level risk factors for adolescent tobacco use. While associations between these risk factors and tobacco use outcomes

have generally been found to be consistent across tobacco products, some differences across products have emerged. For example, the association between SES and risk of cigarette smoking may differ from the association between SES and risk of e-cigarette use. Moreover, the few studies that have more directly compared risk factors for cigarette and e-cigarette use have identified that youth who use e-cigarettes generally have low risk for using cigarettes. While this suggests that e-cigarette use may be attracting youth to cigarette smoking when they otherwise would not have become smokers, that conclusion cannot be drawn from the existing literature. Application of causal inference methods that allow for comparison of risk of cigarette use among adolescents who use e-cigarettes and similar adolescents who do not use e-cigarettes is warranted. Such work would further our understanding of whether e-cigarettes act as a gateway to traditional tobacco product use among adolescents.

### *Community-Level Risk Factors for Adolescent Tobacco Use*

In addition to individual and interpersonal-level risk factors for tobacco use among adolescents, the community in which adolescents live affects their risk of tobacco use. The relationships between adolescent tobacco use and rurality, Appalachia region, neighborhood quality, and neighborhood exposures that promote tobacco use should be considered, as they provide the context for policies enacted at the community level (such as licensing, minimum price, or age restriction laws) that aim to reduce adolescent tobacco use.

*Rurality, Appalachia, and Adolescent Tobacco Use*

Rural areas of the U.S.[e] are characterized by poorer health outcomes across all ages relative to urban areas.[176] For example, people living in rural communities have higher rates of infant mortality,[176] obesity,[177] COPD,[176] ischemic heart disease,[176] and lung cancer incidence and mortality,[178] compared to adults living in urban communities. Some factors underlying these poorer health outcomes in rural areas include lower educational attainment,[179] income,[176] and use of medical care,[180,181] as well as cultural factors that may support adoption and continuation of poor health behaviors.[182] Additionally, a major contributor to rural/urban health disparities is the elevated prevalence of tobacco use and exposure to second-hand smoke in rural areas.[183] The increased prevalence of tobacco use in rural areas is most prominent for non-menthol cigarettes[178,183,184] and SLT;[183–185] use of SLT is three times more prevalent among adults living in rural areas than urban areas.[184] Disparities in life expectancy between rural and urban areas are growing, and major causes for the increasing discrepancy include heart disease, stroke, COPD, and lung cancer.[186] This highlights the importance of studying the distributions and determinants of health behaviors, including tobacco use, that underlie this disparity.

Disparities in rural/urban tobacco use begin during adolescence. Prevalence of ever[187] and current use[187–189] of tobacco products is higher among adolescents living in rural compared to urban areas. One reason for this disparity may be the increased

[e] Rural areas are defined by the U.S. Census Bureau as all non-urban areas. Urbanized areas are defined as areas of 50,000 or more people. Urban clusters are defined as areas of 2,500 to 49,999 people. All other areas are defined as rural.[175]

perceived ease of access of cigarettes and SLT for rural adolescents compared to urban adolescents.[190] This increased perceived ease of access to tobacco products is likely driven by both the increased prevalence of tobacco use among adults in their communities and the decreased prevalence of within-home smoking bans in rural compared to urban areas.[183] A second reason for this disparity could be increased exposure to tobacco marketing,[189,191] as well as decreased media support for tobacco control policies in rural areas compared to urban areas.[192] Finally, tobacco control policies overall tend to be weaker in rural areas than urban areas. In rural areas, cigarette excise taxes are marginally lower[189] and indoor smoking bans are less common.[183]

Another way to classify communities in the U.S. is by Appalachian status. Over 25 million Americans live in Appalachia, which is comprised of both urban and rural communities and covers 420 counties across 13 states.[193] The Appalachian region has historically been characterized by widespread poverty, although recent diversification of industry in some Appalachian communities has resulted in more economic heterogeneity across the region and decreased poverty rates overall.[193] However, many Appalachian counties are still considered economically distressed or at risk of becoming distressed. In Ohio, for instance, three Appalachian counties are considered economically distressed and ten are at risk of becoming distressed.[194]

Health outcomes in Appalachian communities are poor compared to non-Appalachian communities, especially for cancer. Cancer mortality rates are higher in Appalachia than the rest of the U.S., particularly for colorectal cancer, cervical cancer, and lung cancer.[195] Incidence of cancer across all sites is also higher in Appalachian

communities than non-Appalachian communities, and there is evidence of this disparity decreasing over time for some cancers.[196] However, disparities in the incidence rates of lung and bronchus, oral and pharynx, or larynx cancer are not narrowing over time.[196] Contributing to these disparities is the high prevalence of tobacco use in Appalachia. Overall, the prevalence of smoking is nearly four percentage points higher in Appalachian communities compared to the rest of the U.S., but the prevalence of smoking across Appalachian communities differs substantially, ranging from 4% to 45% of adults.[197] Prevalence of SLT use is also generally higher in states with Appalachian counties compared to states without Appalachian counties, although there is also an elevated prevalence of SLT use in western states with large rural populations.[198]

Theorized causes of elevated prevalence of tobacco use in Appalachia, particularly cigarette smoking and SLT use, are multifactorial. Demographic characteristics of the region, including low socioeconomic status and education,[193] as well as economic reliance on tobacco farming in some communities,[199] contribute to increased prevalence of tobacco use. For the latter point, there is additional evidence that growing up in a tobacco-growing community puts youth at risk of earlier initiation of tobacco use.[200] Cultural factors that are unique to Appalachia also contribute to increased prevalence of tobacco use in the region. Appalachian residents tend to have close interpersonal relationships with their extended family members,[201] and qualitative research indicates that this closeness to family members who use tobacco contributes to generational transmission of tobacco use behavior.[116,199] Appalachian adolescents with close ties to family members who use tobacco have relatively easy access to tobacco

products,[116] as well as role models of tobacco use.[199] Regarding SLT use specifically, wishes to emulate male family members who use SLT motivate adolescent males to initiate use of the product.[116] Moreover, use of SLT has been described as a rite of passage for male adolescents in Appalachian communities, seen as an almost inevitable part of becoming a man.[116] Reinforcement of these cultural norms through tobacco marketing may also increase the prevalence of tobacco use among adolescents and adults in Appalachia. Conveying messages of masculinity, individuality, and ruggedness,[202] SLT advertisements are perceived by Appalachia residents to reflect the culture of their community.[116]

In summary, rural and Appalachian communities experience poor health outcomes, and one contributor to these poor health outcomes is the elevated prevalence of cigarette and SLT use. Both types of communities are characterized by increased levels of economic distress, as well as other factors supporting adolescent tobacco use. Such factors include a high prevalence of tobacco use among adults, which increases youth access to tobacco products and establishes tobacco users as role models; viewing tobacco use as a rite of passage; exposure to targeted tobacco marketing; and weaker tobacco control policies at the home and community levels. Improved understanding of how these factors work together to affect adolescent tobacco use outcomes would be a step forward toward reducing urban/rural and Appalachian/non-Appalachian health disparities.

### *Neighborhood Quality and Adolescent Tobacco Use*

Neighborhood quality, which is often operationalized using objective indicators for socioeconomic status or racial composition of a neighborhood, or more subjective indicators including safety, social cohesion, or collective efficacy, has been linked with numerous health outcomes. Poor neighborhood quality has been associated with increased risk of premature death,[203,204] mental health problems,[205] and chronic disease,[204,206,207] as well as health behaviors that contribute to chronic disease, such as poor diet and increased sedentary time.[208,209] As youth enter adolescence, their greater independence[105] results in increased exposure to features of their neighborhoods and larger communities.[210] Thus, investigation into how neighborhood quality influences adolescents' health behaviors, including tobacco use, is warranted.

The methods used to evaluate whether there is an association between neighborhood quality and adolescent tobacco use outcomes have been varied, and accordingly, studies have found mixed results. Much of the research has been longitudinal in design, however, some longitudinal studies used prevalent rather than incident tobacco use as their outcomes. Next, the definition of a youth's "neighborhood" was in most cases his or her home census tract, but in other cases census block group or school district. Additionally, some studies defined neighborhood quality by objective measures (e.g., census-tract level indicators such as percent of families below the federal poverty level), while others used subjective or perceived measures of neighborhood quality (e.g., social cohesion or collective efficacy). Finally, the measures of objective or subjective neighborhood quality have not been consistent across studies. For example, in some cases a neighborhood is classified as disadvantaged if a certain proportion of

households in that neighborhood are below the federal poverty level. In other cases, a neighborhood is classified as disadvantaged based on composite scores of more than one census indicators. Similarly, studies of more subjective measures of neighborhood quality use different constructs to represent neighborhood advantage or disadvantage, such as disorganization, collective efficacy, and perceived neighborhood drug involvement.

Starting with studies using objective measures of neighborhood quality, two longitudinal studies of high school students identified that census tract-level indicators of neighborhood disadvantage as measured at adolescents' baseline homes were not associated with prevalent past-year use of cigarettes[104,211] or e-cigarettes[104] at follow-up. Another study, which evaluated incident tobacco use, found that neighborhood disadvantage measured in adolescents' home census block groups at age 10-15 years did not affect risk of tobacco initiation at follow-up, which was approximately three years later for participants on average.[212] Conversely, in a cross-sectional study of Virginia middle and high school students, living in a socioeconomically disadvantaged school district was associated with increased odds of being a light (smoking 1-5 days of the past 30 days), medium (smoking 6-19 days of the past 30 days), or heavy (smoking 20 or more days of the past 30 days) cigarette smoker compared to living in a more socioeconomically advantaged school district, controlling for age and race.[213]

Studies of the association between perceived neighborhood quality and adolescent tobacco use have generally arrived at more consistent conclusions. In one national U.S. study, adolescents aged 12-18 years who lived in parent-perceived low quality neighborhoods were more likely to be regular cigarette smokers (i.e., smoking daily for

the past 30 days) than adolescents who lived in higher quality neighborhoods.[103] Another study of adolescents who were 11- to 17-years-old identified that youths' risk of smoking progression (from experimentation to dependence) increased as the perceived prevalence of smoking in their home census block group increased, after controlling for parental, peer, and school classmate smoking.[214] This result suggests that neighborhood-level modeling of tobacco use behaviors may influence youth tobacco use above and beyond modeling that occurs at more proximal ecological levels. A third study found that neighborhood disorganization (e.g., high rates of crime, abandoned buildings, and graffiti) increased and neighborhood cohesion (e.g., helpful neighbors and shared neighborhood values) decreased odds of past-year cigarette and e-cigarette use among adolescents, and neighborhood problems with substance use increased odds of past-year use e-cigarette use.[104] A similar study of the association between objective and parental-perceived indicators of neighborhood quality, however, identified that the association between measures of perceived neighborhood quality and past-year tobacco use was null.[211] Notably, although both of these studies were longitudinal by design, their outcomes were prevalent rather than incident tobacco use.

Only one known study accounted for the duration of youths' exposure to disadvantaged neighborhoods based on census tract-level poverty rate, rather than measuring neighborhood-level factors at only one point in time.[28] Additionally, because residential history started at age four years, exposure to neighborhoods with a high poverty rate was ascertained prior to tobacco use initiation. This study identified that longer duration of living in a high-poverty census tract (i.e., a census tract with more than

20% of households below the federal poverty level) vs. a low-poverty census tract (i.e., a census tract with fewer than 10% of households below the federal poverty level) increased risk of cigarette smoking initiation by age 25 for white respondents, but not black respondents.[28]

This latter study's finding that the effects of neighborhood disadvantage differed for white and black respondents aligns with an earlier study's findings that exposure to low-quality neighborhoods adversely affected tobacco use behaviors for white adolescents, but not black adolescents.[215] Potential reasons for this heterogeneity of neighborhood effects by race are the differences in smoking trajectories[133] and increased parental disapproval of smoking among black youth compared to white youth.[127] Another explanation for heterogeneity of the effect of neighborhood quality on tobacco use across racial groups in studies that only measure neighborhood quality at one point in time is that black and Hispanic youth have a longer duration of living in disadvantaged neighborhoods than white youth on average.[216] Thus, black youth and white youth who live in the same disadvantaged neighborhood at a given point in time may have different histories of exposure, risk factors, and protective factors related to tobacco use.

There is also evidence that the effect of individual-level SES on adolescent tobacco use is modified by neighborhood quality, with low-SES youth who live in disadvantaged neighborhoods having faster trajectories from experimentation to established smoking than their higher-SES counterparts who live in disadvantaged neighborhoods, controlling for race/ethnicity, gender, and urban/rural status.[120] Other individual- and interpersonal-level tobacco use risk factors that are modified by

neighborhood quality are authoritative parenting style (which is most protective against adolescent smoking among youth living in disadvantaged neighborhoods),[103] sensation seeking (which increases risk of smoking initiation more among youth living in more advantaged neighborhoods),[212] resistance self-efficacy (which was more protective against tobacco use for youth living in more organized neighborhoods),[104] and peer tobacco use (which increases risk of tobacco use less for youth who live in disadvantaged neighborhoods).[104]

In summary, due to the variety of methods used and definitions employed by studies, it is difficult to ascertain exactly what the association is between neighborhood quality and adolescent risk of tobacco use from the existing literature. Youth living within neighborhoods are heterogeneous with respect to risk and protective factors for tobacco use, and there is evidence that neighborhood quality interacts with these individual- and interpersonal-level risk and protective factors. The existing evidence base, therefore, underscores a need for improved understanding of how systems of individual-, interpersonal-, and community-level risk and protective factors predict adolescent tobacco use.

### *Neighborhood-Level Exposures Promoting Tobacco Use*

Neighborhoods differ with respect to their tobacco-promoting and tobacco-discouraging structural aspects,[217] and there is evidence that neighborhood disadvantage and these structural aspects are associated. Low-SES areas have higher densities of tobacco retailers[32] and higher proportions of retailers that sell tobacco.[33] Moreover,

retailers in low-income, high-racial-minority areas tend to have lower tobacco prices[30] and increased amounts of indoor and outdoor tobacco advertisements.[34] According to tobacco industry internal documents, this targeting of low-SES, high-racial minority communities was intentional.[29,218]

These associations are notable because adolescents are susceptible to the effects of exposure to tobacco marketing in their communites.[36] Living in a census tract with a high density of tobacco retail outlets increased odds of current cigarette smoking among youth and young adults.[35] Higher density of tobacco retailers per mile around adolescents' homes also increased frequency of cigarette smoking[219] and odds of ever cigarette smoking,[38,40] particularly for young adolescents.[38] Finally, adolescents who frequently visited retailers characterized by heavy tobacco advertising (e.g., convenience stores, liquor stores, and small markets) had increased risk of cigarette smoking initiation, after controlling for demographics, parental and peer smoking, risk-taking behavior, media exposures to smoking, school performance, and after-school unsupervised time.[220]

One path through which increased exposure to tobacco marketing may affect youth tobacco use behaviors is through influencing smoker prototypes and social norms. Tobacco retailer density per 1000 youth at the county level has been associated with increased odds of youth thinking smoking makes them look cool.[39] Additionally, increased density of tobacco retailers per square mile around adolescents' homes has been associated with higher perceived prevalence of adult smoking.[40] However, the evidence is mixed, as a study of mostly African American youth found no association between tobacco retailer density within a half mile around adolescents' homes and

thinking adolescents who smoke look cool or have more friends.[221] Another path may involve adolescents' beliefs about the ease of accessing tobacco products. Tobacco retailer density per 10,000 people has been associated with increased perceived availability of cigarettes and decreased perceived underage tobacco law enforcement.[38] A third path may be through affecting adolescents' intentions to use tobacco. One study identified that higher tobacco retailer density within a half mile around adolescents' homes increased intention to smoke within three months, and living closer to a tobacco retailer increased intention to smoke within five years.[221] A fourth path may be through reduced self-efficacy related to abstaining from smoking, as exposure to a high density of tobacco retailers decreased adolescents' readiness to quit smoking and increased their likelihood of thinking they would accept a cigarette from a peer.[221]

To conclude, youth are increasingly exposed to features of their neighborhoods as they mature through adolescence. For youth who live in disadvantaged neighborhoods, this also means increased exposure to tobacco marketing and reduced prices of tobacco products. Because youth are price-sensitive and susceptible to the effects of exposure to tobacco marketing, this results in an increased risk of tobacco use. Such findings provide useful targets for policy-level interventions to reduce adolescent tobacco use.

### *Policy Approaches to Tobacco Control*

Numerous tobacco control policies have been implemented in the U.S. at the federal, state, and local levels. However, reductions in the prevalence of tobacco use have not been equitable across the population.[222] As described above, neighborhood

composition is associated with tobacco retailer density and tobacco prices,[30] putting the adolescents who live in neighborhoods with a low-SES, high-racial-minority population at increased risk of exposure to high tobacco retailer density and low tobacco prices. This section will focus on policies that may reduce these place-based disparities in accessibility to tobacco products as well as policies that aim to reduce youth purchasing of tobacco products overall.

*Licensing and Zoning Laws*

Licensing is used by states, counties, or cities to regulate businesses.[223] States, like Ohio, that require tobacco retailers to be licensed may place requirements on businesses that sell tobacco, such as restricting sales to minors.[223] Other applications of licensing laws are that they can restrict the types of retailers that can sell tobacco, how close tobacco retailers can be to each other, how many can operate per a geographic area (sometimes linked to population size), and how close retailers can be to schools.[223,224] Zoning laws regulating land use can define what type of business are allowed to operate in a district.[223] Thus, zoning laws could be applied to prevent or cap the number of tobacco retailers operating in residential areas or areas that are frequented by youth.[224]

To date, several municipalities have restricted the types of retailers that can sell tobacco by banning sales at pharmacies.[225] Simulation studies have found relatively modest effects of this approach for reducing retailer density compared to other approaches, however.[226–228] Longitudinal research comparing actual reduction in retailer density in cities that implemented a ban on tobacco sales at pharmacies to comparable

cities without a ban confirmed that this approach did result in a reduction in retailer density.[229] However, the magnitude of reduction in density appears to differ substantially depending on the location,[229] so it is unclear how this approach would affect tobacco retailer density in Ohio. Importantly, no studies have concluded that banning tobacco sales at pharmacies would reduce place-based disparities in tobacco availability;[226,227] in fact, effects may be strongest in suburban communities.[227]

Other approaches to reducing tobacco retailer density include limiting the proximity of tobacco retailers to each other or to schools. Simulation studies evaluating the effects of limiting the proximity of tobacco retailers to each other (typically using a 500-foot limit) have identified larger decreases in tobacco retailer density compared to banning tobacco sales at pharmacies.[227,228] Further, effects may be strongest in poor, urban settings.[227] Similarly, prohibiting tobacco retailers within 1000 feet of schools may lead to the greatest reduction in retailer density in low-income and high-racial-minority census tracts.[230] Notably, these simulation studies all modeled the effects of these approaches outside of Ohio. With Ohio's blend of urban and rural—and Appalachian and non-Appalachian—counties, the effects of simulations in New York, Missouri, California, and North Carolina may not translate to what would be observed in Ohio. The only indication of potential difference in effects according to rurality come from a North Carolina study that reported banning tobacco advertising at retailers within 1000 feet of schools would affect 2.5 to 3 times as many retailers in urban compared to rural areas.[231]

*Policies Related to Tobacco Prices*

As tobacco prices tend to be lower in low-income, high-minority areas,[30] laws that set flat rate minimum prices (i.e., laws that prohibit tobacco products from being sold under a certain price even with discounts) or eliminate tobacco price discounts are other potential routes to reduce place-based disparities in tobacco availability.[232,233] Even in locations with high cigarette excise tax rates, discounts are widely available to reduce the price of tobacco purchases. In fact, the cigarette industry spent $8.6 billion on advertising and promotion in 2017; $7.4 billion was spent on price discounts to retailers and wholesalers, and $301.9 million was spent on coupons.[234] That same year, the SLT industry spent $718.3 million on advertising and promotion, with $438.5 million going toward price discounts to retailers and wholesalers and $76.9 million going toward coupons.[235] Thus, flat rate minimum price laws and bans on price discounts— assuming the minimum price is set high enough—are methods to even out the distribution in prices across neighborhoods of different incomes and demographics.

There is evidence that, in practice, flat rate minimum price laws do increase the prices of tobacco products. In the past six years, Boston and three Minnesota municipalities set minimum prices for single cigars and cigars sold in packs of 4 or fewer.[236,237] In addition to seeing significant increases in the price of single and two-pack cigars after policy implementation, the proportion of retailers sellng single or two- or three-packs of cigars also decreased substantially. Additionally, compliance with the policy was quite high, with 75-100% of retailers complying in each city.[236,237] In Boston, there was also evidence that policy implementation reduced disparities in cigar price and availability across neighborhoods,[237] though this was not evaluated in the Minnesota

study. At the national level, recent research demonstrated that states with flat rate minimum price laws for cigarettes had higher priced cigarettes,[238] although it is possible that such states have high support for tobacco control measures overall, which could also lead to raised prices. These results are in contrast to older studies that found null or opposite effects of minimum price laws (i.e., that minimum price laws resulted in *lower* prices of cigarettes), but it should be noted that such laws were initially put in place to protect smaller retailers from being undersold by large merchandisers and thus were not very strong.[239,240] Ultimately, simulation studies estimate that strong flat rate minimum price laws would result in decreases in the prevalence of tobacco use, particularly for lower SES individuals.[241,242] There is also evidence that higher tobacco prices are associated with increased smoking cessation,[45] and reduced smoking initiation among adolescents.[44]

Similarly, prohibition of price discounts, including coupon redemption, multi-pack discounts, and buy one/get one free offers (hereafter referred to as "price discounts") can be used to raise the price of tobacco products.[243] From 2011 to 2016, price discounts applied at the point-of-sale reduced the price of cigarettes by 25% to 37% and little cigars by 4.1% to 19.2% in the U.S, with the magnitude of price reduction depending on type of retailer.[244] Even among youth who are too young to legally take advantage of price discounts at the point-of-sale, there is evidence that this practice promotes youth tobacco use. Youth exposed to tobacco coupons have increased odds of being susceptible to smoking and intending to purchase cigarettes, as well as reduced self-efficacy in quitting smoking.[245] Policies banning coupon redemption and multi-pack

discounts have been implemented in Providence, RI and New York City, NY, and were upheld in spite of tobacco industry legal challenges citing restriction of free speech.[246]

In conclusion, the average price of cigarettes in the U.S. is far below the $10 per pack cost recommended in the 2014 Surgeon General's report.[1] Combining bans on price discounts with flat rate minimum price policies raises prices above and beyond the effects of flat rate minimum price laws alone,[238] and may accordingly lead to greater reductions in the prevalence of youth smoking. One simulation study, for example, estimated that banning the sale of cigarettes below $10 would result in 602,425 fewer adolescent smokers in the U.S.; paired with a ban on price discounts, the total result would be 637,270 fewer adolescent smokers.[247] Importantly, the estimated reduction in smoking prevalence was highest in states with low excise taxes and high prevalences of youth smoking[247]—suggesting that such a policy approach may be particularly useful at reducing the prevalence of youth tobacco use in Ohio.

*Tobacco 21*

Tobacco 21 (T21) policies prohibit the sale of tobacco products to youth or young adults under 21-years-old. The primary rationale for this policy is that it limits the ability of older teens and young adults ages 18-20 to supply tobacco products to their younger friends, as one of the major sources of tobacco products among youth is through their peers.[248] Additionally, such policies make it more difficult for adolescents and young adults to try tobacco products during a period at which they are at high risk for doing so and becoming addicted.[1] A simulation of the health impacts of a T21 policy enacted at

the national level concluded that it would result in a 12% decrease in adult smoking prevalence in the U.S., and that decreases in smoking initiation would be greatest among youth ages 15-17 years.[249] Ultimately, this simulation estimated that increasing the minimum legal age of tobacco sales to 21 years would result in 50,000 fewer lung cancer deaths, 223,000 fewer premature deaths, and a reduction of 4.2 million years of life lost.[249] A different simulation study identified that T21 may result in reductions in adult smoking prevalence equivalent to aggressive excise taxes.[250] As the 2009 TCA prohibited the FDA from raising the minimum age to purchase tobacco products in the U.S. above 18 years,[48] enactment of this policy has occurred at the state and local levels.

As of July 2019, 18 states and over 475 municipalities have passed a T21 ordinance,[251] including Ohio in 2019.[252] Columbus, Ohio, prohibited the sale of any tobacco product to youth or young adults under the age of 21 in September 2017.[253] Across the U.S., T21 polices have widespread support, with over 70% of adults supporting the policy in 2013.[254] In addition, in approximately 30 states, T21 policies enacted at the local level are not subject to pre-emption by state law—removing a barrier to implementation of this policy at the local level.[255] Importantly, there is evidence that such policies do actually result in reductions in youth smoking. In Needham, MA, the first city to pass a T21 policy, the rate of decline of youth current smoking exceeded that of nearby comparison communities with no such policy.[256] The percentage of youth under 18-years-old who purchased cigarettes also decreased more in Needham than in the comparison communities.[256]

*Flavored Tobacco Product Bans*

The TCA banned the sale of flavored cigarettes with the exception of menthol;[48] however, flavors of other tobacco products, including e-cigarettes, little cigars, hookah, and SLT are still permitted in most states and localities.[f] Presently, Maine and New Jersey are the only states to restrict the sale of flavored tobacco products.[258,259] A rapidly-growing list of over 200 localities have placed additional restrictions on flavored tobacco products, including over 45 that have also restricted or banned sale of menthol cigarettes.[259] Youth in the U.S. prefer flavored tobacco products: Among youth who were current tobacco users in 2014, an estimated 70% had used at least one flavored product in the past 30 days.[260] Additionally, promotion of menthol cigarettes and availability of flavored cigars are more prevalent in neighborhoods with a high proportion of African Americans,[261,262] contributing to place-based disparities in tobacco marketing.

Overall, banning flavored tobacco products reduces youth tobacco use. After flavored cigarettes were banned in the U.S., reductions were observed in the prevalence of youth cigarette smoking and amount of cigarettes smoked by youth at the national level.[263] At the same time, however, increases were observed in the prevalence of menthol cigarette smoking and use of flavored cigars and pipes.[263] Thus, there is evidence that the ban of cigarette flavors resulted in some youth substituting with menthol cigarettes or other flavored tobacco products rather than abstaining completely. A study of a more comprehensive flavor ban also found reductions in youth tobacco use.

[f] On November 15, 2018, the FDA proposed rules to restrict sales of flavored e-cigarettes in retailers without age restrictions (except for mint and menthol), ban menthol cigarettes and cigars, and ban flavored non-premium cigars.[257]

In 2010, New York City started enforcing a flavor ban across all tobacco products (again, menthol was excluded from the ban). In the following years, there was a decrease in the prevalence of adolescent use of flavored tobacco products, as well as use of tobacco overall.[264]

### *Conclusion*

To summarize, tobacco control policies enacted at the federal, state, and local levels have reduced youth tobacco use. Some policies, including licensing or zoning laws, price laws, and flavor bans additionally have the potential to reduce place-based disparities in tobacco accessibility. Other policies that may not affect place-based disparities in tobacco accessibility, like T21, nonetheless reduce youth tobacco use overall and are likely to have large, positive impacts on the population's health.

## Summary

Adolescent use of traditional tobacco products continues to decline in the U.S. However, increases in the prevalence of emerging tobacco product use have offset these declines, resulting in no change in the prevalence of adolescent tobacco use overall.[6] A substantial body of research has described the health effects of tobacco use, as well as individual- and interpersonal-level risk factors for tobacco use. Additionally, living in rural or Appalachian areas has been consistently associated with increased risk of using tobacco products. How other aspects of place, such as perceived neighborhood quality, affect adolescent tobacco use is less well understood. Polices have been implemented at

the federal, state, and local levels to curb adolescent tobacco use, including policies that increase tobacco prices, ban flavors, and raise sales ages to 21. How the implementation of T21 affects other characteristics of the retail environment after being implemented is unstudied, though. The overarching goal of this research, therefore, is to extend our understanding of 1) how use of emerging tobacco products relates to risk of using traditional tobacco products, 2) how exposure to low-quality neighborhoods affects risk of using traditional and emerging tobacco products, and 3) whether implementation of T21 policy results in changes to the tobacco retailer environment.

# Chapter 2. Research Design and Methods

## Overview

The proposed research aimed to improve understanding of adolescent tobacco use by evaluating factors at the individual, community, and policy levels of the social ecological model. Respectively, this research: 1) identified whether e-cigarette use served as a gateway to use of cigarettes and SLT, 2) described the effects of perceived neighborhood quality on use of traditional and emerging tobacco products, and 3) measured whether implementation of T21 policy was associated with changes to tobacco retailer practices. Assessments of e-cigarettes' potential gateway effects and the effects of exposure to lower quality neighborhoods were completed using a prospective cohort of adolescent males living in urban and Appalachian Ohio. The evaluation of potential retailer changes post-implementation of T21 was completed using five years of audits of Columbus, Ohio, retailers that held a cigarette dealer license.

## SA1 & SA2: Setting & Participants

The Buckeye Teen Health Study (BTHS) is a prospective cohort study of N=1220 males ages 11- to 16-years-old who live in Franklin County (N=708) and Appalachian Ohio (N=512) (Appalachian counties include Brown, Clermont, Guernsey, Lawrence,

Morgan, Muskingum, Noble, Scioto, and Washington). Households were sampled using address-based sampling (N=991) and convenience sampling methods (N=229). Male youths' parents, guardians, or other caretakers also enrolled in the study and provided additional information about the male youths' SES, household exposure to tobacco use, and neighborhood during childhood. The study's enrollment occurred from January 2015 to June 2016, and youth were followed every six months for two years; their parents were followed yearly for two years.[g] Thus, male youths' tobacco use was measured at baseline, and six, twelve, eighteen, and twenty-four months later. Only males were enrolled in the BTHS because an aim of the original study was to measure predictors of SLT use, which is much more prevalent among males than females.[3] While this limited the generalizability of our results, it did improve our ability to stably measure whether e-cigarettes served as a gateway to SLT use, which was unstudied to our knowledge.

## SA1 & SA2: Procedures

### *Research Design*

The objective of specific aim 1 was to determine whether youth who used e-cigarettes were at increased risk of initiating use of cigarettes or SLT (risk of initiating cigarettes and SLT were evaluated separately; see Figure 1). Thus, a prospective study allowing for measurement of e-cigarette use prior to the occurrence of our outcomes was necessary. For specific aim 1, this had the following implications on our research design:

[g] The full male youth and parent cohorts were followed for two years. A limited number of participants completed three years of follow-up, however. Some parent data from the three-year follow-up were used in aim 2 as described later.

1. Youth who were ever users of e-cigarettes at baseline but reported no cigarette or SLT use at baseline were retained in all analyses and part of the exposed (i.e., e-cigarette user) group.
2. Youth who were ever users of e-cigarettes, as well as cigarettes or SLT, at baseline were retained in product-specific (i.e., cigarette or SLT) analyses and were part of the exposed group if their reported age of first using e-cigarettes pre-dated their age of first using cigarettes or SLT. They were part of the unexposed group if their cigarette or SLT use preceded their use of e-cigarettes.
    a. Youth who were ever users of e-cigarettes, as well as cigarettes or SLT, at baseline were removed from product-specific analyses if their reported age of first use of e-cigarettes was equal to the age that they first used cigarettes or SLT because temporality could not be established.
3. Youth who were never users of e-cigarettes, cigarettes, or SLT at baseline were retained in analyses as long as they did not initiate e-cigarettes and cigarettes or SLT at the same time point. If they initiated e-cigarettes prior to cigarettes or SLT, they were part of the exposed group. If they initiated cigarettes or SLT before e-cigarettes, or never initiated e-cigarettes, they were part of the unexposed group.

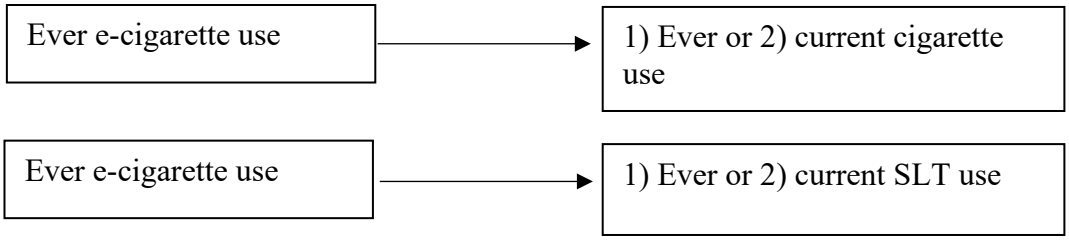


**Figure 1.** Simplified model of specific aim 1 research design.[a]

[a] This figure is only intended to convey temporality of the study design. The potential outcomes framework and propensity score model are omitted here for brevity.

The objective of specific aim 2 was to describe how perceived neighborhood quality at age 10 was associated with risk of initiating emerging and traditional tobacco products. Like specific aim 1, exposure to perceived neighborhood disadvantage had to occur prior to youths' initiation of tobacco products to measure risk. Unlike specific aim 1, exposure data was collected retrospectively from parents by inquiring about the perceived quality of youths' neighborhood at age 10.

While we were unaware of any quantified measure of a parent's ability to reliably recall details of their child's residential history, such as neighborhood quality, asking parents to recall addresses of a few key points in time in their child's life has been completed in prior research and thus is at least feasible.[265] Although our method of ascertaining youths' neighborhood exposures during middle childhood is subject to information bias, the bias would be non-differential misclassification of exposure as it was unlikely that parents' ability to accurately recall the quality of their child's neighborhood at age 10 was related to their child's use of tobacco products.

*Instrument Development*

The baseline survey used for aims 1 and 2 measured ever and current use of e-cigarettes, hookah, cigarettes, SLT, traditional cigars, and little cigars and cigarillos (see Appendix A for items used in this research). Youth who reported ever use of a tobacco product at baseline were asked how old they were when they first used that product. This survey also measured sensation seeking, delay discounting, race, alcohol use, marijuana use, and birthdate. Follow-up surveys of male youth measured ever and current use of the same tobacco products. Tobacco and substance use items were obtained from the Population Assessment of Tobacco and Health Study.[266] Sensation seeking[267] and delay discounting[268] items were also obtained from validated scales.

The baseline survey for parents/guardians measured their tobacco use and highest level of education. Parents/guardians who lived with male youth at age 10 were additionally asked to answer questions related to the perceived quality of that neighborhood on their 24- and 36-month follow-up surveys. Items were obtained from valid and reliable scales measuring perceived neighborhood safety,[269,270] social disorder,[271] physical disorder,[271] and social cohesion.[272] As items measuring residential history and neighborhood quality were added after the 24 month survey was already in the field, these items were also added to the 36 month survey in an attempt to collect this information for more participants. Study enrollment occurred over an 18-month period, so these time points overlapped for six months.

*Data Collection*

Tobacco use data for specific aims 1 and 2 were collected in the same way. At baseline and 24-months, youth completed an audio computer-assisted self-interview (ACASI) to answer most items. For this research, the only items that were not completed in an ACASI format were delay discounting, race, and birthdate, which were collected in an interviewer-administered format. For the other follow-ups, youth completed telephone surveys. Youth were instructed to only say the number associated with their response on telephone surveys instead of their actual response to increase honesty in reporting when other family members might be nearby. Parent participants completed paper-and-pencil self-administered surveys at baseline, on which they reported their highest level of education and household tobacco use. All parent follow-ups were completed via telephone survey.

*Dependent Variables*

For specific aim 1, the dependent variables were binary indicators of 1) ever use of cigarettes, 2) current use of cigarettes, 3) ever use of SLT, and 4) current use of SLT. Ever and current use of these products could be reported at any time point from baseline through the 24-month follow-up. To be included in analyses, however, youth must not have initiated use of these products at the same age they initiated e-cigarettes.

For specific aim 2, the dependent variables were binary indicators of ever use of 1) emerging and 2) traditional tobacco products. Emerging tobacco products included e-cigarettes or hookah. Traditional tobacco products included cigarettes, SLT, traditional

cigars, or cigarillos/little cigars. Age of initiating an emerging or traditional tobacco product was ascertained in two ways, depending on when the participant started to use the product. At baseline, youth self-reported the age that they first tried tobacco products, which was used as the age of tobacco initiation for participants who had initiated tobacco prior to baseline. For youth who reported their initiation of tobacco products on a follow-up survey, the age that they were when they took the survey was recorded as their age of first use. For youth who initiated more than one emerging or traditional tobacco product, the earliest age of initiation of a product in the respective category was used.

*Independent Variables*

For specific aim 1, we derived two binary variables to identify participants who 1) initiated e-cigarette use without first smoking cigarettes, and 2) initiated e-cigarette use without first initiating SLT (i.e., the exposed groups). Participants were in the unexposed groups if they never initiated e-cigarettes, or they initiated e-cigarettes after initiating cigarettes or SLT. As described earlier, this was based on ages of initiation as reported at baseline, as well as initiation of product use at follow-up time points.

For specific aim 2, the independent variables of interest were perceived measures of neighborhood quality. For these measures, we first identified all cases where two parent/guardian participants completed the perceived neighborhood quality items. In these cases, we randomly selected one parent's responses for analysis. We also reverse-scored items as necessary so that they all were scored to have the lowest numbered response as the most negative and highest as the most positive perception of

neighborhood quality. Next, we performed a confirmatory factor analysis (CFA) of the perceived neighborhood quality items answered by participants' parents to confirm that they loaded on safety, social disorder, physical disorder, and social cohesion factors. Model fit was assessed using the root mean square error of approximation (RMSEA), comparative fit index (CFI), Tucker-Lewis index (TLI), and chi-square goodness of fit test. RMSEA values of 0.06 or lower and CFI and TLI values of 0.95 or higher were *a priori* criteria for good fit.[273] Due to the large sample, we were likely to reject the chi-square goodness of fit test in the presence of even minor deviations from multivariate normality;[274] however, results were reported for transparency. If the model fit was rejected according to the RMSEA, CFI, or TLI, an exploratory factor analysis would be conducted to determine if a better factor structure could be identified. After the factor structure was confirmed, we calculated the mean value of indicators on each scale for all participants who answered at least 30% of the items on the scale. These means were used as the exposure variables in our models.

*Preparation for Data Analysis*

Prior to aim 1 and aim 2 analyses, the baseline and follow-up datasets were inspected to identify out-of-range or implausible values of our independent and dependent variables. Due to the open-response field and ACASI data collection at baseline, the age of tobacco product initiation was the most likely to contain implausible values. Entries that were larger than the participant's age were set to missing, as were ages of initiation below age 6. Although it was possible that a child may have initiated

tobacco products at age 5 or younger, it was perhaps more likely that he missed the "1" when entering his age (i.e., he meant to enter "13" and instead entered "3"). Moreover, given the age of participants in this study, it was unlikely that participants accurately recalled their age of first tobacco use during very early childhood.

After cleaning the datasets, multiple imputation of tobacco use outcomes, key predictors, and covariates was completed. Due to differences in the analytic samples between specific aims 1 and 2, as well as differences in predictor variables and covariates, separate multiple imputation datasets were created for each aim. Incomplete follow-up was observed for some participants; 92.7% completed the 6-month follow-up, 85.7% completed the 12-month follow-up, 82.5% completed the 18-month follow-up, and 73.4% completed the 24-month follow-up. Because participants were permitted to return to the study after missing a time point, the missing data pattern was arbitrary rather than monotonic. The imputation plan was as follows:

1. For participants who missed an earlier time point but confirmed no tobacco initiation at a later time point, the absence of tobacco use at a later time point was filled in to the earlier time point.
2. Participants who were ever users of tobacco products at baseline had their ever use of the applicable products carried forward to all future time points.
3. After completing steps 1 and 2, participants who were still missing tobacco use outcomes had ever and current use imputed by conducting multiple imputation. The same procedure was used to impute age of initiation for participants who

reported implausible ages of initiation at baseline, as well as missing values of predictor variables or covariates needed for aim 1 and aim 2 analyses.

The imputation models contained variables associated with intermittent or complete drop-out from the study, as well as variables proposed to be used in specific aims 1 and 2;[275] as described above, distinct imputation models were used for aims 1 and 2. Baseline covariates that had missing values due to item non-response but were needed for the analytic model were also imputed (e.g., ever alcohol and marijuana use). As most of the variables in our imputation model were not distributed multivariate normal, we used multiple imputation by chained equations (MICE) rather than the Markov Chain Monte Carlo procedure, which assumes a joint multivariate normal distribution for all variables in the imputation model. MICE, in contrast, uses a separate conditional distribution for each variable that will be imputed.[276] Variables were imputed in order from least- to most-missing—creating a monotonic missing pattern as the imputation progressed. Categorical variables were imputed using logistic regression (i.e., a "1" or "0" was imputed), and continuous variables were imputed using linear regression. A total of 25 imputed datasets were created for aim 1 anlayses.[277] Due to a smaller proportion of missing data in aim 2 analyses, a total of 5 imputed datasets were created. All aim 1 and aim 2 analyses that follow were performed on the multiply-imputed datasets and results were combined using Rubin's method.[278]

For specific aim 1, the two derived e-cigarette ever use variables described above were the dependent variables in the construction of propensity scores, which were used in the estimation of the causal effect of ever e-cigarette use on cigarette and SLT use (see

Model 1 for our potential outcomes framework). Although observational studies, such as the present study, generally have an unknown treatment assignment mechanism, causal inference is still feasible when the treatment assignment is *regular*. This means that the treatment assignment is individualistic (i.e., one's treatment assignment does not depend on others' treatment assignments), probabilistic (i.e., treatment assignment probability is nonzero for all participants), and unconfounded (i.e., treatment assignment is exogenous, or does not depend on covariates). As the present study met the first two criteria of regular treatment assignment, the propensity scores, then, were a form of dimension reduction that served to balance the distribution of covariates that may confound the association between e-cigarette use and cigarette or SLT use (see Model 2 for a simplified propensity score model). In other words, the goal was to create a scenario in which covariates were balanced by "treatment" assignment, or that "treatment" was independent of covariates as is the case with randomized experiments. It should be noted, however, that the propensity score cannot be used to balance unmeasured confounders and thus we cannot assume that his method removed all sources of bias.

**Model 1.** Potential Outcomes Framework for Specific Aim 1

$$Y_i^{obs} = T_i Y_i^1 + (1 - T_i) Y_i^0$$

Where:

- $Y_i^{obs}$ = the observed cigarette or SLT use outcome for participant *i*
- $T_i$ = ever e-cigarette use by participant *i*
- $Y_i^1$ = potential outcome associated with ever e-cigarette use for participant *i*

- $Y_i^0$ = potential outcome associated with never e-cigarette use for participant *i*

**Model 2.** Simple Propensity Score Model

$$e(\boldsymbol{X}) = P(T = 1|\boldsymbol{X})$$

Where:

- e(X) = the propensity score
- T = ever e-cigarette use
- X = matrix of covariates

The propensity score model included variables that were substantively associated with e-cigarette use and could reasonably be thought to precede initiation of e-cigarette use. These variables included birth year, race, region (Franklin County or Appalachia), household socioeconomic status (highest level of parental education), tobacco use by adults in the household, sensation seeking, delay discounting, and initiation of alcohol, marijuana, or other tobacco products prior to e-cigarettes (except for cigarettes or SLT). After propensity scores were estimated, we proceeded with analyses as described below.

To prepare for specific aim 2's analyses, we constructed a dataset that included indicators of ever use of emerging and traditional tobacco products, age of first emerging and traditional tobacco product use or censoring, indicators of perceived neighborhood quality, and the covariates used in aim 2 analyses (described below).

*Data Analysis Plan*

For aim 1, we started by calculating the absolute standardized differences (ASD) for covariates in the propensity score model prior to conducting the propensity score match. This established a baseline of covariate distribution imbalance by ever e-cigarette use prior to matching. Although ASD values were calculated for this project using R, formulas for continuous and categorical predictors are provided in Equation 1. It should be noted from the ASD formulas that this measure evaluated distribution-level covariate balance rather than individual-level covariate balance. As estimating the treatment effect only requires that the mean of covariates is balanced across treatment groups, this is acceptable (see Appendix B). Next, we visually assessed common support, or the overlap in the distribution of propensity scores among e-cigarette users and non-users by comparing histograms of propensity score distributions for each group. Ideal common support plots would demonstrate enough overlap in the distribution of propensity scores to support matching e-cigarette users to non-users across the distributions of scores; such overlap would allow us to estimate the population average treatment effect. If there was limited overlap, we would only be able to estimate the population average treatment effect on treated (or control). In this case, rather than estimating the causal effect of e-cigarette use on cigarette or SLT initiation for all participants, we would be estimating the causal effect of e-cigarette use on cigarette or SLT initiation for e-cigarette users only. Thus, such a check pre-match was necessary to determine what causal effect we estimated post-match.

After these pre-match checks, we conducted an optimal match for both of our propensity scores using the "matchit" and "optmatch" packages in R; the distance metric for the match was the linear propensity score. The optimal match was used because it finds the smallest total distance in the linear propensity score among all possible pairings. We matched two never e-cigarette users to each e-cigarette user. After matching, we again calculated the ASD to determine whether the balance of covariates improved. *A priori*, ASD values of <10% were considered acceptable.[279] If ASD values indicated a poor post-matching distribution of covariates, we would try different matching distance metrics, including the propensity score, Mahalanobis distance, or Euclidean distance. If that did not achieve acceptable ASD values, we would check whether higher-order terms may be required in our propensity score model and consider completing a 1:1 match instead. Finally, if acceptable ASD values were still not reached, we would include the imbalanced covariate in the analytic regression model to reduce the bias in our estimated causal effect.

**Equation 1**. ASD Formulas for Continuous and Categorical Covariates

$$ASD = \frac{100(\bar{x}_{Treatment} - \bar{x}_{Control})}{\sqrt{\frac{s^2_{Treatment} + s^2_{Control}}{2}}}$$

$$ASD = \frac{100(p_{Treatment} - p_{Control})}{\sqrt{\frac{p_T(1-p_T) + p_C(1-p_C)}{2}}}$$

After the propensity score match was complete, we ran generalized linear models (GLMs) with a log link to test whether ever e-cigarette use increased risk of initiation of 1) ever cigarette use, 2) current cigarette use, 3) ever SLT use, and 4) current SLT use (Model 3). Although conditional logistic regression could also be used for this analysis and would preserve the pairing structure,[280] preservation of the pairing structure is unnecessary for valid risk ratio estimates in prospective studies with matching.[281]

**Model 3.** Generalized Linear Model Estimating Risk of Cigarette or SLT use According to Ever E-Cigarette Use

$$g(x) = \beta_0 + \beta_1 ecigarette$$

Where:

- $\exp(\beta_1) =$ risk ratio comparing risk of cigarette (or SLT) initiation for e-cigarette ever users compared to never users.

For aim 2, Cox proportional hazards models were used to estimate the short-term (i.e., instantaneous) risk of initiating traditional tobacco products (cigarettes, SLT, and cigars) and emerging tobacco products (e-cigarettes and hookah).[h] As described above, the time variable was participants' age in years. Adjusted models controlled for confounding variables identified from a directed acyclic graph (DAG), including race,

[h] As some participants could be considered to never be at risk of using tobacco (i.e., the prevalence of tobacco use is not expected to ever reach 100%), cure survival analysis models were considered. However, as the study's follow-up was only two years, and most participants were not followed to adulthood when one might be considered no longer at risk of tobacco initiation, the application of cure models is inappropriate as no participants could be considered long-term "survivors" of tobacco initiation.[282]

tobacco use by adults in the household, region, and household socioeconomic status operationalized by parental education (Figure 2). These confounders were selected based on substantive reasoning and model selection was not be used. As the hazard ratio is non-collapsible, inclusion of covariates in the model that were not true confounders could result in biased estimates.[283]

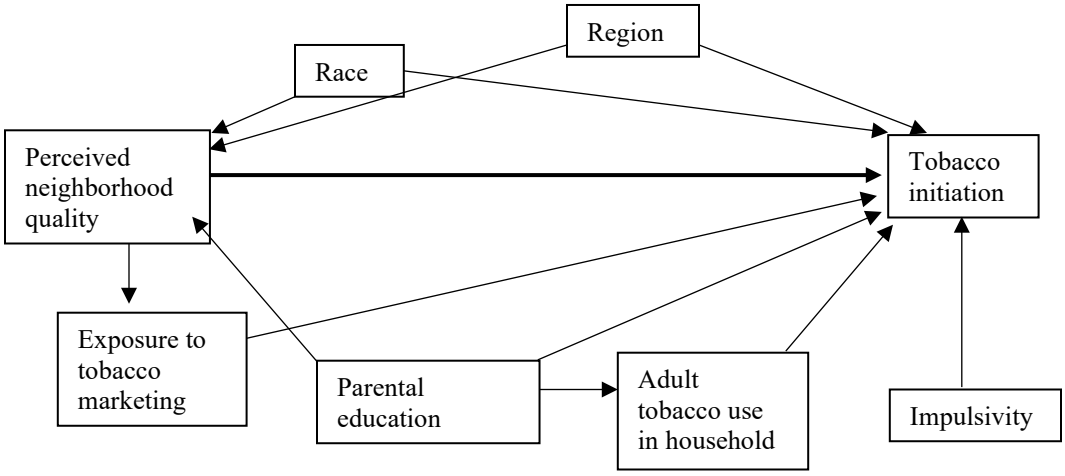


**Figure 2.** DAG demonstrating relationships between exposure to neighborhood disadvantage, initiation of tobacco products, and potential confounding variables[a]

[a] This DAG describes the relationships between the exposure, outcome, and covariates that might be considered as confounders. Examination of the relationships between variables, however, reveals that it is only necessary to control for parental education, parental tobacco use, region, and race, as they are likely to be associated with both the exposure and outcome variables and are not on the causal pathway or selection factors.

Average values of the perceived neighborhood quality scales as described above (i.e., safety, social disorder, physical disorder, and cohesion) were independent predictors

in separate Cox proportional hazards models that also included tobacco use by adults in the household, race, region, and parental education. Predictors were included in separate models due to multicollinearity. Average values on the perceived social and physical disorder scales were reversed so that higher values represented more socially or physically disordered neighborhoods; average values on the perceived safety and cohesions scales were left as they were from the CFA, with higher values representing safer, more cohesive neighborhoods. Cox regression was then used to model the short-term risk of initiation of traditional and emerging tobacco products (Model 4). Because perceived neighborhood quality data were only available for participants' neighborhoods at age 10, youth who initiated tobacco use prior to this age were considered left truncated.

We evaluated linearity in the log-hazard by inspecting Martingale residuals plots, which are plots of our model's deviations from the observed data against values of the independent variable we are testing. If the linearity assumption for any of our independent variables was violated, as indicated by failure of the residuals to scatter randomly around 0, we would inspect the distribution of responses and then categorize the predictor variable into tertiles representing low, medium, and high levels of the variable. After the linearity checks, we checked the proportional hazards assumption for all predictor variables and covariates by inspecting Schoenfeld residuals plots and conducting Schoenfeld residuals tests. When a covariate violated the proportional hazards assumption, we stratified the Cox model by that covariate. If a predictor variable violated the proportional hazards assumption, an interaction term between that predictor and time would be included in the model.

The final models resulted in hazard ratios (HR) estimating the short-term risk of emerging or traditional tobacco product initiation that was associated with parents' perceptions of safety, social disorder, physical disorder, and cohesion in boys' neighborhoods at age 10, controlling for covariates.

**Model 4**. Cox Proportional Hazards Model of Short-Term Risk of Emerging (or Traditional) Tobacco Product Use by Perceived Neighborhood Quality at Age 10

$$h(t|\boldsymbol{x},\boldsymbol{\beta}) = h_0(t)\exp\{\beta_1 per\_quality + \beta_2 par\_educ + \beta_3 adult\_tobacco + \beta_4 race\_black + \beta_5 race\_other + \beta_6 region\}$$

Where:

- per_quality = participant's score on the perceived safety, social disorder, physical disorder, or cohesion scale
- par_educ = 1 if neither parent/guardian graduated from college; = 0 otherwise
- adult_tobacco = 1 if at least one adult in the participant's household was a tobacco user; = 0 otherwise
- race_black = 1 if participant is black non-Hispanic; = 0 otherwise
- race_other = 1 if participant is not black non-Hispanic or white non-Hispanic; = 0 otherwise
- region = 1 if Appalachia; = 0 otherwise

SA3: Setting

The objective of specific aim 3 was to determine whether the tobacco retail environment changed post-implementation of T21 policy. From the alcohol literature, age-based audience segmentation of marketing practices at retailers has been used to appeal to "starter," or young drinkers differently from "established," or older drinkers.[284] This resulted in marketing sweeter drinks that masked the taste of alcohol and were cheaper or price-discounted to younger drinkers at retailers.[284] Investigation of tobacco marketing practices by census tract characteristics suggests that the tobacco industry also segments marketing practices in the retail environment by age. Tobacco retailers in areas with younger populations had lower priced tobacco products[285] and were more likely to have promotions for menthol cigarettes.[286] Thus, it follows that retailers that are no longer permitted to sell tobacco to younger people may change their marketing practices to be more appealing to more established tobacco users, which could result in higher tobacco prices and reduced availability or promotion of flavored products. Conversely, it is also possible that retailers could respond to T21 by trying to recruit new young adult tobacco users with low prices or promotion of flavored tobacco products.

The setting for aim 3 was retailers holding a cigarette dealer license in Columbus, Ohio, before and after implementation of T21. Although auditing a census of retailers for this aim would have been ideal, it was only feasible to audit 74 to 103 of them in 2014, 2016, 2017, 2018, and 2019. Retailers were sampled by stratifying Franklin County by location and median income levels, then drawing a random sample of retailers from each stratum.[287] Over half of sampled retailers were convenience stores or gas stations, and the

rest were grocery stores, mass merchandisers, pharmacies, liquor stores, bars/restaurants, and tobacco shops. The same retailers were audited each year, and replenishment samples of retailers were drawn over time. Although Franklin County retailers outside of Columbus, Ohio, were also audited, they were not included in the present study due to small cell sizes and uneven enforcement of T21 across localities that had implemented T21.

## SA3: Procedures

### *Research Design*

To determine whether the trajectories of prices, availability of flavored products, exterior advertising, and price promotions in retailers changed after implementation of T21, we observed the retail environment before and after implementation. As stated above, T21 was implemented in Columbus, Ohio, in September 2017.[253] This means that we observed retailers for a three years before (2014, 2016, and 2017) and two years after (2018 and 2019) T21 was implemented.

### *Instrument Development*

The instrument used for retailer audits (provided in Appendix A) was adapted from prior work.[288] Measures included the price of the cheapest pack of cigarettes in the store; the price of one pack of Marlboro Reds, Newport Green Full Flavor Menthols, and one blu disposable e-cigarette; availability of menthol cigarettes and flavored cigarillos/little cigars, SLT, and e-cigarettes (yes/no for each product); exterior

advertisements for large cigars, hookah, and flavored and unflavored cigarettes, cigarillos/little cigars, SLT, and e-cigarettes (yes/no for each product; collected only from 2016 to 2019); and interior and exterior price promotions for large cigars, hookah, and flavored and unflavored cigarettes, cigarillos/little cigars, SLT, and e-cigarettes (yes/no for each product; collected only from 2016 to 2019).

*Data Collection*

Undergraduate and graduate student fieldworkers were trained to collect store audit data. Moderate-to-good inter-rater reliability was achieved at each wave prior to collecting data (Cohen's $\kappa > 0.5$). At each wave, data were collected by pairs of fieldworkers during daytime in late spring or summer. In 2014, data were collected on paper-and-pencil surveys. From 2016 to 2019, data were collected using a smartphone Qualtrics survey, allowing for more discreet data collection. Most data were collected by visually inspecting the retailer's exterior and interior advertisements, promotions, and available products. The price of the cheapest pack of cigarettes, however, was collected by asking a clerk what the cheapest pack price was in 2014, 2016, and 2019. In 2017 and 2018, field workers obtained the price of the cheapest pack of cigarettes by asking to buy the cheapest pack of cigarettes in the store (and then purchasing it).

*Dependent Variables*

As we were interested in describing how the retail environment may have changed post-implementation of T21, there were several dependent variables

characterizing the retail environment for this aim. Continuous dependent variables included prices of 1) the cheapest cigarette pack, 2) Marlboro Reds, 3) Newport Menthols, and 4) blu disposable e-cigarettes. Availability of flavored tobacco products was modeled as a categorical variable (4 flavored products sold vs. fewer). The remaining dependent variables were modeled as counts: 1) Count of flavored and unflavored tobacco product categories with exterior advertisements, and 2) count of flavored and unflavored tobacco product categories with interior or exterior price promotions.

*Independent Variables*

The primary independent variables were year and implementation of T21 policy at each year (yes vs. no). Other covariates used in this analysis were retailer type and census tract indicators that have been associated with lower tobacco prices and availability of flavored products. Retailer type was categorized as convenience store or gas station vs. other. For census tract indicators, we first spatially joined each retailer to a census tract using ArcMap,[289] then merged in census tract indicators for proportion of households under the federal poverty level (dichotomized at $\geq$ 20% vs. less, using the U.S. Census Bureau's definition of high-poverty areas[290]), proportion of black non-Hispanic people (dichotomized at $\geq$ 25% vs. less, as in prior research examining tobacco retailer characteristics in Ohio[287]), and proportion of people under 18-years-old (dichotomized at the Franklin County median). These census tract indicators controlled for other factors that may drive characteristics of the retail environment. Census tract

characteristics came from the American Community Survey's five-year estimates for 2013 to 2017.

*Data Analysis Plan*

Mixed effects models with random intercepts and an unstructured covariance matrix were used for all dependent variables, as this method distinguishes between-retailer and within-retailer sources of variability.[291] It also allows retailers to vary randomly in their baseline values of dependent variables. Another benefit of mixed models for this analysis was that they do not require the same number or timing of observations for each retailer. This was important as it allowed us to include retailers that were missed for one of the years, as well as retailers that were audited but were nonetheless missing data for one or more of our dependent variables. In all models, fixed effects included year, T21 implementation, and the census tract indicators described above. Random intercepts modeled differences in retailers' means from the population average. The alpha level was set at 0.01 for all analyses to account for multiple tests and improve interpretability of results. SAS version 9.4 was used for all analyses.[292]

Linear mixed effects models were used to model the price-related dependent variables over time (Model 5). To determine whether the trajectory of prices changed upon implementation of T21, a product interaction term of year and T21 was included in the model. Assumptions of the linear mixed models, including homoscedasticity and multivariate normality of errors, were evaluated by inspecting residuals plots and quantile-quantile plots, respectively. Violations of either assumption would be addressed

by transforming the dependent variable to a form that resulted in meeting model assumptions.

**Model 5.** Linear Mixed Effects Model for Price Analyses

$$E(Y_i|X, b_i) = \beta_0 + \beta_1 year_i + \beta_2 tob21_i + \beta_3 (year \times tob21)_i + \beta_4 retailer\_type_i + \beta_5 poverty_i + \beta_6 race_i + \beta_7 youth_i + b_{0i}$$

Where:

- $E(Y_i|b_i) =$ the mean price of cheapest cigarettes, Marlboro Reds, Newport Menthols, or one blu e-cigarette[i] for retailer *i*
- year = year of data collection for retailer *i*
- tob21 = tobacco 21 implemented for retailer *i* (yes/no)
- retailer_type = type of retailer for retailer *i* (convenience store or gas station vs. other)
- poverty = census tract poverty level for retailer *i* (high vs. moderate or low)
- race = census tract percent black non-Hispanic for retailer *i* (high vs. moderate or low)
- youth = census tract percent school-aged youth for retailer *i* (high vs. moderate or low)
- $b_{0i}$ = random intercept for retailer *i*

[i] Results of blu e-cigarette models are not presented in the Chapter 5 manuscript due to a large proportion of missing data and small variability in prices. Models would not converge.

Logistic mixed effects models were used to model the count of flavored tobacco products available (4 vs. 3 or fewer; Model 6). A product interaction term of year and T21 policy was used to test whether the trend in odds of 4 flavored tobacco products being available changed after T21 was implemented. Prior to final analyses, linearity in the logit was assessed using fractional polynomials.

**Model 6.** Logistic Mixed Effects Model for Availability of Flavored Products

$$\text{logit}\{E(Y_i|X, b_i)\} = \beta_0 + \beta_1 year_i + \beta_2 tob21_i + \beta_3 (year \times tob21)_i + \beta_4 retailer\_type_i + \beta_5 poverty_i + \beta_6 race_i + \beta_7 youth_i + b_{0i}$$

Where:

- $\text{logit}\{E(Y_i|X, b_i)\}$ = the log-odds of selling 4 vs. fewer flavored tobacco products for retailer *i*
- year = year of data collection for retailer *i*
- tob21 = tobacco 21 implemented for retailer *i* (yes/no)
- retailer_type = type of retailer for retailer *i* (convenience store or gas station vs. other)
- poverty = census tract poverty level for retailer *i* (high vs. moderate or low)
- race = census tract percent black non-Hispanic for retailer *i* (high vs. moderate or low)
- youth = census tract percent school-aged youth for retailer *i* (high vs. moderate or low)

- $b_{0i}$ = random intercept for retailer *i*

Poisson mixed effects models were similarly used to model the count of our remaining dependent variables (Model 7). A product interaction term of year and T21 policy was used to determine whether the trajectory of count of advertisements for flavored products and price promotions changed after implementation of T21. We conducted a chi-square goodness-of-fit test after running the multivariable Poisson models; if the p-value was less than 0.05, we concluded that the Poisson model did not fit the data. We concluded that there was overdispersion if the Pearson chi-square statistic divided by the degrees of freedom was much greater than 1, and that there was underdispersion if the Pearson chi-square statistic divided by the degrees of freedom was much less than 1. If overdispersion was present, a negative binomial mixed model was used.[293] If underdispersion was present, a Poisson mixed model with robust standard errors was used.

**Model 7.** Poisson Mixed Effects Model for Advertising and Promotions Analyses

$$\log\{E(Y_i|X, b_i)\} = \beta_0 + \beta_1 year_i + \beta_2 tob21_i + \beta_3 (year \times tob21)_i + \beta_4 retailer\_type_i + \beta_5 poverty_i + \beta_6 race_i + \beta_7 youth_i + b_{0i}$$

Where:

- $\log\{E(Y_i|X, b_i)\}$ = the mean log-count of exterior advertisements or price promotions for retailer *i*

- year = year of data collection for retailer *i*
- tob21 = tobacco 21 implemented for retailer *i* (yes/no)
- retailer_type = type of retailer for retailer *i* (convenience store or gas station vs. other)
- poverty = census tract poverty level for retailer *i* (high vs. moderate or low)
- race = census tract percent black non-Hispanic for retailer *i* (high vs. moderate or low)
- youth = census tract percent school-aged youth for retailer *i* (high vs. moderate or low)
- $b_{0i}$ = random intercept for retailer *i*

# Chapter 3. Electronic Cigarette Use and Risk of Cigarette and Smokeless Tobacco Initiation among Adolescent Boys: A Propensity Score Matched Analysis


## Abstract

**Introduction.** Electronic cigarette (e-cigarette) use among adolescents is associated with increased risk of subsequent cigarette smoking initiation in observational research. However, the existing research was not designed to answer causal questions about whether adolescent e-cigarette users would have initiated cigarette smoking if they had never used e-cigarettes. The current study used a causal inference framework to identify whether male adolescent e-cigarette users were at increased risk of initiating cigarette smoking and smokeless tobacco (SLT) use, compared to similar boys who had never used e-cigarettes.

**Methods.** Boys from urban and rural Appalachian Ohio (N=1220; ages 11-16 years at enrollment) reported use of e-cigarettes, cigarettes, and SLT at baseline and every six months for two years. A propensity score matched analysis, completed in 25 multiple imputation datasets, matched one e-cigarette user to two e-cigarette non-users. Risk ratios (RRs) comparing risk of initiating cigarettes and SLT for e-cigarette users and nonusers were estimated.

**Results.** Compared to non-users, e-cigarette users were over twice as likely to later initiate both cigarette smoking (RR=2.71; 95% CI: 1.89, 3.87) and SLT use (RR=2.42; 95% CI:1.73, 3.38).

**Conclusion.** Findings extend the existing evidence that e-cigarettes increase the risk of initiating other tobacco products and support public health interventions to decrease adolescent e-cigarette use.

## Background

In 2018, the decreasing trend in prevalence of tobacco use among adolescents that had been observed since 2011 ended due to increases in electronic cigarette (e-cigarette) use.[3,6] That year, 20.8% of high school students and 4.9% of middle school students in the U.S. reported using e-cigarettes in the past 30 days, with e-cigarettes being the most common product used.[6] Though e-cigarettes may prove to be a less harmful alternative for adults who are current tobacco users, adolescents' use of e-cigarettes is a public health concern. Evidence from studies of adults suggests that e-cigarette use is associated with poor cardiovascular health outcomes,[294] and studies involving adolescents have shown that e-cigarette users have increased risk of asthma,[89] symptoms of chronic bronchitis,[87] and cough.[88] Because relatively few youth use nicotine-free e-cigarettes,[295] there are also neurological consequences associated with e-cigarette use due to nicotine exposure. Nicotine dependence can begin during adolescence as a result of e-cigarette use,[93] and a developing brain's exposure to nicotine can affect maturation processes related to executive function, emotion regulation, and reward processing.[11,12]

Adolescent e-cigarette use is also associated with subsequent initiation of cigarette smoking.[7] Several recent longitudinal studies have identified that non-smoking youth who had used e-cigarettes at baseline were more likely than other youth to start smoking cigarettes at follow-up.[7] Such associations were found regardless of whether the exposure was ever use[108,154,157,296,297] (i.e., having puffed an e-cigarette, even once or twice) or past 30-day use.[108,153,155,296,298] A meta-analysis of nine longitudinal studies identified that ever use of e-cigarettes at baseline increased the odds of ever cigarette use at follow-up (pooled odds ratio [OR] = 3.62; 95% confidence interval [CI]: 2.42, 5.41).[7] Past 30-day e-cigarette use at baseline similarly increased odds of past 30-day cigarette use at follow-up (pooled OR = 4.28; 95% CI: 2.52, 7.27).[7] To our knowledge, only one study measured the association between e-cigarette use and subsequent initiation of other tobacco products.[108] This study identified that baseline e-cigarette use was associated with increased odds of initiating hookah, cigars, and pipes one year later.[108] However, we are aware of no research that has evaluated whether e-cigarette use is associated with risk of initiating tobacco products that are not inhaled, like SLT.

A critique of the argument that e-cigarettes increase the risk of cigarette smoking initiation is that adolescents who progressed to cigarette smoking after using e-cigarettes might have started using cigarettes anyway.[299] In other words, these youth may have a "common liability" for tobacco use, which drives the observed associations.[299,300] This argument is worth consideration due to the overlap in some risk factors for e-cigarette use and cigarette smoking, including use of other substances,[155] impulsivity, older age, male sex, and peer and family tobacco use.[8] However, other research has identified divergent

risk factors for e-cigarette use and cigarette smoking. E-cigarette users tend to have less severe mental health symptoms than cigarette smokers,[9] and the association between e-cigarette use and subsequent cigarette smoking appears to be strongest among adolescents who were otherwise at low risk of cigarette smoking.[108,157,297] Other studies have assessed whether the association between e-cigarette use and cigarette smoking is bi-directional (e.g., cigarette use increases risk of later e-cigarette initiation), which would suggest that e-cigarette users and cigarette smokers share common liability for tobacco use; however, findings have been mixed.[153–155]

In addition to the possibility of a common liability for tobacco use driving the association between e-cigarette use and cigarette smoking among adolescents, existing studies are limited by relatively short follow-ups periods (with a few exceptions[108,153,155]), which may not be enough time to observe the extent of the transition from e-cigarette use to cigarette smoking initiation. Another limitation, due to the observational, longitudinal design necessary to answer this research question, is that studies experience attrition that is often related to risk factors for tobacco use. Though a few studies addressed item or unit nonresponse using maximum likelihood estimation, weighting, or multiple imputation[153,155,296] most conducted a complete case analysis. Finally, the existing research in this area was not designed to answer the causal question of whether adolescents who started smoking cigarettes after they had used e-cigarettes would have done so anyway. Although a randomized experiment would be the optimal way to address this causal question, ethically it cannot be conducted. However, causal inference methods such as propensity score analysis (matched or inverse probability of treatment

weighting) can be used in observational research to better mimic random treatment assignment.

*Theoretical Framework*

The theoretical framework for the current study is the social ecological model, which describes how factors at the individual-, interpersonal-, community-, and policy levels influence health behaviors.[16] Many of the risk factors for e-cigarette use that were described above (e.g., impulsivity, age, and sex) occur at the individual level. Peer and family tobacco use are risk factors at the interpersonal level. Community-level risk factors for e-cigarette use may include urbanicity or rurality, neighborhood quality,[104] and exposure to e-cigarette advertising.[301,302] At the policy level, flavor bans or T21 policy could reduce adolescent risk of e-cigarette initiation.[249,264] An important feature of the model is that it allows factors across multiple levels to individually and jointly affect behavior. In the current study, we used observed risk factors across multiple levels to estimate each participant's risk of being an e-cigarette user. Ultimately, although we could not include policy-level risk factors for estimation of propensity scores, results could have policy implications.

*Aim*

The goal of the current study was to determine whether e-cigarette use is causally related to ever and past 30-day cigarette or SLT initiation in a cohort of adolescent males. Due to the possibility that a common liability for tobacco use drives the observed

associations between e-cigarette use and cigarette smoking in the existing longitudinal research, we used propensity score matching to create an analytic sample of exposed (i.e., e-cigarette users) and unexposed (i.e., e-cigarette never users) participants who were balanced on risk factors for e-cigarette use. Then, we followed these cohorts prospectively to measure whether risk of cigarette or SLT initiation differed between groups. In addition to the causal approach, we aimed to strengthen the literature by following participants for longer than existing research and using multiple imputation to address missingness due to study attrition.

## Methods

### *Design*

Participants were enrolled into the Buckeye Teen Health Study from January 2015 through June 2016 and completed surveys every six months for two years. All participants were 11- to 16-years-old at baseline and male, as an aim of the parent study was to measure predictors of SLT use (which is more prevalent among males).[3] At baseline, participants lived in urban Franklin County, Ohio (N=708) or one of nine rural Appalachian Ohio counties (N=512); participants who moved out of a study county during the study were eligible to continue participation. Male youth were 14 years old on average at study enrollment and 69.2% were non-Hispanic white. Additional details about the cohort's demographics can be found elsewhere.[303,304] A majority of participants were recruited using address-based probability sampling (N=991), and the remainder

were recruited using convenience sampling methods (N=229), including newspaper advertisements, recruitment at community events, and flyers posted in the community. Only one male youth was eligible to participate in each household. Up to two parents or guardians (hereafter referred to as parents) could enroll in the study.

*Procedures*

The Ohio State University's Institutional Review Board approved all study procedures. Male youth provided assent, and their parents provided permission to enroll in the study. Boys who turned 18-years-old during the study period were re-consented to the study as adults. Parents who enrolled in the study provided informed consent.

The baseline and two-year follow-up sessions were completed in person at participants' homes or a mutually agreed-upon public location. Sensitive items (e.g., substance use) were administered via audio computer-assisted self-interviewing (ACASI), and the remaining items were interviewer administered. When permitted, youth were separated from their families when completing the ACASI portion of the questionnaire. The six-, twelve-, and eighteen-month follow-up surveys were administered over the phone. For sensitive items, youth were instructed to say the number associated with their response rather than stating their full response to protect their privacy (e.g., answering "B" instead of "menthol").

Parents completed a self-administered survey at baseline to provide additional information about the family's socioeconomic status and tobacco use in the home.

*Measures*

**Dependent variables**. Cigarette and SLT use were assessed at each survey using items from the Population Assessment of Tobacco and Health (PATH) study.[266] Participants were classified as ever cigarette smokers if they answered "yes" to the question: "Have you ever tried cigarette smoking, even one or two puffs?" They were classified as past 30-day cigarette smokers if the last time they smoked a cigarette, even one or two puffs, was in the past 30 days. Similarly, participants were classified as ever SLT users if they selected "yes" for: 1) snus pouches; or 2) loose snus, moist snuff, dip, spit, or chewing tobacco in response to the following question: "Have you ever used any of the following smokeless tobacco products, even one or two times?" They were classified as past 30-day SLT users if the last time they used snus or any other SLT product was in the past 30 days. Participants self-reported their age of first using cigarettes or SLT if they had ever used the product at baseline.

**Independent variables**. E-cigarette use was assessed at each survey using PATH items.[266] Participants were classified as ever e-cigarette users if they answered "yes" to the question: "Have you ever used an e-cigarette, such as Smoking Everywhere, NJOY, Blu, or Vapor King, even one or two times?" (These were popular e-cigarette brands at the time of data collection.) Participants self-reported their age of first using e-cigarettes if they had ever used them at baseline.

**Covariates**. Covariates used in the propensity score model (described below) included variables that were associated with e-cigarette use in the literature and could reasonably be assumed to precede initiation of e-cigarette use. These variables included birth year,[298] race (dichotomized to white non-Hispanic vs. other),[298] region (urban vs. Appalachian), parental education (college degree vs. less), living with at least one adult tobacco user (yes vs. no),[8] impulsivity[8] (mean sensation seeking score[267] [Cronbach's $\alpha$=0.70] and the natural log of delay discounting[268] k-score), and substance use that was initiated prior to e-cigarette use (other tobacco products, marijuana, and alcohol).[155,298] Baseline values of all sociodemographic and impulsivity measures were used in the propensity score models, as these were expected to be relatively stable. For substance use, all waves of data were used, when available, to determine whether the substance initiation occurred prior to e-cigarette use; tobacco use was assessed at each wave, marijuana use was assessed at baseline, and alcohol use was assessed at baseline and the 12-month follow-up.

Susceptibility to using tobacco products was also used in the imputation models and was measured at baseline and the 12-month follow-up. Susceptibility was assessed for each product by asking participants whether they would smoke/use the tobacco product soon and whether they would smoke/use the tobacco product if offered by a friend. Response options included "definitely yes," "probably yes," "probably not," and "definitely not." Any response other than "definitely not" to either item was coded as being susceptible to using the product. Results were combined across products to determine whether each participant was susceptible to any tobacco product (yes/no).

Male youth reported all covariate values except for region (assessed upon sampling), parental education, and tobacco use by adults in the household (both parent-reported).

*Statistical Analyses*

A sequence of statistical methods implemented during analysis is provided in Figure 3.

**Missing data**. There was a small proportion of item non-response for tobacco use and sociodemographic items (≤5%). These values were imputed using hot deck single imputation prior to the current study; see the Aim 1 Appendix for additional details. Item non-response was also observed for baseline alcohol use, marijuana use, and impulsivity measures (<9%). Moreover, item non-response and implausible values were observed for self-reported age of first using substances at baseline (e.g., reporting first using e-cigarettes at age 3). As hot deck single imputation had not already been performed, these missing values were imputed using multiple imputation by chained equations (MICE; imputation procedures described in detail below and in Aim 1 Appendix). Twenty-five multiple imputation datasets were created.

Unit nonresponse was a larger issue, especially as the study progressed. Retention was 92.7% at 6 months, 85.7% at 12 months, 82.5% at 18 months, and 73.4% at 24 months. Additional information about the missingness pattern and mechanism is provided in the Aim 1 Appendix. Missing data as a result of unit nonresponse were handled in three ways. First, in cases where non-use of a tobacco product or substance was reported

at a survey wave that came after the missing wave, this non-use was used to fill in the missing wave (e.g., a participant who said he had never used e-cigarettes on the 18-month survey but missed the 12-month survey would be re-coded to be a non-user at the 12-month time point). Second, ever use of a substance at an early wave was used to fill in ever use of the same product on later, unobserved waves. Third, MICE was completed to impute values that remained missing; 25 datasets were created. Multiple imputation was implemented for ever use of e-cigarettes, cigarettes, SLT, other tobacco products, alcohol, and marijuana across study waves. Current use of e-cigarettes, cigarettes, and SLT were also imputed for all waves, conditional on participants being an ever user of each respective product at each wave.

Propensity score estimation and matching, and all statistical analyses, were completed in the 25 imputed datasets. Results were combined following Rubin's method.[278]

**Propensity score model and matching**. Prior to the estimation of propensity scores, participants were classified into one of two exposure groups, which represented the dependent variable in the propensity score model: e-cigarette ever users and e-cigarette never users. Because we were estimating whether e-cigarette use increased the risk of initiating cigarette smoking and SLT use, e-cigarette use had to precede initiation of cigarettes or SLT for one to be included in the exposed group. Thus, the e-cigarette users group included participants who reported e-cigarette use when they had not already initiated cigarette smoking (for the cigarette incidence models) or SLT use (for the SLT

incidence models); participants who had initiated both e-cigarettes and cigarettes/SLT at baseline were classified as e-cigarette users if their self-reported age of first using e-cigarettes was younger than that of cigarettes/SLT. The e-cigarette non-users group included participants who never reported e-cigarette use or reported e-cigarette initiation after they had already begun using cigarettes/SLT. Participants who initiated e-cigarettes and cigarettes/SLT at the same age or survey wave were excluded from analyses and not assigned propensity scores, as temporality of product initiation could not be established.

Multivariable logistic regression models including the covariates described above were used to estimate the probability of each participant being an e-cigarette user (e.g., their propensity score). All time points were used to ascertain e-cigarette, cigarette, and SLT use. In other words, participants who had initiated e-cigarettes any time through the 18-month follow-up were classified as e-cigarette users as long as they did not initiate use of cigarettes or SLT first. Although propensity scores were estimated in the same way for cigarette and SLT analyses, participants were assigned separate propensity scores for cigarette and SLT analyses due to the possibility that they would be classified into different exposure groups as a result of the temporality of their product use.

After propensity scores were estimated, common support was visually assessed by inspecting histograms of propensity scores, stratified by e-cigarette user status. This was done to ensure that there would be an adequate count of e-cigarette non-users to match to e-cigarette users. Next, pre-match absolute standardized differences (ASDs) were calculated to determine the extent of imbalance for each covariate according to e-cigarette user status prior to matching. The propensity score match was then completed,

with each e-cigarette user being matched to two e-cigarette non-users. An optimal matching algorithm and linear propensity score distance were used to complete the match. After the match was completed, ASDs for each covariate were again calculated, stratified by e-cigarette user status. *A priori*, post-match ASD values <0.10 for all covariates indicated an acceptable match.[279] Propensity score estimation and matching were completed using RStudio version 1.1.383.[305] The packages "MatchIt" and "optmatch" were used for the propensity score match.

**Statistical analysis**. Generalized linear models with log links were used to estimate risk ratios (RRs) comparing the risk of: 1) ever cigarette use; 2) past 30-day cigarette use; 3) ever SLT use; and 4) past 30-day SLT use according to e-cigarette user group. Because the dependent variables were initiation of cigarettes or SLT at any age or survey wave, we did not do a repeated measures analysis. Models were run in the 25 matched datasets; participants who were not matched were excluded from all analyses (analytic sample sizes are reported in the Results section). Any covariate that remained imbalanced after the propensity score match, as indicated by an ASD value > 0.1, would be included in the final models to control for residual confounding. An alpha value of 0.05 was used to assess statistical significance. Statistical analyses were completed using SAS version 9.4.[292]

*Sensitivity Analysis*

We conducted a complete case analysis using participants who were compliant at all five time points and were not missing data for variables in the propensity score model. A 1:2 propensity score match was also completed in this dataset and generalized linear models with log links were used to estimate RRs as in the analysis using multiple imputation.

## Results

The analytic sample size across the imputed datasets after the propensity score match ranged from 348 to 387 for cigarette incidence analyses (N=116 to 129 e-cigarette users; N=101 to 126 initiated cigarette ever use) and from 435 to 486 for SLT incidence analyses (N=145 to 162 e-cigarette users; N=108 to 131 initiated SLT ever use). The difference in sample sizes between cigarette and SLT analyses was due to more participants initiating e-cigarettes and cigarettes at the same age and therefore being removed from the analysis.

Pre-match, there was sufficient common support in propensity scores by e-cigarette user group (Figure 4), and thus all e-cigarette users in each dataset were able to be matched to two e-cigarette non-users. Pre-match, there was notable imbalance in the distribution of several covariates between e-cigarette users and non-users: use of other tobacco products, use of marijuana, sensation seeking mean score, and birth year according to e-cigarette use (all ASD values > 0.2; Table 1). Post-match, acceptable

covariate balance was achieved in both the cigarette and SLT incidence analytic samples (Table 2).

Although covariates were well balanced by e-cigarette use, there were some differences in characteristics of the final analytic samples for cigarette and SLT incidence analyses (Table 2). For example, the proportion of participants living in Appalachia was greater in the cigarette incidence analytic sample. The proportions of participants who were of minority race/ethnicity, marijuana users, and other tobacco product users were higher in the SLT incidence analytic sample.

*Risk of Cigarette and SLT Initiation*

Compared to male youth who never used e-cigarettes, those who used e-cigarettes were more than twice as likely to subsequently initiate ever cigarette smoking (RR=2.71; 95% confidence interval [CI]: 1.89, 3.87) and ever SLT use (RR=2.42; 95% CI: 1.73, 3.38; Figure 5). Moreover, they were at increased risk of becoming past 30-day cigarette smokers (RR=2.20; 95% CI: 1.33, 3.64) and SLT users (RR=1.64; 95% CI: 1.01, 2.64).

*Complete Case Analyses*

All e-cigarette users were able to be matched to two non-users in the complete case analyses. The total sample size was 135 in cigarette incidence analyses and 156 in SLT incidence analyses. Acceptable balance was achieved for all covariates (results not shown), with the exception of living with an adult tobacco user in the cigarette incidence analytic dataset (ASD=0.12) and natural log of K-score in the SLT incidence analytic dataset (ASD=0.11). Because these values were close to the *a priori* ASD cut-off of 0.10,

and to more directly compare results between the complete case analyses and imputed analyses, these covariates were not included in the final models.

Compared to the results from the imputed analyses, point estimates for all complete case analyses were attenuated toward the null (Table 3). This, combined with the reduced power driven by study attrition, led to no statistically significant findings.

## Discussion

E-cigarette use increased the risk of initiating both cigarettes and SLT in a cohort of adolescent boys who were balanced on risk factors for e-cigarette use. Additionally, e-cigarette use increased the risk of having smoked cigarettes or using SLT in the past 30 days, which indicates more regular tobacco use among adolescents. We therefore add to the growing literature that has demonstrated that e-cigarette use increases the risk of using other tobacco products among adolescents in the U.S.

A causal link between e-cigarette use and onset of cigarette smoking or SLT use is plausible physiologically and behaviorally. Physiologically, nicotine addiction and dependence as a result of exposure to nicotine in e-cigarette liquid is a mechanism through which e-cigarette use could plausibly lead to cigarette smoking and SLT use.[93] This assertion is supported by evidence that use of other tobacco products has also been associated with onset of cigarette smoking among adolescents, including hookah, other non-cigarette combustible tobacco products, and SLT.[296] Behaviorally, the actions involved in vaping e-cigarettes are similar to those involved in smoking cigarettes. Thus, hand-to-mouth movement, puffing, and inhalation/exhalation habits can be established

among e-cigarette users, even in the absence of nicotine, due to consistent repetition of these behaviors that becomes automatic.[306] Moreover, the establishment of these behaviors could lead to more positive expectancies related to cigarette smoking, which mediates the association between e-cigarette use and cigarette smoking onset.[307]

Our findings that e-cigarette-using adolescents, who were otherwise similar to e-cigarette non-users, were more likely to progress to cigarette smoking and SLT use have serious public health implications. First, in addition to the respiratory health consequences of vaping among youth,[87–89] there is emerging evidence that e-cigarette use is associated with poor cardiovascular health among adults.[308] Second, youth who become addicted to nicotine will have to deal with the chronic condition of addiction.[309] Finally, the U.S. has made steady progress in reducing the prevalence of cigarette and SLT use among adolescents since 2011.[3] The health consequences of using both products have been well established for decades, and cigarettes remain the leading preventable cause of death in the U.S.[1] If e-cigarettes do in fact lead more adolescents to using these harmful tobacco products, the burden of tobacco on the public's health will remain high.

*Strengths and Limitations*

One strength of the current study was the use of multiple imputation to address attrition, which retained adolescents at high risk of tobacco use in the analyses. The complete case analyses demonstrated that excluding these participants biased the estimated RRs toward the null. This bias likely occurred because baseline ever and current tobacco use, as well as predictors of tobacco use among adolescents like

substance use and living with an adult tobacco user,[8,155] were strongly associated with study attrition. In other words, our sample after study attrition was at much lower risk of tobacco use overall, and therefore the e-cigarette users who remained in the study likely had a lower probability of transitioning to using a second tobacco product than those who dropped out. Moreover, the sample size was much smaller, resulting in reduced power to detect differences in risk of cigarette/SLT initiation by e-cigarette exposure group.

A second strength of our study was the use of a propensity score matched analysis to estimate risk of cigarette and SLT initiation by e-cigarette exposure group, which enabled us to demonstrate that the transitions from e-cigarette use to cigarette and SLT use were not solely the result of a common liability for using tobacco products. A third strength was our large pre-match sample size, which supported our ability to match every e-cigarette user to two non-users in all 25 imputed datasets and achieve good post-match covariate balance. A fourth strength was the longitudinal study design, which collected data every six months from participants for two years, and additionally allowed us to retrospectively evaluate whether youth who entered the study as dual users of e-cigarettes and cigarettes/SLT had used e-cigarettes first. This allowed us to keep higher risk youth who initiated tobacco use at earlier ages in the analysis.

There were also several limitations of the current study, which can be addressed in future work to strengthen the evidence base on this topic. The first limitation was that girls were excluded because the objective of the parent study was to examine SLT use, which is more prevalent among adolescent males.[3] Given differences in the prevalence of and risk factors for tobacco use according to sex,[3,111] we cannot assume the same results

would be found among girls. The second limitation was that our participants were sampled from Ohio, and so results might not generalize to male youth in the rest of the U.S. A third limitation was coarseness of measuring age of product use, which resulted in excluding some e-cigarette users from analyses due to our inability to establish temporality of product use. Given the rapid transitions between products that can occur among adolescent tobacco users,[310] future work with more frequent follow-ups would be useful.

A fourth limitation was that we could not include every important predictor of e-cigarette use in the propensity score model. Notably, we could not include peer use of tobacco or mental health symptoms in the propensity score model because we could not discern whether those exposures were prior to e-cigarette use for participants who entered the study as e-cigarette users. For other exposures in our propensity score model (i.e., region, parental education, tobacco use by adults in the household, and impulsivity) we had to assume that the values of these variables were the same as they were prior to the participant's initiation of e-cigarette use. For region, the urban vs. Appalachian status was also a coarse measurement, as the Appalachian region has heterogeneity in urbanicity and rurality, as well as risk factors for tobacco use like area socioeconomic status.[193] Relatedly, the propensity score analysis only balanced observed covariates, and thus unmeasured confounding remained a potential source of bias.

A fifth limitation was that, because we were restricted to using ever e-cigarette use as the exposure variable (because we only knew the age that participants became ever users), we were unable to conduct detailed analyses that would have more direct policy

implications. For example, preference for flavored e-cigarettes among adolescents has been associated with more frequent e-cigarette use[311] and cigarette smoking susceptibility[312] among adolescents. Because we did not ascertain the age that participants used the e-cigarette flavors they had tried, and therefore could not determine whether flavored e-cigarette use preceded cigarette or SLT use among dual users, we were unable to examine whether e-cigarette flavor preferences increased risk of cigarette or SLT use. Findings of such research could be used to justify banning flavors of e-cigarettes to prevent tobacco use among youth. Similarly, although participants reported where they acquired tobacco products (e.g., from a retailer, from a friend or family member, online, etc.), these measures were only obtained from past 30-day tobacco users rather than all users of each product. In future work, knowledge of where participants obtained their tobacco products could be used to support T21 policy implementation.

*Conclusion*

This study identified that e-cigarette use increased the risk of ever and past 30-day cigarette smoking and SLT use initiation among adolescent boys. E-cigarettes pose a public health threat, not only due to the health risks associated with their use, but also because they may lead more adolescents to using cigarettes and SLT. Future work that uses a causal framework to evaluate transitions into established tobacco use in adulthood is warranted.

Tables and Figures

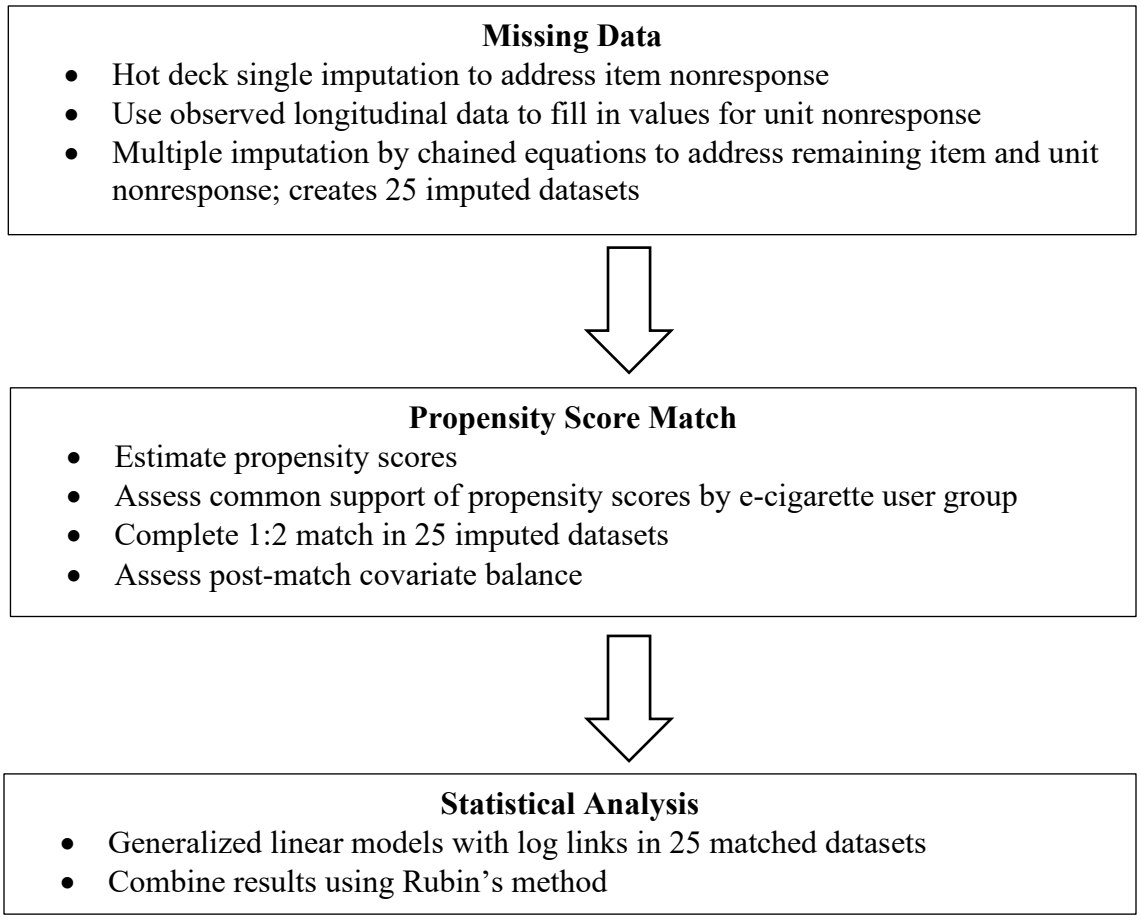


**Figure 3.** Sequence of statistical method implementation

**Table 1**. Pre-Match ASD Values Across 25 Imputed Datasets[a]

| | Cigarette incidence analyses | SLT incidence analyses |
|---|---|---|
| Region | 0.08 | 0.15 |
| Birth year | 0.70 | 0.73 |
| Adult tobacco user in household | 0.19 | 0.16 |
| Parental education | 0.02 | 0.14 |
| Race/ethnicity | 0.10 | 0.18 |
| Sensation seeking score | 0.71 | 0.70 |
| Natural log of K-score | 0.11 | 0.04 |
| Alcohol use | 0.08 | 0.12 |
| Marijuana use | 0.05 | 0.31 |
| Other tobacco use | 0.18 | 0.51 |

Abbreviations: ASD=Absolute standardized difference

[a] Data were collected from adolescent males in urban and Appalachian Ohio. Hot deck single imputation and multiple imputation by chained equations were used to impute missing data due to item and unit nonresponse. ASD values reported in this table were first calculated individually within each of the 25 imputed datasets, and then were averaged across the datasets.

**Table 2.** Characteristics of Ohio adolescent boys included in propensity score matched analysis, 2015-2018[a]

| | Cigarette incidence analyses | | | SLT incidence analyses | | |
|---|---|---|---|---|---|---|
| | E-cigarette ever users | E-cigarette never users | Post-match ASD | E-cigarette ever users | E-cigarette never users | Post-match ASD |
| Appalachian region (%) | 45.2 | 45.2 | 0.03 | 35.3 | 37.8 | 0.05 |
| Birth year (mean) | 2000.4 | 2000.4 | 0.03 | 2000.4 | 2000.4 | 0.03 |
| Adult tobacco user in household (%) | 39.7 | 38.3 | 0.05 | 38.0 | 37.1 | 0.03 |
| Parent graduated college (%) | 54.4 | 54.4 | 0.04 | 48.1 | 49.8 | 0.04 |
| Minority race/ethnicity (%) | 20.0 | 20.4 | 0.03 | 30.8 | 29.0 | 0.04 |
| Sensation seeking score (mean) | 3.37 | 3.35 | 0.03 | 3.35 | 3.31 | 0.04 |
| Natural log of K-score (mean) | -4.03 | -4.04 | 0.05 | -4.12 | -4.14 | 0.03 |
| Alcohol use (%) | 23.7 | 23.1 | 0.04 | 25.4 | 26.0 | 0.03 |
| Marijuana use (%) | 7.3 | 8.1 | 0.04 | 16.3 | 13.6 | 0.08 |
| Other tobacco use (%) | 20.8 | 20.7 | 0.03 | 33.4 | 28.8 | 0.09 |

Abbreviations: ASD=Absolute standardized difference

[a] Data were collected from adolescent males in urban and Appalachian Ohio. Hot deck single imputation and multiple imputation by chained equations were used to impute missing data due to item and unit nonresponse. Summary statistics and ASD values reported in this table were first calculated individually within each of the 25 imputed datasets, and then were averaged across the datasets. Due to rounding of descriptive statistics, some ASD values are greater than 0 when there appears to be no difference in balance of covariates.

**Table 3.** Risk of cigarette and SLT initiation for e-cigarette users compared to non-users estimated from a propensity score matched, complete case analysis, Ohio, 2015-2018[a]

| | Incident Cigarette Smoking | | | | Incident SLT Use | | | |
|---|---|---|---|---|---|---|---|---|
| | Ever use | | Past 30-day use | | Ever use | | Past 30-day use | |
| | RR | 95% CI | RR | 95% CI | RR | 95% CI | RR | 95% CI |
| E-cigarette use | | | | | | | | |
| Never | Ref | | Ref | | Ref | | Ref | |
| Ever | 2.22 | 0.90, 5.47 | 1.25 | 0.41, 3.82 | 1.67 | 0.72, 3.86 | 1.56 | 0.58, 4.18 |

Abbreviations: RR=Risk ratio; CI=confidence interval

[a] Data were collected from adolescent males in urban and Appalachian Ohio. RRs and standard errors for confidence intervals were estimated following propensity score matching using a generalized linear model with a log link.

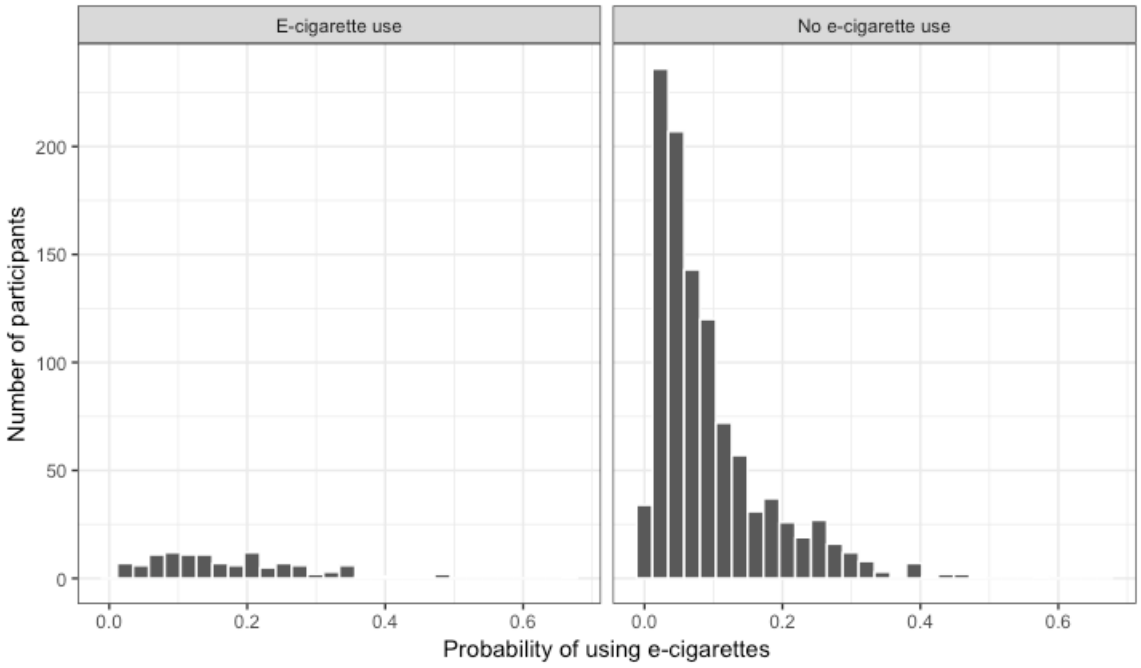


**Figure 4**. Assessment of Common Support in First Imputed Dataset[a]

[a] Common support histograms were consistent across imputed datasets.

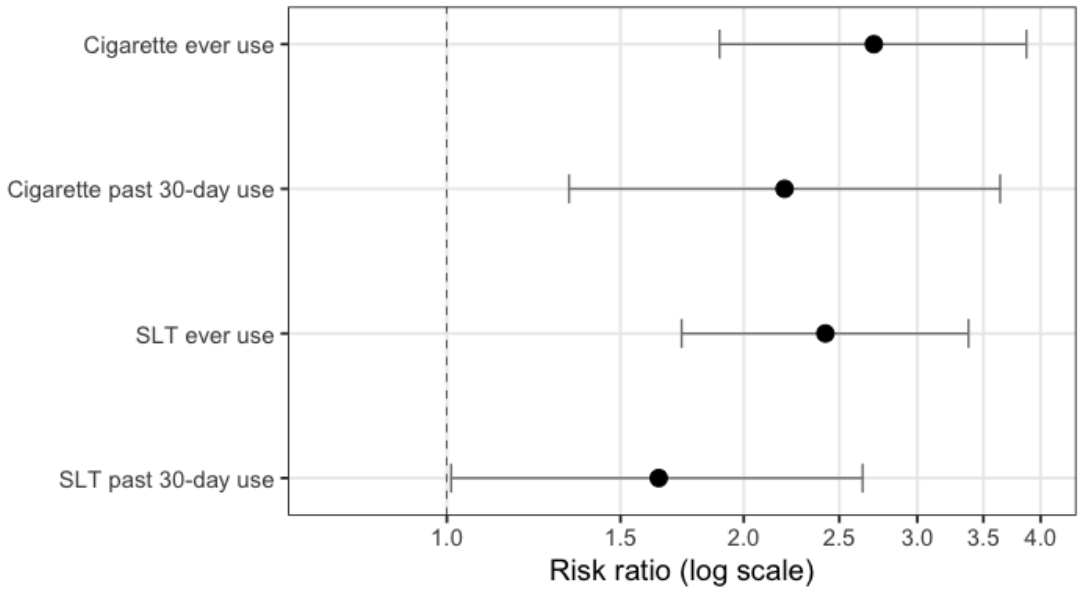


**Figure 5.** Risk of cigarette and SLT initiation for e-cigarette users compared to non-users estimated from a propensity score matched analysis in 25 imputed datasets, Ohio, 2015-2018[a]

[a] Data were collected from adolescent males in urban and Appalachian Ohio. Hot deck single imputation and multiple imputation by chained equations were used to impute missing data due to item and unit nonresponse. RRs were estimated following propensity score matching in 25 imputed datasets using a generalized linear model with a log link. RRs and standard errors used to calculate confidence intervals across the 25 imputed datasets were obtained using Rubin's method.[278]

Supplementary Material

*Aim 1 Appendix: Missing Data and Imputation Procedures*

*Item nonresponse.* For the hot deck single imputation of missing baseline items, participants were stratified by age at enrollment (11-12, 13-14, and 15-16 years), region, and household adult tobacco use. This imputation was done prior to the current study, and imputed values were left to be consistent with prior work. Hot deck single imputation was completed using SAS version 9.4.[292]

For the multiple imputation of missing baseline items, logistic regression models were used to impute substance use variables, and linear regression models were used to impute the impulsivity measures and ages of first using tobacco products.

*Unit nonresponse.* Participants were not removed from the study due to missing a survey wave, and thus the missing data pattern was not monotonic. Study attrition was associated with several observed covariates, including non-white race, lower parental education, living with an adult tobacco user, Appalachian region, alcohol use, marijuana use, and any tobacco product use. Because of this, we assumed unit nonresponse was missing at random (i.e., missingness was associated with observed rather than unobserved variables).

To be consistent with the analytic model, the imputation model included all covariates used in the propensity score model.[275] Susceptibility to using tobacco products was also added to the imputation model due to its association with initiating tobacco use.[298] Logistic regression models were used for the imputation, and 25 datasets were created. MICE was completed using Stata version 14.2.[313]

# Chapter 4. Perceived Neighborhood Quality and Risk of Tobacco Use Among Adolescent Boys: A Longitudinal Study


## Abstract

**Introduction.** As the prevalence of traditional tobacco product (e.g., cigarettes, cigars, and smokeless tobacco) use continues to decrease among adolescents in the United States, the prevalence emerging tobacco product (i.e., e-cigarettes and hookah) use has increased. Most of the investigation into risk factors for using traditional and emerging tobacco products has occurred at the individual and interpersonal levels of influence. Applying the social ecological model framework, the current study includes the neighborhood-level and evaluates the effects of four measures of perceived neighborhood quality (i.e., safety, social disorder, physical disorder, and cohesion) on adolescents' risk of initiating traditional and emerging tobacco products.

**Methods.** Adolescent boys (11- to 16-years-old; N=1220) and their parents from urban and Appalachian Ohio enrolled in a longitudinal study in 2015 and 2016. Boys reported ever use of traditional and emerging tobacco products at baseline (including the age they initiated use of each product) and every six months for two years. Parents reported the perceived quality of the neighborhood boys lived in when they were 10 years old. Cox proportional hazards regression modeled the risk of initiating ever use of traditional and

emerging tobacco products from age 10 through the end of adolescence, controlling for race, parental education, tobacco use by adults in the household, and region.

**Results.** Measures of perceived neighborhood quality were obtained for N=542 boys. Among these boys, parents' perceptions of neighborhood physical disorder at age 10 (e.g., presence of litter, graffiti, and vacant buildings) was associated with increased risk of initiating traditional tobacco products throughout adolescence (hazard ratio = 2.01; 95% confidence interval: 1.09, 3.79). No other measures of perceived neighborhood quality were associated with initiating traditional or emerging tobacco product use.

**Conclusion.** Living in a more physically disordered neighborhood during middle childhood increased adolescent boys' risk of initiating traditional tobacco products. This study's findings were limited by the large amount of attrition of parent participants, which reduced our power and resulted in a cohort that was at reduced risk of tobacco use overall. Results suggest that interventions and policies that target youth living in more physically disordered neighborhoods may reduce their risk of initiating traditional tobacco products.

## Background

Over the past few years, the tobacco products used by adolescents in the United States (U.S.) have changed rapidly. While the prevalence of cigarette, cigar, and smokeless tobacco (SLT) use among high school students has declined from 2011 to 2018, the prevalence of electronic cigarette (e-cigarette) use increased from 1.5% to 20.8%, and the prevalence of hookah smoking remained fairly stable after spiking in

2014.[3,6] The pattern was similar for middle school students, although the prevalence of hookah smoking increased from 2011 to 2018.[3,6] Thus, progress is being made toward reducing the use of traditional tobacco products (i.e., cigarettes, cigars, and SLT) among adolescents in the U.S. at the same time that use of emerging tobacco products (i.e., e-cigarettes and hookah, which has been historically used in other cultures but is new to the U.S. marketplace) has increased.

Use of any tobacco product by adolescents has health consequences. Symptoms of nicotine dependence begin to emerge even at low levels of tobacco use,[84] and use of cigarettes, SLT, e-cigarettes, and hookah have been associated with onset of nicotine dependence symptoms during adolescence.[90–93] Importantly, early age of initiation has been associated with increased symptoms of nicotine dependence.[94] Exposure to nicotine during adolescence can adversely affect the functioning of nicotinic acetylcholine receptors in the developing brain, which are involved in emotional regulation, executive function, and reward processing.[11] Alterations to adolescent brain development, in turn, may be associated with the increased risk of depression and anxiety that have been reported among adolescent tobacco users.[72] Use of cigarettes and e-cigarettes has also been associated with adverse respiratory symptoms[14,87] and asthma[56,314] among adolescents.

The social ecological model, a framework describing how multiple levels of influence affect health behaviors, can be used to describe adolescents' risk of tobacco use.[16] Under this framework, risk factors for use of emerging and traditional tobacco products occur at the individual, interpersonal, neighborhood, and policy levels of

influence. Regarding individual- and interpersonal-level risk factors, older age (within adolescence),[3] male sex,[108,109] other substance use,[144,315] and peer and family use of tobacco[8,171] increase risk of using both emerging and traditional tobacco products. Moreover, lower parental education, a proxy for lower socioeconomic status (SES), has been associated with risk of cigarette smoking among adolescents,[119–121] although studies of its association with use of emerging tobacco products have had inconsistent findings.[90,110,123] Race/ethnicity is another individual-level factor that appears to have different associations with use of traditional vs. emerging tobacco products among adolescents in the US. For example, e-cigarettes were the most-used tobacco product among white non-Hispanic and Hispanic high school students in 2017 and 2018.[3,6] Those same years, cigars were the most-used tobacco product among black non-Hispanic high school students.[3,6]

Neighborhood-level risk factors can be examined using objective measures (e.g., census tract indicators of SES) or perceived measures (e.g., self-reported disorder and cohesion) of neighborhood quality. Regarding the objective measures, studies of their association with tobacco use among adolescents have had mixed results. Some studies have concluded that adolescents who live in socioeconomically disadvantaged census tracts are not at increased risk of using tobacco,[104,211,212] while others have found the opposite.[28,213] Regarding studies of the effect of perceived neighborhood quality on tobacco use, higher levels of neighborhood disorganization and lower levels of neighborhood cohesion have been associated with higher odds of cigarette and e-cigarette use among youth.[104] Additionally, adolescents who lived in neighborhoods that their

parents perceived to be low quality were more likely to be regular cigarette smokers than other adolescents.[103] At least one study, however, concluded that adolescents who lived in adult-perceived lower quality neighborhoods were not more likely to use tobacco.[211]

The existing literature into the effects of neighborhood quality on adolescent tobacco use outcomes is limited in that: 1) prevalent rather than incident tobacco use is typically modeled, and 2) most research has only focused on cigarette smoking. The former is a limitation because it prevents examining more nuanced questions, such as whether certain neighborhood characteristics are associated with earlier initiation of tobacco products. This question is important because earlier use of nicotine products results in a greater likelihood of continued tobacco use in adulthood.[85] Moreover, when modeling prevalent rather than incident tobacco use, the study can only answer the question of whether tobacco use was initiated within a specified age range. As existing research typically classifies participants as tobacco users based on their use in the past year or past 30 days,[103,104] participants who initiated tobacco use before enrolling in the study but are intermittent users would not be counted as tobacco users.

Failure to study neighborhood-level risk factors for using non-cigarette tobacco products is a limitation because adolescents use a variety of tobacco products.[3] Given the observed discrepancies in individual-level risk factors (e.g., SES and race) for traditional vs. emerging tobacco use, it is possible that there are also differences in neighborhood-level risk factors for the use of these products among adolescents. This is also a limitation because, in the current U.S. regulatory environment, cigarillos and little cigars can typically be obtained for a lower price and in more flavors than cigarettes (in most

municipalities)—potentially making them more appealing to adolescents.[316] Moreover, lower-SES communities tend to have cheaper priced tobacco products,[30] making them more appealing to price-sensitive adolescents. Finally, failure to include SLT use when estimating associations between the neighborhood environment and use of tobacco ignores a product that is more prevalently used in rural and Appalachian areas,[198] which continue to have stubbornly high rates of tobacco use.[197]

*Theoretical Framework*

The current study can be organized using two theoretical frameworks—one more general and one more specific to the research question. The social ecological model, as described above, is the more general framework.[16] For this study, we are primarily interested in how qualities of the community (in this case, the neighborhood) that adolescents lived in during middle childhood (i.e., age 10) affect their risk of initiating emerging and traditional tobacco products through adolescence. Because individual-level characteristics such as race and SES are strongly associated with neighborhood characteristics and are also, on their own, associated with the risk of using emerging and traditional tobacco products, they will be included in all analyses. Similarly, parental tobacco use, a risk factor at the interpersonal level, is both associated with a family's SES (and thus its neighborhood) and an adolescent's tobacco use outcomes, and therefore it is important to control for.

The theoretical framework more specific to the current study is Diez Roux and Mair's model for neighborhood social control's effect on health behaviors which

connects the neighborhood environment to the manifestation of disparate health outcomes (Figure 6).[317] This study investigates the association between the *neighborhood social environment* and tobacco use (i.e., a *behavioral mediator*) that leads to disparate health outcomes. In particular, we are interested in whether parents' perceptions of social control in their child's neighborhood at age 10 (operationalized through the constructs of safety, social disorder, and physical disorder,) are associated with initiation of tobacco use among adolescents. These aspects of neighborhood may relate to adolescent substance use initiation through stress. The stress reduction hypothesis suggests that adolescents may use substances (e.g., tobacco) to cope with stress from their environments.[318] Moreover, these measures ultimately describe a lack of neighborhood social control that can result from lower neighborhood SES.[317] Lower SES neighborhoods tend to have a higher prevalence of adult tobacco use[122] and a higher density of tobacco retailers,[32] which additionally put adolescents at increased risk of tobacco initiation via increased perceived accessibility of tobacco products[38] and social norms promoting tobacco use.[40]

The construct of *cohesion*, which includes measures of trust, shared values, and willingness to help one's neighbors may relate to adolescent tobacco use initiation through collective efficacy. Collective efficacy theory suggests that closeness and shared trust among community members buffers adolescents against participating in harmful behaviors, such as tobacco use.[272] This buffering occurs via community members monitoring youth activities, taking action when youth participate in delinquent activities, and advocating for resources to promote healthier choices for youth.[272] Thus, high levels

of neighborhood cohesion may be protective against adolescent tobacco use due to adults intervening when they notice youth using tobacco and advocating for community policies to make tobacco less attractive or more difficult to obtain by youth.

Together, we expect that adolescents who live in communities that are perceived to have poorer safety and cohesion, and greater social and physical disorder, will ultimately have a greater risk of using tobacco products. Due to the relative newness of e-cigarettes and hookah relative to cigarettes, cigars, and SLT, and the differences in risk factors that occur at other levels of the social ecological model (i.e., one's SES and race), we will examine risk of using these products separately.

### *Aims*

To address limitations of the existing literature and test the proposed theoretical framework, the aims of the current study were to estimate the associations between perceived neighborhood quality at age 10 and short-term risk of initiating 1) emerging tobacco products, and 2) traditional tobacco products among adolescent boys.

## Methods

### *Setting and Participants*

Male youth ages 11- to 16-yearswere recruited from urban Franklin County, Ohio (N=708) or one of nine rural, Appalachia Ohio counties (N=512). Only boys were eligible to participate because an aim of the parent study was to measure predictors of SLT initiation, and the prevalence of SLT use among girls in the U.S. is quite low.[3] A

majority of households (N=991) were recruited via probability address-based sampling; the remainder (N=229) were recruited via convenience sampling methods. In households where more than one male youth was eligible to participate, the one who had the most recent birthday was selected. In addition to age and residency requirements, boys had to have the capacity to complete study procedures (e.g., cognitive, vision, and hearing abilities) to enroll.

Up to two parents or caregivers (hereafter referred to as "parents") were permitted to enroll in the study (N=1847). They provided additional information about household socioeconomic status, tobacco use by household members, and the perceived quality of male youths' neighborhoods at age 10. Eligibility criteria included living in the same household as the boy and serving as a caregiver of the boy if not a parent or guardian (e.g., a grandparent).

*Procedures*

For the male youth cohort, data were collected at baseline via audio computer assisted self-interviewing (ACASI) and interviewer administered questionnaires. ACASI was used to administer sensitive items, such as substance use, and male youth completed these items in a room by themselves when permitted. Less sensitive items, like demographics and delay discounting, were interviewer administered.

Follow-up data were collected from male youth at 6, 12, 18, and 24 months post-baseline. The 6- through 18-month follow-up surveys were administered over the telephone. To protect participants' privacy, participants were instructed to say the letter

that corresponded with their response rather than their actual response (e.g., "B" instead of "menthol"). At the 24-month follow-up, most participants repeated the in-person data collection procedures from baseline (86.9%). To complete follow-ups with as many boys as possible, phone surveys were used at this time point as well for participants who had moved too far away to feasibly complete an in-person interview or were too busy to complete the longer in-person session. The telephone version of the 24-month follow-up survey collected the same tobacco use items that were needed for the current study, and so their data were included in all analyses.

For the parent cohort, data were collected at baseline via a self-administered paper-and-pencil survey. Parents completed follow-up surveys 12, 24, and 36 months post-baseline via telephone; only 24- and 36-month follow-up data were used for the current study, as these time points included items measuring perceived quality of the male youths' neighborhoods at age 10.

The Ohio State University Institutional Review Board approved all study procedures. Male youth provided assent and their parents or legal guardians provided permission. Boys who turned 18-years-old during the study were re-consented to study procedures as adults. Parents provided consent to be interviewed.

*Measures*

**Dependent variables.** Dependent variables included ever (i.e., lifetime) use of: 1) emerging and 2) traditional tobacco products (yes vs. no). Emerging tobacco products included e-cigarettes, which are a relatively new tobacco product, or hookah, which is

new to the U.S. Traditional tobacco products included cigarettes, SLT, traditional cigars, or cigarillos/little cigars (hereafter referred to as cigars). Ever use of each tobacco product was assessed at all time points. Ever use of inhaled tobacco products (i.e., cigarettes, e-cigarettes, cigars, and hookah) was assessed with the following item: "Have you ever tried [tobacco product], even one or two puffs?" For SLT, the item was asked separately for snus and other forms of SLT, like dip or chewing tobacco, with the following item: "Have you ever used any of the following smokeless tobacco products, even one or two times?" Responses to the e-cigarette and hookah ever use items were collapsed into the outcome variable for emerging tobacco use (used either product vs. used neither product). Responses to the cigarette, snus/SLT, cigars items were collapsed into the outcome variable for traditional tobacco use (used any products vs. used no products).

Age of initiating an emerging or traditional tobacco product was ascertained in two ways, depending on when the participant started to use the product. For participants who had initiated tobacco use prior to enrolling in the study, their self-reported age of first use was used. When they had already initiated more than one emerging or more than one traditional tobacco product at baseline, the earliest age of first use was used. For participants who reported initiating tobacco use on a follow-up survey, their age when completing the survey was included in the analyses. When participants never initiated emerging or traditional tobacco products, their age at the 24-month follow-up was used as the censoring age in analyses.

**Independent variables.** Independent variables included parent-reported ratings of perceived safety,[269,270] social disorder,[271] physical disorder,[271] and cohesion[272] of male

youths' neighborhoods at age 10 years (Table 4). These items were added to the parents' 24- and 36-month follow-up surveys after data collection had begun. Because each wave of data collection spanned 18 months, no parents completed the items on both follow-up surveys. Only parents who lived with the male youth participant when was he was 10 years-old were eligible to answer the perceived neighborhood quality items. In cases where both parents answered the items, one parent's responses were randomly selected to be used in analyses.

Prior to analyses, a confirmatory factor analysis (CFA) was completed to confirm that the model with four latent variables acceptably fit the data. For the CFA, items were re-scored to have higher values represent higher quality neighborhoods (i.e., more safe/cohesive and less socially/physically disordered). *A priori*, root mean square error of approximation (RMSEA) $< 0.06$, comparative fit index (CFI) $\geq 0.95$, and Tucker-Lewis index (TLI) $\geq 0.95$ were the criteria to establish acceptable model fit. CFA was completed using the lavaan package in RStudio version 1.1.383.[305,319]

Following the CFA, mean scores of items on each scale were calculated to create one continuous variable representing each scale to be used in analyses. To improve the interpretability of model coefficients, items on the social and physical disorder scales were re-scored so that higher averages represented more socially and physically disordered neighborhoods. The scoring of the safety and cohesion scales were not changed following the CFA.

**Covariates.** Variables that could confound the association between perceived quality of participants' neighborhood at age 10 and initiation of emerging or traditional

tobacco products were included in all analyses. Confounding variables were selected using a directed acyclic graph (Figure 7). Variables included race (white non-Hispanic, black non-Hispanic, and other), region (urban vs. Appalachia), parental education (college education vs. less), and tobacco use by any adult in the household (yes vs. no). All confounding variables were measured at baseline and were treated as time-constant covariates. Race was self-reported by male youth, region was recorded at sampling, and parental education and adult tobacco use in the household were reported by parents.

Additional variables were used in the imputation model for imputing missing tobacco use outcomes due to unit nonresponse (detail is provided below). These variables were included due to their strong association with either unit nonresponse or tobacco initiation. Variables included birth year, sensation seeking[267] mean score (Cronbach's alpha = 0.70), log of delay discounting k-score,[268] ever alcohol use, ever marijuana use, and susceptibility to using tobacco. Susceptibility to using tobacco was assessed separately for each product by asking participants who had never used the product whether they would smoke/use each tobacco product soon and if they would smoke/use each tobacco product if offered by a friend. Response options included "definitely yes," "probably yes," "probably not," and "definitely not." Any response other than "definitely not" to either item was coded as being susceptible to using the product. Results were combined across categories of emerging and traditional tobacco products to identify participants who were susceptible to using any emerging or traditional tobacco products, respectively. All variables were measured at baseline. Susceptibility to using tobacco was re-assessed at 12-months, which was used to impute 18- through 24-month ever tobacco

use outcomes. Ever alcohol use was re-assessed at 12 and 24 months. Ever marijuana use was re-assessed at 24 months. Follow-up measures of alcohol and marijuana use were used to impute tobacco use outcomes at concurrent and subsequent time points.

### *Missing Data*

**Item nonresponse.** Item nonresponse was observed for a small proportion of tobacco use and sociodemographic variables at baseline and follow-up (≤5% missing). Missing data for tobacco use variables, race, parental education, and tobacco use by adults in the household were imputed using hot deck single imputation. Stratification variables included age at enrollment (11-12, 13-14, and 15-16 years), region, and household adult tobacco use. Hot deck imputation was completed using SAS version 9.4.[292]

Other covariates that were needed to impute missing tobacco use items due to unit nonresponse (described below) were missing a small proportion of data themselves due to item nonresponse. These covariates included sensation seeking mean score, log of delay discounting k-score, and ever use of alcohol and marijuana (all <8% missing). Some participants also reported implausible ages of first using tobacco (i.e., < 6-years-old), and these values were set to missing. Multiple imputation by chained equations (MICE) was completed to impute these values in five datasets. Items in the imputation model included birth year, race, region, parental education, adult tobacco use in the household, susceptibility to emerging and traditional tobacco products, and prior use of emerging

and traditional tobacco products. Linear regression was used to impute continuous variables, and logistic regression was used to impute categorical variables.

Finally, item nonresponse was observed for mean values of three predictor variables: perceived neighborhood safety, social disorder, and cohesion (all <2% missing). These mean values were imputed alongside the covariates describe above using MICE.

**Unit nonresponse.** Although 742 parents completed the perceived neighborhood quality scales on the 24- or 36-month follow-up survey, they only represented 542 male youth participants (i.e., 200 surveys were from parents who had the same son, and only one parent's responses were randomly selected to be used in the analysis). Thus, there was a substantial amount of missing data (56%) for the predictor variables due to unit nonresponse. These values were not imputed, and all analyses were only completed on the 542 youth whose parents answered these items.

Of the 542 male youth included in analyses, the following actions were completed to address missing ever use of emerging or traditional tobacco products at each survey wave due to unit nonresponse. First, ever use of an emerging or traditional tobacco product that was reported on earlier survey waves was carried forward to later, missed survey waves. Next, never use of emerging or traditional tobacco products reported on later survey waves was carried back to earlier, missed survey waves. After those steps, a small proportion of missing responses for ever use of emerging or traditional tobacco products on a follow-up survey was observed (<5%). These missing responses were

imputed using MICE to create five datasets. Only five datasets were created due to the small amount of missing data present in the analytic dataset.[320]

All MICE procedures were completed using Stata version 14.2.[313]

*Statistical Analyses*

**Overview.** First, descriptive statistics were calculated to compare the distribution of covariates for those who were included in the current study and those who were excluded due to missing data for the perceived neighborhood quality variables. Next, Cox proportional hazards regression was used to model the short-term (i.e., instantaneous) risk of initiating: 1) emerging, and 2) traditional tobacco products by the four measures of perceived neighborhood quality for participants' neighborhoods at age 10 (perceived safety, social disorder, physical disorder, and cohesion). Due to multicollinearity, separate models were run for each predictor variable. Because the predictor variables represented boys' neighborhoods at age 10, boys who had initiated emerging or traditional tobacco product use at or prior to age 10 (n=2 and n=8, respectively) were removed from the risk set. In other words, the data were left truncated. All analyses controlled for race, region, parental education, and tobacco use by adults in the household. An alpha value of 0.05 was set to denote statistical significance.

**Cox model assumption checks.** Model assumptions were checked in each multiple imputation dataset prior to completing final analyses. First, linearity of continuous variables was assessed by visually inspecting Martingale residual plots; failure of the residuals to scatter randomly around 0 indicated a violation of the linearity

assumption. Next, the proportional hazards assumption was assessed by visually inspecting Schoenfeld residual plots. A violation of the proportional hazards assumption would be indicated by a trend in the Schoenfeld residuals over time. After inspecting the plots, Schoenfeld residual tests were completed for each predictor and covariate. Model assumption checks were completed using Stata version 14.2.[313]

Variables that did not meet the linearity assumption would be categorized into tertiles representing low, medium, and high levels of the predictor variables. Variables that did not meet the proportional hazards assumption would be stratification variables in the Cox proportional hazards model. If the effects of our primary predictor variables were not homogeneous across levels of the stratification variable (tested by including an interaction between the predictor and stratification variable to the model), a product interaction with time would instead be used in the final model to address the proportional hazards violation.

**Analyses.** After ensuring Cox proportional hazards model assumptions were met, final models were run and results were combined across the five imputed datasets using Rubin's method.[278] Estimated coefficients were exponentiated to produce hazard ratios (HRs). Final Cox proportional hazards models and combination of results across the five datasets were completed using SAS version 9.4.[292]

## Results

### *Participant Characteristics*

The 542 boys in the analytic sample were 14.1-years-old on average when they enrolled in the BTHS and 82.2% were white non-Hispanic; 36.7% lived in Ohio Appalachia, 62.7% had at least one parent who graduated college, and 23.6% lived with an adult tobacco user (Table 5). As demonstrated in Table 5, these boys were quite different from those who were not included in the analytic sample due to their parents not answering the perceived neighborhood quality items. Boys who were not included in the current study were more likely to be emerging and traditional tobacco users, live in Appalachia Ohio, and live with an adult tobacco user than the boys who were included. The excluded boys were also less likely to be white non-Hispanic and to have a parent who graduated college.

Two boys were removed from the risk set for emerging tobacco use analyses, and eight boys were removed from the risk set for traditional tobacco use analyses due to initiating use prior to or at age 10 years. The follow-up time for both analyses was from age 11 through the oldest observed age, which was 19-years. Across the five imputed datasets, 99 to 100 participants initiated ever use of emerging tobacco products and 115 to 117 initiated ever use of traditional tobacco products during the follow-up period.

### *Confirmatory Factor Analysis*

The CFA results identified that the model with four latent variables (safety, social disorder, physical disorder, and cohesion) had acceptable fit (RMSEA=0.059, CFI=0.964,

TLI=0.954). The chi-square goodness of fit test rejected the model fit ($\chi^2$[133]=373.3, p<0.001), although this was expected given the large sample size, as even minor deviations from multivariate normality can lead to a high chi-square statistic.[274] The average scores for each predictor variable were strongly correlated (Table 6).

*Short-Term Risk of Emerging Tobacco Product Initiation*

All perceived neighborhood quality variables met the linearity assumption, in all five datasets, according to Martingale residual plots (examples included Figure 8). However, according to Schoenfeld residual plots and tests, one covariate (adult tobacco use in the household) did not meet the proportional hazards assumption (examples of results included in Table **7**). A stratified Cox model was used as effects of all predictor variables were homogeneous across strata of adult tobacco use in the household.

Overall, no measures of perceived neighborhood quality affected short-term risk of initiating emerging tobacco products (Table 8). In general, living in safer, more cohesive neighborhoods appeared to be protective, as did living in less socially and physically disordered neighborhoods. However, results were not statistically significant at the alpha = 0.05 level.

*Short-Term Risk of Traditional Tobacco Product Initiation*

All perceived neighborhood quality variables met the linearity assumption according to Martingale residual plots, in all five datasets (examples included in Figure 9). According to the Schoenfeld residual plots and tests, parental education violated the

proportional hazards assumption (examples of results included in Table 7). A stratified Cox model was used as effects of all predictor variables were homogeneous across strata of parental education.

Only perceived physical disorder affected the short-term risk of traditional tobacco product initiation. A one-point increase in the physical disorder scale was associated with double the short-term risk of initiating a traditional tobacco product (Table 8; p=0.02). No other measures of perceived neighborhood quality affected short-term risk of traditional tobacco product initiation (Table 8).

## Discussion

As the physical disorder in boys' neighborhoods at age 10 increased, their short-term risk of initiating ever use of a traditional tobacco product also increased, after controlling for race, region, parental education, and living with an adult tobacco user. Perceived safety, social disorder, and cohesion of their neighborhoods at age 10 did not affect risk of initiating traditional tobacco products, although the associations were generally in the hypothesized directions. Similarly, we identified no statistically significant associations between parent-perceived neighborhood quality and adolescents' risk of initiating emerging tobacco products, although estimated associations were again in the hypothesized directions.

Our results are consistent with prior work that has identified associations between perceived neighborhood quality and tobacco use among adolescents. Higher neighborhood disorder (e.g., crime, graffiti, vacant buildings, and street fights) has been

associated with increased odds of past-year cigarette and e-cigarette use in a study of California high school students.[104] Likewise, living in a neighborhood that one's parents rated as lower quality has been associated with increased odds of being a regular smoker (i.e., smoking one cigarette per day for the past 30 days) in a nationally representative sample of U.S. adolescents ages 12-18.[103] With the current study's focus on initiating ever use of tobacco products and inclusion of participants who initiated tobacco use from age 10 through adolescence, our results extend the literature on this topic.

Our results are also consistent with both the social ecological model and models of neighborhood social control. Regarding the social ecological model, we identified that one's neighborhood characteristics affect his risk of beginning to use tobacco products after controlling for individual- and interpersonal-level risk factors. Thus, the neighborhood environment uniquely contributed to adolescents' risk of starting to use traditional tobacco products. Regarding models of neighborhood social control, we identified that the neighborhood social environment affected the risk of initiating traditional tobacco use, which ultimately contributes to health disparities (Figure 6).[317] According to the stress reduction hypothesis, people who are exposed to disordered neighborhoods during middle childhood may be more likely to start using traditional tobacco products to reduce the stress caused by their neighborhood environment.[318] However, because this study did not measure stress we could not test whether this mechanism underlies the observed associations.

Our results are also plausible due to the potential for normative and structural factors increasing risk of tobacco use in more disordered neighborhoods. Neighborhood

disorder can manifest when a neighborhood has reduced resources, including financial resources.[317] Lower SES neighborhoods, in turn, tend to have a higher prevalence of adult tobacco use,[122] which has been associated with increased risk of tobacco use among youth by affecting youths' perceptions of tobacco accessibility and descriptive norms related to tobacco use.[38,40] Lower SES neighborhoods also tend to have increased density of tobacco retailers,[32] lower tobacco prices,[30] and more tobacco advertisements.[34] Thus, it is possible that some of the association we observed between perceived neighborhood disorder and initiation of traditional tobacco product use could be mediated by these factors.

Overall, however, most of the measures of perceived neighborhood quality were not associated with short-term risk of initiating tobacco use. Our lack of statistically significant results could be due to a few factors. First, our study experienced significant attrition among parent participants at the 24- and 36-month follow-up surveys (i.e., when measures of perceived neighborhood quality were assessed). Some of this nonresponse was due to timing, as the items had not been added to the parent survey yet (i.e., 32% of parents' windows for the 24- or 36-month survey did not overlap with when the measures had been added). However, much of the nonresponse was due to parents not taking their survey. Attrition was strongly associated with risk factors for tobacco use overall. Not only did this reduce our power to detect effects, it also resulted in a cohort that was at reduced risk of initiating tobacco products overall. Relatedly, the adolescent cohort was relatively young, with some participants being censored as early as 13-years-old. Thus, it is possible that perceived safety, social disorder, and cohesion do affect short-term risk of

initiating tobacco products during adolescence, but we did not have enough tobacco initiation events to detect an effect.

Regarding the lack of statistically significant findings for emerging tobacco products in particular, given the mixed findings for individual-level SES and race as risk factors for use of emerging tobacco products,[3,90,110,123] it is possible that associations between neighborhood quality and emerging tobacco product use would not be as strong as it is for traditional tobacco products, or that there would actually be no association. Additionally, e-cigarettes and hookah were classified as emerging tobacco products in the current study because they are newer to the U.S. marketplace. It is possible, then, that in cases where adolescents were starting to use tobacco products for reasons related to their neighborhood environment (e.g., stress reduction), that they found traditional tobacco products easier to acquire from a friend or family member, through peers, or by purchasing at a retailer, although the retailer environment could have changed with the evolving tobacco marketplace in the interim.

Results of the current study can be used to inform interventions and future research. As the association we observed between neighborhood physical disorder and adolescent tobacco use has been reported previously,[104] we add to evidence in support of interventions that target youth who live in disordered neighborhoods. Given the stress-reduction hypothesis,[318] interventions that provide youth with healthy ways to cope with stress may be beneficial. Interventions aiming to reduce affiliation with peers who use tobacco and increase efficacy in refusing tobacco products may also be beneficial for youth who live in physically disordered neighborhoods.[104] Municipal actions that reduce

the presence of litter and broken glass or remove graffiti would additionally make neighborhoods less physically disordered, and therefore may reduce the risk of initiating tobacco products among adolescents who live there.

There are several directions that future research could take to advance our understanding of the neighborhood's effects on adolescent tobacco use. First, additional investigation into individual-level mediators and modifiers of the association between physical disorder and tobacco use would identify potentially modifiable risk factors or at-risk groups of youth to be targeted with interventions. Second, research that also incorporates objective neighborhood measures would be informative. For example, examination of the potential correlation between perceived measures of neighborhood quality and neighborhood-level factors that promote tobacco use (e.g., tobacco retailer density, advertising, tobacco prices) would be useful to better understand our observed association between perceived physical disorder and risk of traditional tobacco use among adolescents. Additionally, investigation of these neighborhood-level factors that promote tobacco use as mediators of the association between perceived neighborhood quality and risk of tobacco use among adolescents would provide justification for policies that may reduce risk of tobacco initiation in disordered neighborhoods. Third, research that is designed from the outset to investigate the association between neighborhood exposures and risk of tobacco use would ideally start at a much earlier age and follow participants into adulthood. This would prevent early tobacco initiators from being excluded from analyses, and further, other important tobacco use milestones (e.g.,

progression to regular use or dependence) could be modeled more efficiently as dependent variables.

*Limitations*

The following limitations apply to the current study. First, the exclusion of girls limits our ability to generalize our results to all adolescents. Given observed differences in risk factors for tobacco use between adolescent boys and girls at the intrapersonal level,[111,113] it is possible that the observed associations found in this study do not apply to adolescent girls. Second, we did not obtain objective measures of boys' neighborhoods at age 10. For example, it would have been useful to know details about the neighborhood's SES (e.g., percent of families living below the poverty level, racial composition, percent unemployment, etc.) so that we could: 1) estimate whether these factors were associated with risk of initiating tobacco, and 2) control for these effects in our analyses. In the current study, the failure to control for these objective measures of neighborhood SES leaves unmeasured confounding, which could have resulted in our results being biased away from the null.

Third, our retrospective ascertainment of the perceived quality of boys' neighborhoods at age 10 meant we had to make assumptions about the confounders we controlled for. For example, we had to assume that boys who lived with an adult tobacco user when they enrolled in the BTHS at age 11 to 16 also lived with an adult tobacco user when they were 10. We also assumed that boys lived in the same region at age 10 that they did when they enrolled. Moreover, ascertainment of neighborhood quality only at

age 10 meant that our data were left truncated, or that participants who initiated emerging or traditional tobacco use prior to age 10 were excluded from analyses. Obtaining measures of neighborhood quality going back to birth would have prevented this issue. A related, fourth, limitation was that we did not know the exact age that boys initiated tobacco use. Instead, we were limited to self-reported ages for boys who had initiated tobacco use prior to baseline, or six-month increments for boys who initiated tobacco use over the course of the study. Moreover, boys were not asked to retrospectively report when they started using tobacco products more frequently or when they became nicotine dependent at baseline. Thus, we could not model short-term risk of either of these outcomes in the current study.

Fifth, we did not measure parenting behaviors that could be protective in settings of low neighborhood quality. One study found that parenting style (i.e., authoritarian, authoritative, and permissive) modified the effect of neighborhood disorder on risk of regular cigarette smoking among adolescents.[103] Examination of this in the current study would have been useful, as it would add to the evidence that parenting style interventions may protect against tobacco use initiation for adolescents who live in more disordered neighborhoods. A sixth limitation was that we relied on parents' reports of neighborhood quality. Although this has precedence in prior work,[103] it is possible that youths' reports of neighborhood quality would differ. Thus, it is also possible that the associations we observed between perceived neighborhood quality and tobacco initiation would differ if we instead used youths' perceptions of neighborhood quality.

*Strengths*

Our study also had several strengths. First, this study was longitudinal in design and used incident rather than prevalent tobacco use as the dependent variable. Both factors allowed us to establish that our exposure variables did not occur after our outcome variables. Although we did not use a causal framework, our results are stronger due to the assurance of temporality of the associations we detected. Second, our use of Cox proportional hazards regression rather than another type of generalized linear model (e.g., logistic regression) allowed us to model the short-term risk of initiating tobacco use from middle childhood through the end of adolescence—even though a majority of our participants had not reached adulthood by the end of their follow-up. In other words, we did not have to limit analyses to ages that all participants had reached by the end of follow-up to determine whether the risk of tobacco initiation differed according to perceived neighborhood quality. Third, by using perceived neighborhood quality at age 10 as our exposure variable, few participants were removed from the analysis due to left truncation. Importantly, this allowed us to include most early initiators of tobacco products, who are at increased risk of becoming nicotine dependent and continuing tobacco use in adulthood.[85] Fourth, parents defined the neighborhood boys lived in at age 10; they were not asked to only think about the census tract or school district they lived in, for example. This may have resulted in a more accurate representation of the areas boys were exposed to than more arbitrary administrative boundaries. Fifth, modeling risk of initiating emerging and traditional tobacco products separately added nuance to our findings and made them more timely. As the prevalence of emerging tobacco product use

continues to rise and the prevalence of traditional tobacco use continues to fall among adolescents in the U.S.,[3] examination of risk factors for using these products separately improves our understanding of what may be driving the surge in emerging tobacco product use. A related, sixth, strength was that we included several tobacco products in the current study rather than focusing on only one or two products. Given racial[3] and regional[198] differences in products used by adolescents in the U.S., this makes our results more applicable to adolescents overall.

*Conclusion*

This longitudinal study identified that living in a physically disordered neighborhood at age 10 increased boys' risk of initiating ever use of cigarettes, SLT, or cigars through adolescence. Although associations between other measures of perceived neighborhood quality and risk of initiating emerging or traditional tobacco products were not statistically significant in the current study, future work in a larger cohort that is also at greater risk of tobacco use overall may be better powered to detect effects. Moreover, future work that considers individual-, interpersonal-, and neighborhood-level mediators and modifiers of the associations between perceived neighborhood quality and risk of using emerging and traditional tobacco products could inform interventions and policy approaches to reduce adolescents' risk of initiating tobacco use. Continued study of risk factors for using a variety of tobacco products will be necessary to achieve progress in reducing adolescents' use of both emerging and traditional tobacco products in the U.S.

Tables and Figures

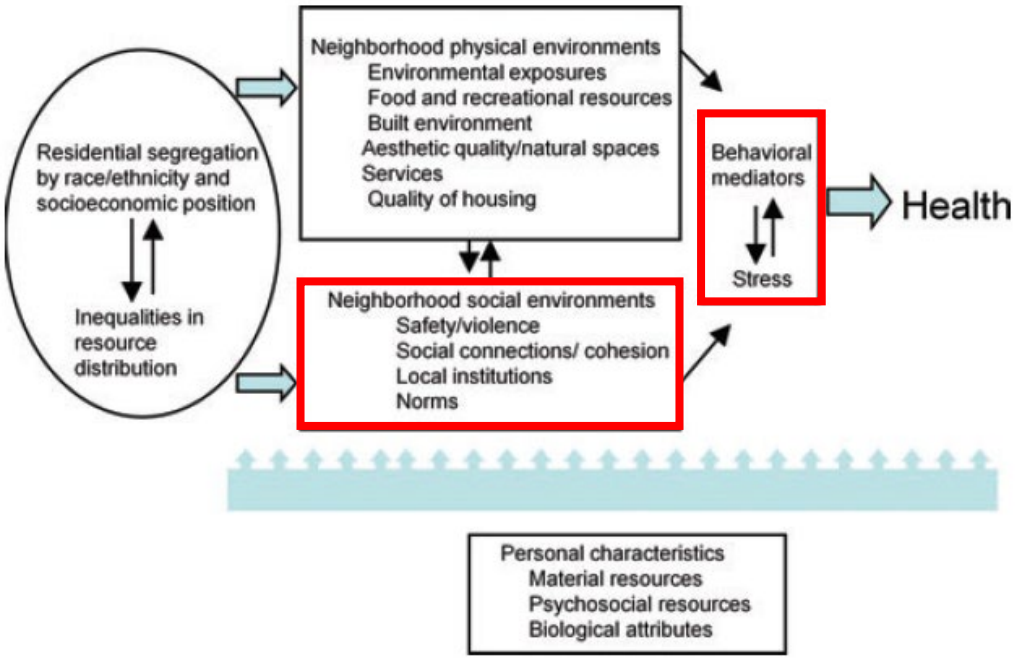


**Figure 6**. Hypothesized relationship between the neighborhood environment and health outcomes.[a]

[a] Figure was obtained from Diez Roux & Mair, 2010.[317] The boxes highlighted in red represent the associations being estimated in the present study.

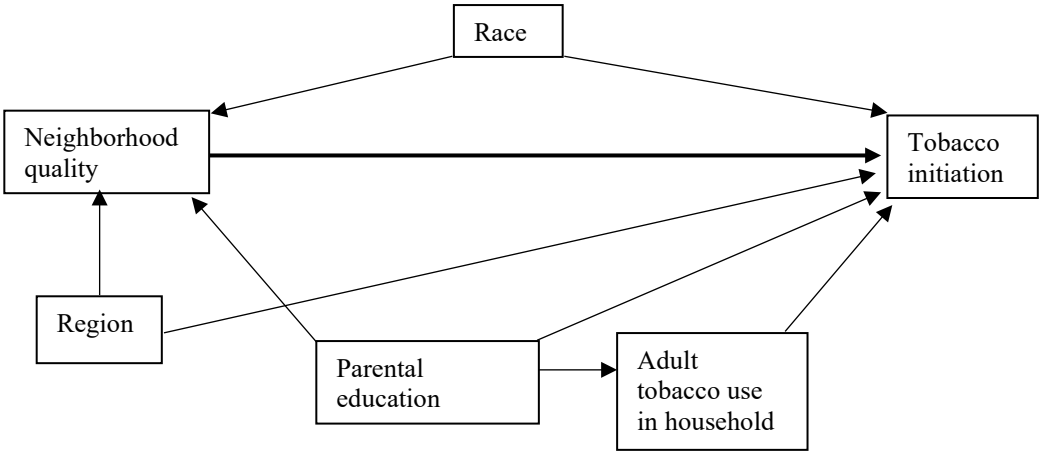


**Figure 7.** Directed acyclic graph demonstrating relationships between perceived neighborhood quality, initiation of tobacco products, and confounding variables

**Table 4.** Latent variables of perceived neighborhood quality, items, and scoring for analytic models.

| Latent variable | Item |
|---|---|
| Perceived safety[a] | Many people in your neighborhood were afraid to go outside at night. |
| | There were areas of this neighborhood where everyone knows "trouble" is expected. |
| | You're taking a big chance if you walk in this neighborhood alone after dark. |
| | I felt safe walking in this neighborhood.[c] |
| | Violence was a problem in this neighborhood. |
| | I felt safe from crime in this neighborhood.[c] |
| Perceived social disorder[b] | How much of a problem was drinking in public? |
| | How much of a problem was people selling or using drugs? |
| | How much of a problem was groups of teenagers or adults hanging out in the neighborhood and causing trouble? |
| | How much of a problem was noise in the neighborhood? |
| | How much of a problem was yelling or fighting? |
| Perceived physical disorder[b] | How much of a problem was litter, broken glass, or trash on the sidewalks and streets? |
| | How much of a problem was graffiti on buildings and walls? |
| | How much of a problem was vacant or deserted houses or storefronts? |
| Perceived cohesion[a] | This was a close-knit neighborhood.[c] |
| | People in that neighborhood were willing to help their neighbors.[c] |
| | People in that neighborhood generally didn't get along with each other. |
| | People in that neighborhood shared the same values.[c] |
| | People in that neighborhood could be trusted.[c] |

[a] Response options and scoring for Cox proportional hazards models were "1, strongly agree;" "2, agree;" "3, neither agree nor disagree;" "4, disagree;" and "5, strongly disagree."
[b] Response options and scoring for Cox proportional hazards models were "3, a big problem;" "2, somewhat of a problem;", and "1, not a problem."
[c] Item was reverse scored for Cox proportional hazards models.

**Table 5.** Characteristics of participants included in the current study's analytic sample vs. those who were excluded[a]

| | Boys in analytic sample (N=542) | Boys outside of analytic sample (N=678) | p-value[b] |
|---|---|---|---|
| Age at enrollment (mean [SD]) | 14.1 (1.6) | 14.0 (1.6) | 0.3 |
| Ever used emerging tobacco product by end of follow-up[c] (%) | 18.8 | 30.2 | <0.001 |
| Ever used traditional tobacco product by end of follow-up[c] (%) | 21.4 | 37.2 | <0.001 |
| Race (%) | | | <0.001 |
| White non-Hispanic | 82.2 | 71.5 | |
| Black non-Hispanic | 8.5 | 15.9 | |
| Other | 10.3 | 12.5 | |
| Appalachia region (%) | 36.7 | 46.2 | 0.001 |
| At least one parent graduated college (%) | 67.2 | 42.9 | <0.001 |
| Lives with an adult tobacco user (%) | 23.6 | 38.4 | <0.001 |

[a] Boys in the analytic sample had at least one parent complete a follow-up survey at 24 or 36 months that included the perceived neighborhood quality items.
[b] The p-value for age of enrollment was obtained from a t-test. All other p-values were obtained using chi-square tests.
[c] Because multiple imputation was not completed for missing tobacco use outcomes among boys outside of the analytic sample, these rows only include distributions among complete cases. Emerging tobacco products included e-cigarettes and hookah. Traditional tobacco products included cigarettes, traditional cigars, cigarillos/little cigars, and smokeless tobacco.

**Table 6.** Correlations between average scores on perceived safety, social disorder, physical disorder, and cohesion scales.[a]

| | Perceived safety | Perceived social disorder | Perceived physical disorder | Perceived cohesion |
|---|---|---|---|---|
| Perceived safety | 1.00 | | | |
| Perceived social disorder | -0.87 | 1.00 | | |
| Perceived physical disorder | -0.74 | 0.86 | 1.00 | |
| Perceived cohesion | 0.77 | -0.61 | -0.46 | 1.00 |

[a] Correlation coefficients using Fisher's *z* transformation were combined across the five imputed datasets using Rubin's method.[278] All correlations significantly differed from 0 (all p-values <0.001).

**Table 7**. Results of Schoenfeld residual tests in first imputed dataset[a]

| | $\chi^2$ | DF | p-value |
|---|---|---|---|
| Emerging tobacco use models | | | |
| Perceived safety | 0.05 | 1 | 0.82 |
| Perceived social disorder | 0.28 | 1 | 0.60 |
| Perceived physical disorder | 1.49 | 1 | 0.22 |
| Perceived cohesion | 0.03 | 1 | 0.87 |
| Black non-Hispanic race | 0.01 | 1 | 0.93 |
| Other race | 0.14 | 1 | 0.70 |
| Parental education | 2.31 | 1 | 0.13 |
| Region | 2.92 | 1 | 0.09 |
| Adult tobacco user in household | 4.62 | 1 | 0.03 |
| | | | |
| Traditional tobacco use models | | | |
| Perceived safety | 0.00 | 1 | 0.98 |
| Perceived social disorder | 0.32 | 1 | 0.57 |
| Perceived physical disorder | 0.81 | 1 | 0.37 |
| Perceived cohesion | 3.08 | 1 | 0.08 |
| Black non-Hispanic race | 0.03 | 1 | 0.87 |
| Other race | 3.27 | 1 | 0.07 |
| Parental education | 4.13 | 1 | 0.04 |
| Region | 0.57 | 1 | 0.45 |
| Adult tobacco user in household | 1.52 | 1 | 0.22 |

Abbreviations: DF = Degrees of freedom

[a] Covariate values reported are from the perceived safety models; time (non-transformed) was used to assess proportional hazards assumption. Results did not differ substantially across models or datasets.

**Table 8.** Short-term risk of initiating emerging and traditional tobacco products according to perceived quality of neighborhood at age 10[a]

| | Emerging tobacco products[b] | | Traditional tobacco products[c] | |
|---|---|---|---|---|
| | HR[d] | 95% CI | HR[d] | 95% CI |
| Perceived safety | 0.85 | 0.64, 1.11 | 0.90 | 0.70, 1.17 |
| Perceived social disorder | 1.32 | 0.73, 2.40 | 1.30 | 0.76, 2.20 |
| Perceived physical disorder | 1.63 | 0.78, 3.41 | 2.01 | 1.09, 3.69 |
| Perceived cohesion | 0.78 | 0.57, 1.07 | 1.07 | 0.76, 1.50 |

Abbreviations: HR = hazard ratio; CI = confidence interval

[a] Measures of perceived neighborhood quality were collected from parents and guardians of male youth participants during the study's 24- and 36-month follow-ups. Cox proportional hazards models estimated the short-term risk of initiating emerging and traditional tobacco products. All analyses controlled for race, region, parental education, and tobacco use by adults in the household. Analyses were combined across five imputed datasets using Rubin's method.[278]

[b] Emerging tobacco products included e-cigarettes and hookah.

[c] Traditional tobacco products included cigarettes, traditional cigars, cigarillos/little cigars, and smokeless tobacco.

[d] HR associated with a one-point increase in the predictor.

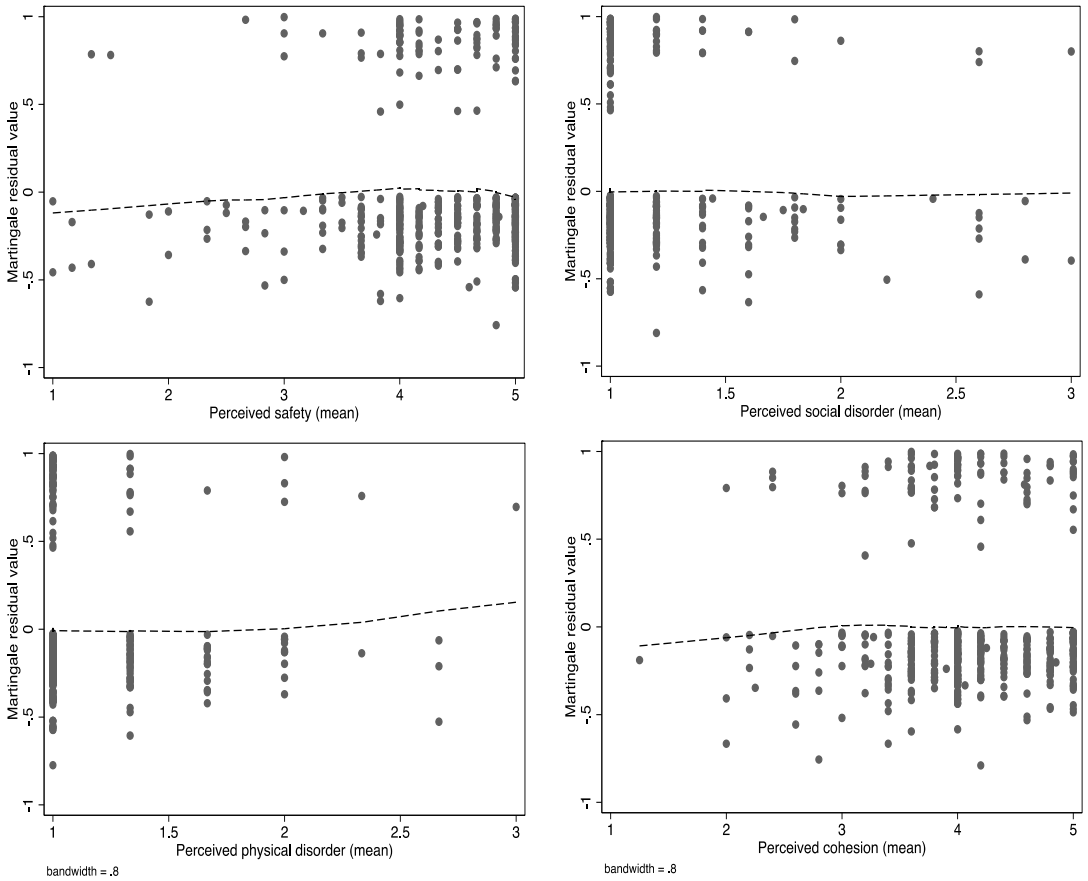


**Figure 8**. Martingale residual plots assessing linearity of perceived neighborhood quality variables for emerging tobacco use outcome Cox proportional hazards models (first imputed dataset)[a]

[a] Results were consistent across imputed datasets.

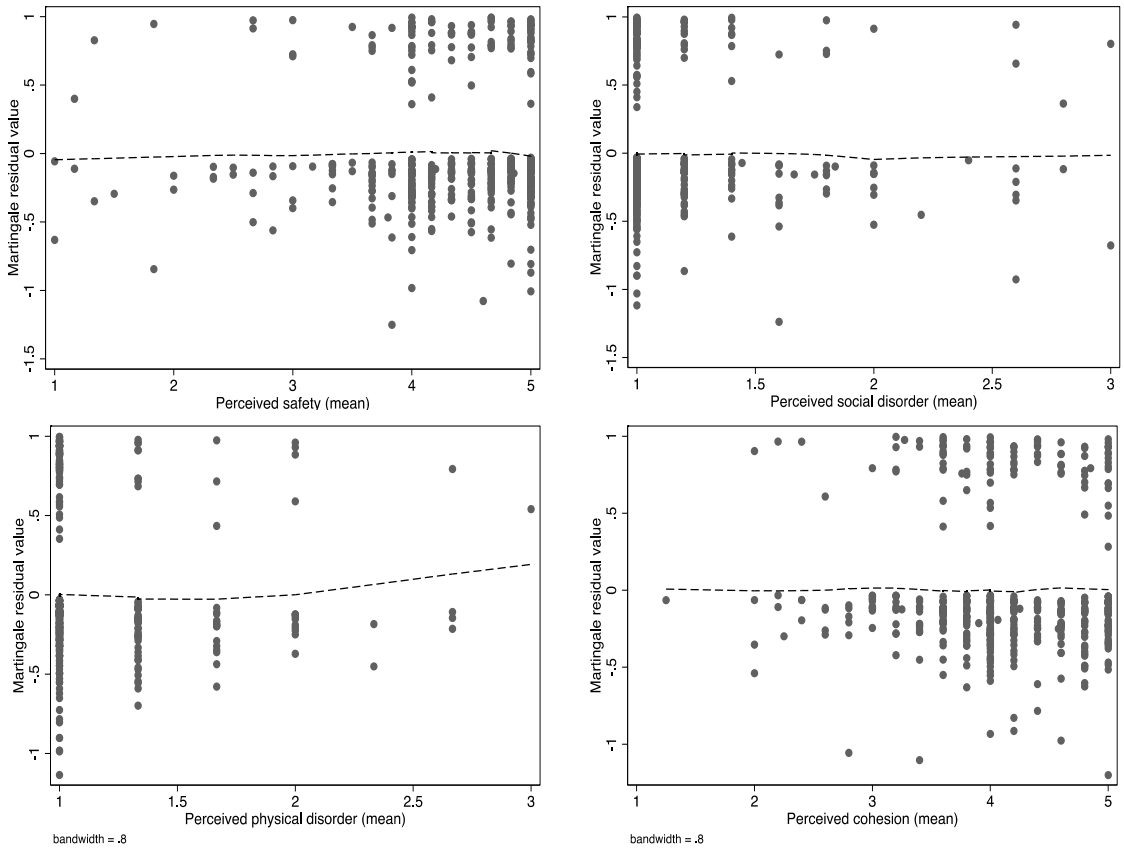


**Figure 9.** Martingale residual plots assessing linearity of perceived neighborhood quality variables for traditional tobacco use outcome Cox proportional hazards models (first imputed dataset)[a]

[a] Results were consistent across imputed datasets.

# Chapter 5. The Tobacco Retail Environment in Columbus, Ohio, Before and After Tobacco 21


## Abstract

**Introduction.** Tobacco 21 (T21) policies raise the minimum legal sales age to purchase tobacco products from 18 to 21 years. To date, over 475 localities have implemented a T21 policy in the United States. Columbus, Ohio, began enforcement of a Tobacco 21 (T21) ordinance in September 2017. The objective of the current study was to evaluate whether the tobacco retail environment in Columbus changed after T21 implementation with respect to trajectories of 1) cigarette prices, 2) availability of flavored tobacco products, 3) exterior advertisements for tobacco products, and 4) price promotions for tobacco products.

**Methods.** A stratified random sample of Columbus retailers holding a cigarette dealer license was audited in 2014, 2016, 2017, 2018, and 2019 (N=74 to 103 retailers per year; the same retailers were audited over time). Trained fieldworkers completed audits in pairs during daylight in late spring and summer months. Generalized linear models with mixed effects were used to evaluate whether time trends in prices of Marlboro Reds, Newport Menthols, or the cheapest cigarettes; availability of flavored tobacco products; exterior advertisements; and interior and exterior price promotions changed post-T21

implementation. All models controlled for store type and census tract poverty level, race, and percent youth.

**Results.** Implementation of T21 was associated with a change in the trajectory of the price of Marlboro Reds (per-year price increase of $0.25 pre-T21 vs. $0.08 post-T21; p=0.008). Similarly, the per-year change in count of price-promoted tobacco products changed post-T21 (21% decrease per year pre-T21 vs. 29% increase per year post-T21; p=0.004). No statistically significant changes in the trends of flavored product availability or exterior advertisements were observed.

**Conclusion.** Implementation of T21 was associated with changes in the trajectories of cigarette prices and price promotions. In both cases, the change in trajectory resulted in tobacco products being available at lower prices than they would have been if the pre-T21 trajectory had continued. Results underscore the need for continued surveillance of the tobacco retail environment before and after localities or states implement T21 policies.

## Background

Tobacco 21 (T21) policies raise the minimum legal sales age (MLSA) to purchase tobacco products from 18 to 21 years. To date, 18 states (including Ohio, where the policy was recently approved but is not yet implemented) and over 475 localities have adopted T21 policies.[251] An obvious benefit of T21 policies is that they make it more difficult for adolescents and young adults to obtain tobacco products for themselves. As

95% of adult smokers initiated smoking by the time they were 21-years-old, and 8% initiated specifically between the ages of 18 and 21,[1] this alone implies that T21 policies, if well enforced, would reduce the prevalence of tobacco use among adolescents and young adults. However, the primary rationale for implementing T21 is that it reduces the ability of older teens and young adults to supply their younger friends with tobacco products.[248]

Studies of T21 have provided support for this rationale, and they have further described how policy implementation may affect the prevalence of youth tobacco use in the United States (US). A simulation study of the potential impacts of a national T21 policy in the US identified that the greatest decrease in smoking initiation (an estimated decrease of 25%) would be among 15- to 17-year-olds, who are likely to have people ages 18 or 19 in their social networks.[321] Other research compared the trend in prevalence of youth smoking in Needham, Massachusetts, which was the first locality in the US to implement a T21 policy, to nearby communities that had not implemented T21. In the four years following Needham's implementation of T21, the prevalence of current cigarette smoking among youth decreased more quickly in Needham than in nearby communities, and decreases were observed for males, females, white, and non-white youth.[322] Moreover, the proportion of youth who purchased cigarettes at retailers decreased more in Needham.[322]

Other benefits of T21 policies are that the public tends to approve of them and there are relatively few legal difficulties associated with implementation. Regarding policy support, 70.5% of adults and 63.9% of youth support raising the MLSA for

tobacco products to 21 years in the US.[254,323] Even a majority of adult current smokers support T21 policies,[254] although, perhaps unsurprisingly, the same is not true of current smokers under age 21.[323,324] Regarding legal difficulties, T21 laws cannot be challenged under the First Amendment because they regulate purchasing rather than advertising or other methods of communication.[255] Also, although the Family Smoking Prevention and Tobacco Control Act (TCA) prevents the Food and Drug Administration (FDA) from raising the MLSA for tobacco products above 18 nationwide, it does permit state and local governments to raise the MLSA.[48] The main legal barrier to implementation of T21, then, is state-level preemption of local governments' ability to raise the MLSA for tobacco products. In 19 states, state law preempts local governments from raising the MLSA (although, in some cases, the preemption language is somewhat ambiguous).[255] In Ohio, before the state raised the MLSA to 21, state law did not preempt localities from raising the MLSA above 18.[255]

The city of Columbus, Ohio, passed a T21 ordinance in December 2016,[325] with enforcement beginning in September 2017.[253] In addition to raising the MLSA for cigarettes, e-cigarettes, hookah, pipes, smokeless tobacco (SLT), cigars, rolling papers, and other tobacco products and paraphernalia, the policy required: 1) identification checks for sales up to age 30, 2) display of T21 signage at the point of sale and on display cases, 3) prohibition of vending machine tobacco or paraphernalia sales, and 4) acquisition of a license from the Columbus Public Health department to sell tobacco products.[326] Additionally, retailers holding a tobacco sales license are inspected to monitor their compliance with the T21 ordinance; civil fines of $500 are issued for the

first violation, and civil fines of $1000 are issued for subsequent violations within two years.[327] Tobacco sales licenses can also be denied or revoked as a result of failure to comply with the T21 ordinance requirements.[328]

Ultimately, the T21 ordinance implemented in Columbus, Ohio, did not merely replace "18" with "21" in the city law. Best practice guidelines for policies aiming to prevent the sale of tobacco products to youth emphasize strong enforcement of the policy, e.g., adequately funding enforcement, articulating the enforcement plan, conducting regular compliance checks, and penalizing those found in violation of the policy.[321,329] Strong T21 policies, then, go beyond simply changing the MLSA. Columbus' T21 ordinance follows best-practice guidelines for T21 policies, and therefore Columbus provides a good setting to study the effects of T21 policies.

Because strong T21 policies change the age of tobacco-purchasing clients, it is plausible that marketing of tobacco products will also change after T21 implementation. One way that the retail environment might change would be to reduce the effort to attract younger consumers. As retailers located in areas with more youth have lower priced tobacco products and more promotions for menthol cigarettes,[285,286] it follows that prices might increase and promotion of flavored products might decrease when the age of the consumer base increases. It is also plausible, however, that prices might decrease and promotion of flavored tobacco products would increase post-T21 implementation in an effort to attract more young adults. Thus, investigation into whether, and how, the retail environment changes post-T21 implementation is necessary to fully appreciate the potential effects of the policy.

*Theoretical Framework*

The theoretical framework motivating the current study is the social ecological model, which describes how risk and protective factors for health behaviors occur at the individual, interpersonal, community, and policy levels of influence.[16] Studying the effects of T21 implementation on the retail environment will describe how a policy affects community-level risk factors for tobacco use. Community-level risk factors for tobacco use include characteristics of the retail environment that youth and adults alike may encounter in their day-to-day lives—regardless of whether they are tobacco users—such as low tobacco prices and price promotions, advertisements, and availability of flavored tobacco products.

Low tobacco prices and price promotions are two ways that the tobacco industry makes their products more appealing and accessible to youth, young adults, and people of lower socioeconomic status.[330] In addition to the strong evidence that higher prices of tobacco products are associated with reduced consumption of those products (via reduced youth uptake, increased cessation, and decreased quantity of products consumed),[331] there is recent evidence that higher prices of cigarettes might drive youth and young adults to using e-cigarettes.[332] In other words, at the same time that high tobacco prices discourage use of a particular product, it is appears that they may also encourage substitution with another product, and thus the effect of tobacco prices on overall patterns of tobacco use is complex.

Tobacco product advertisements at retailers are other community-level risk factors for tobacco use among youth and adults through influencing positive expectancies

of using the product(s), smoker prototypes, and social norms.[333] Youth who frequently visit retailers with heavy tobacco advertising are at increased risk of becoming cigarette smokers,[220] and heavier share of advertising for e-cigarettes and SLT at retailers is associated with increased use of those products among adolescents.[334] Moreover, exposure to tobacco advertisements reduces adult smokers' probability of successful smoking cessation.[335]

Finally, availability of flavored tobacco products is a community-level risk factor for tobacco use, particularly among youth and young adults. Youth and young adult tobacco users in the US have a strong preference for flavored tobacco products,[336,337] and an estimated 70% of youth current tobacco users report using a flavored product in the past 30 days.[260] The TCA banned cigarette flavors other than menthol,[48] but there are currently no federal restrictions, or restrictions in Columbus, Ohio, on flavors of other tobacco products (the FDA has proposed a ban on flavored e-cigarettes except for mint and menthol at retailers that can be accessed by youth).[338]

*Current Study*

To our knowledge, no research has evaluated the effect of T21 implementation on characteristics of the tobacco retail environment, such as prices, flavored product availability, and advertising and promotions. This is a notable gap in the literature, as characteristics of the retail environment affect youth and young adult tobacco use and may change in response to a policy that increases the age of the consumer base. For example, the alcohol industry's marketing practices appeal to "starter," or young drinkers

differently from “established,” or older drinkers by marketing sweeter drinks at lower prices.[284] The tobacco industry also practices audience segmentation by offering lower priced tobacco products[285] and more price promotions for menthol cigarettes[286] in areas with younger populations. Thus, the aims of the current study are to evaluate whether trajectories in 1) cigarette prices, 2) availability of flavored tobacco products, 3) exterior advertising, and 4) price promotions at tobacco retailers changed post-implementation of T21 in Columbus, Ohio. As T21 ordinances continue to be rapidly adopted across the country, including in the state of Ohio, results of this research will inform tobacco control efforts to reduce tobacco use among youth and young adults.

## Methods

### *Setting*

A list of retailers holding a cigarette dealer license in Franklin County, Ohio, was obtained in 2014. A stratified random sample of 100 retailers was audited that year (the county was stratified by location and median household income).[287] Audits were repeated at these retailers, as well as at a replenishment sample of retailers holding a cigarette dealer license in 2016, 2017, 2018, and 2019 (N=90 to 121 retailers audited per year in Franklin County). Although audits were completed at retailers throughout Franklin County, only data from Columbus retailers (N=74 to 103 per year) were used in the current study. All except for eight retailers were audited at least once in both the pre- and post-T21 periods.

*Procedures*

A retailer audit instrument was adapted from earlier work.[288] Data were collected on paper-and-pencil surveys (2014) or on a smartphone Qualtrics survey (all other years). Characteristics of retailers (described below) were obtained by visually inspecting each retailer or asking the clerk for information that was not readily available (e.g., the price of the cheapest cigarette pack in the store). Each year, retailers were audited during late spring or summer months. All audits were completed during daylight hours. Prior to data collection, undergraduate and graduate student fieldworkers were trained, and moderate-to-good inter-rater reliability was established (Cohen's $\kappa$'s > 0.5). All audits were completed in pairs.

*Measures*

**Dependent variables.** For analyses of *cigarette prices*, dependent variables included the pre-tax price of one pack of Marlboro Reds, Newport Menthols, and the cheapest cigarettes in the store. In cases where only post-tax prices were available (as indicated on signage or from the clerk), the fieldworker noted this in the data collection instrument and the tax was subtracted from the recorded price prior to analysis. Prices were also inspected for unlikely values (e.g., <$2.00 per pack), which were set to missing (N=3). Cigarette prices were obtained in all five years of audits.

For analyses of *flavored tobacco products available*, the dependent variable was the count of categories of flavored products sold at each retailer. Flavored products that

were assessed included menthol cigarettes, flavored e-cigarettes, flavored SLT, and flavored cigarillos (all yes vs. no). A count of categories of flavored products available was then calculated for each retailer (range: 0 to 4). Counts at each retailer were dichotomized to eliminate small cells and improve interpretability: 0 to 3 products (reference category) vs. 4 products. Flavored product availability was obtained in all five years of audits.

For analyses related to *exterior advertising* of tobacco products, the dependent variable was count of all tobacco products that were advertised outside the store. Exterior advertisements for the following products were assessed: menthol and non-menthol cigarettes; flavored and unflavored e-cigarettes, SLT, and cigarillos; large cigars; and hookah (all yes vs. no). A count of all products advertised outside the store was then calculated (range of observed values: 0 to 9). These measures were obtained from 2016 to 2019.

For analyses of *price promotions*, the dependent variable was the count of tobacco products that had advertised price promotions inside and outside each retailer. Interior and exterior price promotions for menthol and non-menthol cigarettes; flavored and unflavored e-cigarettes, SLT, and cigarillos; large cigars; and hookah were assessed and summed (all yes vs. no; range of observed values: 0 to 16). These measures were obtained from 2016 to 2019.

**Independent variables.** Independent variables included year and T21 implementation (yes vs. no). Year was first recoded to 0 to 6 (from 2014 to 2019) to

improve interpretability of results, and then centered at its mean to reduce multicollinearity in regression models.

**Covariates.** Covariates included factors that have substantively been associated with lower tobacco prices and availability of flavored tobacco products.[30] Additionally, the distributions of variables selected as covariates changed over time due to replenishing the sample of retailers after 2014, and thus they were controlled for in all analyses. Covariates included retailer type (convenience store or gas station vs. other) and the following indicators of census tract demographics: percent living below the poverty level, (dichotomized at $\geq$20% vs. less[290]), percent black or African American (dichotomized at $\geq$25% vs. less[287]), and percent youth under 18-years-old (dichotomized at the Franklin County median: $\geq$24.3% vs. less). To obtain census tract characteristics, retailers were first spatially joined to census tracts using ArcMap version 10.3.[289] Next, American Community Survey five-year estimates for 2013 to 2017 of percent of people living below the federal poverty level, percent black race, and percent youth under age 18 were merged to each retailer by census tract.

### *Statistical Analysis*

**Overview.** The goal of the analyses was to determine whether the trajectories of cigarette prices, availability of flavored tobacco products, exterior advertisements for tobacco products, and price promotions changed post-implementation of T21 in Columbus, Ohio. All analyses used mixed models to account for repeated measures at retailers over time. Random intercepts and an unstructured covariance pattern were

specified for all models. Prior to completing final analyses, linearity of the association between year and the dependent variable was assessed in all models. In models of prices and count of exterior advertising and price promotions, this involved inspecting scatterplots for non-linear trends. In models assessing availability of flavored tobacco products, this involved a fractional polynomials assessment.

To test whether observed trajectories in the dependent variables changed post-T21 implementation, product interaction terms between T21 implementation and year were included in the model (see example Model 8); statistical significance of interaction terms was assessed using likelihood ratio tests. To account for multiple testing, an alpha level of 0.01 denoted statistical significance of interaction terms (this alpha level was set due to there being four interactions between year and T21 implementation tested, with the added consideration of making results more interpretable, i.e., presentation of 99% confidence intervals). In cases where interaction terms were statistically significant, trajectories stratified by T21 implementation were reported. All models included fixed effects for store type and census tract poverty level, percent black or African American race, and percent youth as described above. Analyses were completed using SAS version 9.4.[292]

**Cigarette price analyses.** First, the distributions of the price of one pack of Marlboro Reds, Newport Menthols, and the cheapest cigarettes were evaluated over time. Next, mixed effects linear regression models were run to model trajectories in prices of each product, as well as whether trajectories changed post-T21 implementation. Restricted maximum likelihood was used for model estimation. Assumptions of linear regression models, including homoscedasticity and normality of errors, were assessed by

evaluating residual and quantile-quantile plots, respectively. Cigarette prices were missing from up to 15% of retailers each year. Missing values were due to the retailer not selling that brand of cigarettes or the price being unobtainable. These individual observations with missing price data for each retailer were not used in model estimation (other observations from the same retailer without missing price data were used in model estimation).

**Availability of flavored products analyses.** First, the distribution of the count of categories of flavored tobacco products at each retailer was evaluated by year. Next, we calculated the proportion of retailers that consistently offered the same number of categories of flavored tobacco products across all observed years. A mixed effects logistic regression model was then run to estimate the odds of selling 4 vs. 0 to 3 categories of flavored tobacco products over time and whether the trajectory changed post-T21 implementation.

**Exterior advertisements analyses.** First, the distribution of the count of exterior advertisements for all tobacco products at each retailer was visually assessed. A mixed effects Poisson model was then run to model the count of flavored and unflavored tobacco products advertised over time, as well as whether the trajectory changed post-T21 implementation. Robust standard errors were estimated to account for underdispersion.

**Price promotion analyses.** First, the distribution of counts of tobacco products with interior or exterior price promotions at each retailer were visually assessed. Next, counts were modeled over time, and a change in the trajectory post-T21 implementation

was evaluated, using mixed effects negative binomial regression. Poisson regression as not used due to overdispersion.

## Results

### *Retailer Characteristics*

A total of 74 to 103 retailers holding a cigarette dealer license were audited in Columbus, Ohio, in 2014 and 2016-2019. Descriptively, as time progressed, a larger share of the audited retailers were located in census tracts with higher proportions of people who were living below the poverty level and were black or African American (Table 9). The proportion of stores that were convenience stores or gas stations in the sample decreased from 2014 to 2019.

### *Cigarette Prices*

There were no major violations of the assumptions of linear regression models, so prices were left untransformed in all analyses to improve interpretability of results (Figures 10-12). Descriptively, prices of Marlboro Reds, Newport Menthols, and the cheapest cigarettes tended to increase from 2014 to 2019 (Table 10).

The trajectory of the price of Marlboro Reds changed after T21 was implemented ($p=0.008$; Table 11 and Figure 13). Prior to T21 implementation, a one-year increase was associated with a $0.25 increase in the mean price of Marlboro Reds. Post-T21 implementation, the increase in price was $0.08 per pack on average, which did not significantly differ from a $0.00 increase ($p=0.14$). There were no changes in the price

trajectories of Newport Menthols or cheap cigarettes after T21 was implemented. Prices of Newport Menthols were lower at convenience stores and gas stations than other retailers (p=0.01). No other covariates were associated with cigarette prices.

*Availability of Flavored Products*

Each year, 35.8% to 63.5% of retailers sold all four categories of flavored products, and very few retailers sold fewer than two categories of flavored tobacco products (Table 12). Approximately one-third (37.3%) of retailers sold the same number of categories of flavored tobacco products across all years of observation. The change in the trajectory of flavored tobacco product availability (odds of 4 vs. fewer flavored products) after T21 implementation nearly met the threshold of statistical significance (p=0.02). In the main effects model, a one-year increase was associated with a marginally significant 29% increase in odds of selling 4 vs. fewer categories of flavored tobacco products (p=0.03; Table 13). Retailers in census tracts with high poverty levels also had 75% lower odds of selling 4 vs. fewer categories of flavored tobacco products (p=0.002).

*Exterior advertisements for flavored and unflavored tobacco products*

Over one-third of retailers (34.4%) had no exterior advertisements for tobacco products; the count of tobacco products advertised outside of retailers was right-skewed (Figure 15). There was no change in the trajectory of count of tobacco products advertised outside retailers after T21 implementation (p=0.13). In the main effects model,

a one-year increase in year was associated with an estimated 22% decrease in the count of tobacco products advertised outside retailers ($p<0.001$; Table 14).

*Interior and exterior price promotions for tobacco products*

The count of tobacco products with interior or exterior price promotions was right skewed, and 38.1% of retailers offered no price promotions (Figure 16). The trajectory of count of tobacco products with price promotions advertised inside and outside of retailers changed post-T21 implementation ($p=0.004$; Table 15). Prior to T21 implementation, the mean count of tobacco products with price promotions decreased by 21% per year ($p=0.04$). After T21 implementation, the mean count of tobacco products with price promotions increased by 29% per year ($p=0.04$). Retailers located in census tracts with a high proportion of people living below the poverty level had a 47% lower count of tobacco products with price promotions ($p=0.006$).

## Discussion

Overall, in Columbus, Ohio, implementation of T21 was associated with changes in the trajectories of the price of Marlboro Reds and count of price-promoted tobacco products at retailers. In both cases, post-T21 trends resulted in tobacco products being available at a lower price than they would have been if the pre-T21 trends had continued. We did not identify statistically significant changes in the trajectories of flavored product availability or exterior advertising post-T21 implementation. However, we observed a

marginally significant increase in the odds of retailers offering all four measured flavored tobacco products, and a decrease in the count of exterior advertisements for tobacco products, over time.

Although we are unaware of other research examining the effects of T21 on cigarette prices in the U.S., implementation of other tobacco control policies has been associated with changes in cigarette prices. Specifically, the trend of cigarette prices post-implementation of plain packaging in the United Kingdom (UK) and Australia has been examined.[339,340] In both cases, prices of cigarette packs *increased* after plain packaging was implemented, controlling for other time trends in prices.[339,340] Notably, in both settings, there was also evidence that consumers switched to roll-your-own cigarettes[339] (which remained the cheaper option) or cheaper brands of cigarettes[340] after prices increased. This evidence of switching to cheaper products is similar to results in the U.S., where higher cigarette prices have been associated with increased use of e-cigarettes among youth and young adults.[332]

These findings after plain packaging implementation were contrary to our findings related to the price of Marlboro Reds post-T21 implementation, as well as the tobacco industry's own argument that a shift to plain packaging would force brands to compete through lowering prices.[341] Findings might differ for a few reasons. First, unlike the broader target population of plain packaging laws,[342] T21 is a policy aimed primarily at reducing youth and young adult use of tobacco products. Thus, our findings that the price of Marlboro Reds increased less than usual post-T21 implementation are unsurprising, as young adults are price-sensitive consumers.[44] Moreover, Marlboro prices

may have increased less post-T21 to encourage established adult smokers to purchase more cigarettes to make up for the lost 18- to 20-year-old demographic—although 18- to 20-year-old adults only account for approximately 2% of cigarette sales in the U.S. so this latter point might be unlikely.[343] Second, we only observed a change in price trajectories of one brand of cigarettes, which was under the parent company of Altria. As other research has averaged across brands rather than allowing for heterogeneity, it is possible that specific brands did respond to plain packaging in the UK and Australia by decreasing their prices. Third, our retailers were all located in one city, and thus the trajectory in mean price of Marlboro Reds may have changed post-T21 as a result of some other city- or state-specific effect that we did not capture. Further, contrary to high-profile plain packaging laws implemented at a national level, the tobacco industry's pricing strategies might not be fine-tuned enough to make changes at the city level. Ultimately, however, our findings suggest that Altria might respond to T21 ordinances by holding prices down, but because we did not observe the same change in the trend of cheap cigarette prices, it is unclear how much this change in trend for one brand would affect cigarette smoking behaviors (e.g., initiation, cessation, and product switching).

Pre-T21, the count of tobacco products that were price promoted inside and outside of retailers decreased over time in Columbus. A similar decreasing trend in price promotions was reported at tobacco retailers in New York state over the same period of time,[344] indicating that this trend was not localized to the city of Columbus. However, after T21 was implemented, we observed an increasing count of tobacco products that were price-promoted inside or outside tobacco retailers. This change in trend suggests

that tobacco companies responded to T21 policy by offering discounts for more tobacco products, which could reasonably lead to increased tobacco use among price-sensitive young adults;[44] this could also encourage larger purchase quantities for adults who are established smokers.[345] However, available data suggest that industry spending on price promotions for cigarettes and SLT increased through 2017,[234,235] so it is possible that our findings are related to changing advertising and promotional activities that may or may not be in response to implementation of T21 across states and localities.

Although we did not observe a change in the trajectory of categories of flavored products available after T21 implementation, we did identify a marginally significant overall increase in the odds of retailers selling 4 (vs. 0-3) categories of flavored tobacco products over time. Conversely, we observed a decrease in the count of flavored and unflavored tobacco products advertised outside of retailers over time. Regarding availability of flavored products, our results may be related to the increasing popularity of e-cigarettes. JUUL, in particular, has become especially popular in the past few years.[168] In fact, it is possible that the marginally significant change in the trend of flavored product availability we observed post-T21 implementation was strongly related to the soaring popularity of JUUL that occurred simultaneously. Regarding exterior advertising for flavored and unflavored tobacco products, our results again align with tobacco retailer surveillance data from New York state over the same period.[344] Given the overall decrease in tobacco industry spending on outdoor advertising for cigarettes and SLT nationally from 2014 to 2017 (the latest year that spending data are available),[234,235] our

results suggest that the decreasing trend we observed in exterior tobacco product advertising was not localized to Columbus.

*Future Directions*

The results of the current study provide several directions for future research. First, investigation into how other tobacco control policies affect community-level risk factors for tobacco use (e.g., the retail environment) is warranted. Other tobacco control efforts, including licensing or zoning laws that limit the density of tobacco retailers; price-raising strategies such as tax increases, minimum price laws, and coupon redemption/price discounting bans; and flavored product bans could all potentially be associated with changes to how tobacco products are marketed at retailers. These changes, in turn, could result in a decrease in community-level risk factors for tobacco use—or the tobacco industry could adapt to policy changes and ultimately minimize the effects of these policies. In either case, the public health community would benefit by understanding the full impact of any tobacco control policy.

A second, related direction for future research would be evaluating how the changes we observed in the current study after T21 implementation are associated with actual tobacco use behaviors in Columbus, Ohio. As noted earlier, Marlboro was the only brand of cigarettes, of the two that we observed, to hold down prices post-T21; this could result in young adults who smoked other brands switching to Marlboro, or it could have no effect because young adults were primarily smoking cheaper brands anyway. The increase we observed in the count of price-promoted tobacco products post-T21,

however, may more clearly result in increased tobacco use among young adults. Investigation into whether this is actually occurring, and for what products, could justify further tobacco control policies in Columbus (such as a price discounting ban) or interventions to reduce initiation and promote cessation among young adults.

A third direction of future research would be investigation of community-level risk factors for tobacco use that might occur in areas with a high concentration of young adults, such as around universities, or locations frequented by young adults, including bars and nightclubs, post-T21 implementation. In the US, the prevalence of current tobacco use is highest among young adults (41%),[346] and the tobacco industry has historically promoted tobacco use in this demographic with targeted marketing, including at bars and nightclubs.[347] Surveillance of tobacco marketing practices in these settings, which may or may not hold a license to sell tobacco, would be informative as the tobacco industry may increase their marketing to young adults post-T21.

A fourth direction of future research would be closer examination of how specific tobacco companies respond to T21. In the current study, we found that only Altria held down their cigarette prices post-T21 implementation. It is possible that they were also behind the increase in price promotions that we observed post-T21 implementation, and that their cheaper brands of cigarettes might not have increased in price post-T21. Exposing the tobacco industry's strategies to manipulate consumers into using their products has been a successful counter-marketing approach,[348] and a better understanding of how specific companies respond to the public health community's attempts to reduce tobacco use could be useful for future counter-marketing campaigns. A related, fifth

direction of future research would be to gain understanding of *why* the changes we observed occurred at tobacco retailers in Columbus, Ohio, after T21 had been implemented. For example, qualitative interviews could be conducted with managers at tobacco retailers to hear their opinions and experiences about price-related changes that occurred after T21 was implemented.

*Limitations*

The current study's findings should be interpreted in the context of the following limitations. First, all of our retailers were located in Columbus, Ohio. Although this allowed us to evaluate the effects of a well-designed T21 policy, the absence of a comparison community prevented us from determining whether changes we saw in the trajectories of cigarette prices and price promotions post-T21 were related to the T21 policy or some other factor specific to Columbus. Other Franklin County retailers were audited for the parent study, but there were few non-Columbus retailers, which ultimately led to small cells and model convergence issues. Future work that includes a larger sample of retailers outside of Columbus, as well as research conducted in other communities with strong T21 policies outside of Ohio, would be useful.

A second limitation was that we did not evaluate the change in price of different tobacco products pre- and post-T21. Prices of Blu e-cigarettes were recorded at each year of retailer audits, but due to limited variability in prices and a large proportion of missing data (46% to 79% missing by year), models did not converge. Investigation of whether the price of e-cigarettes, SLT, cigarillos, and roll-your-own tobacco changed post-T21

implementation would be useful, as other research has demonstrated that increases in cigarette prices are associated with increased use of e-cigarettes[332] and roll-your-own tobacco.[339] If the prices of these other products do not increase as much as cigarettes post-T21, for example, it might signal product substitution.

A third limitation was related to how we represented flavored product availability, exterior tobacco advertisements, and price promotions in models. Rather than being a true count of all flavored products, advertisements, and promotions, they reflected a count of the product *categories* available, advertised, or promoted. Thus, our findings apply to the *variety* of products available, advertised, and promoted, but not the total burden of flavored products, advertisements, or promotions at retailers. A related, fourth limitation was that an increase in count of flavored tobacco products available could have been due to a retailer offering a new product category they had not sold before (e.g., a retailer that had not sold e-cigarettes but began selling both flavored and unflavored e-cigarettes at a later year). A final limitation was that we had no information about other methods of advertising or price discounting that can affect tobacco purchasing behaviors but are not native to the retail environment, such as direct mail advertisements or coupons.

*Strengths*

A major strength of the current study was that we had repeated measures on the same tobacco retailers from 2014 to 2019. This provided more confidence in the estimated trajectories in the pre- and post-T21 periods. Auditing the same retailers repeatedly also allowed retailers to serve as their own controls, and thus unobserved

differences in clientele characteristics or ownership/management that might contribute to differences in our dependent variables were controlled. A second strength was that the T21 policy in Columbus is strong, particularly because it includes enforcement and penalty components. Not only does this make our findings related to changes in marketing practices post-T21 more plausible, but it also provides information for other localities or states about how the retail environment may change when T21 best-practices are followed. A third strength was that all of our analyses controlled for type of store and census tract demographics, which are substantively associated with our dependent variables and were also descriptively associated with year of data collection in the current study.

### *Conclusion*

This study identified that implementation of T21 in a large midwestern city was associated with changes in the trajectories of Marlboro prices and count of price-promoted tobacco products at tobacco retailers. In both cases, changes indicated that the tobacco industry was attempting to reduce the cost of purchasing products after T21 had been implemented. Continued surveillance of the tobacco retail environment, in locations with and without T21 policies, will be important to fully understand how implementation of T21 may affect the retail environment.

Models

**Model 8.** Example Mixed Effects Generalized Linear Model

$$E(Y_i|X, b_i) = \beta_0 + \beta_1 year_i + \beta_2 tob21_i + \beta_3 (year \times tob21)_i + \beta_4 retailer\_type_i + \beta_5 poverty_i + \beta_6 race_i + \beta_7 youth_i + b_{0i}$$

Where:

- $E(Y_i|b_i) =$ dependent variable
- year = year of data collection for retailer *i*
- tob21 = tobacco 21 implemented for retailer *i* (yes vs. no)
- retailer_type = type of retailer for retailer *i* (convenience store or gas station vs. other)
- poverty = census tract poverty level for retailer *i* (high vs. moderate or low)
- race = census tract percent black non-Hispanic for retailer *i* (high vs. moderate or low)
- youth = census tract percent youth for retailer *i* (dichotomized at Franklin County median)
- $b_{0i}$ = random intercept for retailer *i*

Tables and Figures

**Table 9.** Distribution of retailers over time according to store type and census tract demographics, 2014-2019, Columbus, Ohio[a]

| | 2014 (N=77) | 2016 (N=74) | 2017 (N=98) | 2018[b] (N=95) | 2019[b] (N=103) |
|---|---|---|---|---|---|
| Convenience store or gas station (%) | 71.4 | 64.9 | 66.3 | 68.4 | 62.1 |
| Census tract demographics | | | | | |
| ≥20% below poverty level (%) | 57.1 | 58.1 | 65.3 | 67.4 | 66.0 |
| ≥25% black race (%) | 46.8 | 48.7 | 60.2 | 59.0 | 55.3 |
| % youth > county median (%) | 57.1 | 60.8 | 58.2 | 59.0 | 55.3 |

[a] A stratified random sample of retailers were audited by trained fieldworkers during daylight in late spring and summer months of each year.
[b] Tobacco 21 was implemented in Columbus, Ohio, when audits were conducted in 2018 and 2019. Although the policy was implemented in 2017, all retailer audits that year were completed prior to implementation.

**Table 10.** Descriptive statistics summarizing prices of one pack of Marlboro Reds, Newport Menthols, or the cheapest cigarettes offered at Columbus, Ohio, retailers[a]

| | 2015 (N=77) | 2016 (N=74) | 2017 (N=98) | 2018 (N=95) | 2019 (N=103) |
|---|---|---|---|---|---|
| Marlboro ($) | | | | | |
| Range | 4.80, 7.75 | 5.25, 9.75 | 5.42, 8.99 | 5.79, 7.50 | 5.87, 9.00 |
| Mean (SD) | 5.81 (0.44) | 6.48 (0.61) | 6.52 (0.54) | 6.74 (0.39) | 6.86 (0.63) |
| Median | 5.71 | 6.40 | 6.39 | 6.63 | 6.73 |
| Missing (N) | 9 | 7 | 8 | 8 | 11 |
| Newport ($) | | | | | |
| Range | 5.50, 6.95 | 5.44, 7.99 | 5.35, 8.99 | 5.48, 7.55 | 6.03, 8.99 |
| Mean (SD) | 5.86 (0.28) | 6.57 (0.34) | 6.61 (0.55) | 6.80 (0.33) | 7.03 (0.48) |
| Median | 5.83 | 6.50 | 6.55 | 6.73 | 6.91 |
| Missing (N) | 11 | 10 | 7 | 6 | 14 |
| Cheapest ($) | | | | | |
| Range[b] | 2.78, 9.00 | 3.94, 9.75 | 2.39, 8.99 | 3.69, 9.69 | 3.99, 9.00 |
| Mean (SD) | 4.47 (0.97) | 5.10 (0.84) | 5.00 (0.85) | 5.16 (0.80) | 5.39 (0.84) |
| Median | 4.41 | 5.10 | 5.00 | 5.00 | 5.27 |
| Missing (N) | 7 | 5 | 5 | 3 | 10 |

[a] A stratified random sample of retailers were audited by trained fieldworkers during daylight in late spring and summer months of each year. Prices are pre-tax.
[b] The maximum price of the cheapest cigarettes at a retailer is sometimes greater than the maximum price of Marlboro Reds or Newport Menthols due to a retailer not offering those brands or prices for those brands being missing.

**Table 11.** Prices of Marlboro Reds, Newport Menthols, and cheap cigarettes at Columbus, Ohio, tobacco retailers pre- and post-T21[a]

| | Change in Price (99% CI) | | |
|---|---|---|---|
| | Marlboro Reds | Newport Menthols | Cheapest pack |
| Year (one-year increase) | - | 0.24 (0.19, 0.29) | 0.22 (0.16, 0.29) |
| Post-T21 | 0.08 (-0.06, 0.23) | - | - |
| Pre-T21 | 0.25 (0.19, 0.30) | - | - |
| T21 implemented | - | -0.11 (-0.27, 0.05) | -0.12 (-0.33, 0.10) |
| Convenience store or gas station | -0.18 (-0.35, 0.00) | -0.21 (-0.35, -0.07) | -0.14 (-0.40, 0.12) |
| Census tract demographics | | | |
| ≥20% below poverty level | 0.10 (-0.15, 0.35) | 0.03 (-0.13, 0.19) | 0.09 (-0.38, 0.55) |
| ≥25% black race | 0.17 (-0.07, 0.41) | 0.02 (-0.14, 0.18) | -0.01 (-0.45, 0.43) |
| % youth ≥ county median | -0.08 (-0.32, 0.16) | -0.05 (-0.20, 0.11) | -0.30 (-0.74, 0.15) |

Abbreviations: T21 = Tobacco 21; CI = Confidence interval

[a] A stratified random sample of retailers were audited by trained fieldworkers during daylight in late spring and summer months of 2014, 2016, 2017, 2018, and 2019. Prices are pre-tax. Mixed effects linear regression models with random intercepts were fit.

**Table 12.** Distribution of categories of flavored tobacco products sold at Columbus, Ohio, retailers by year[a]

| | | Count of categories of flavored tobacco products sold | | | | |
|---|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 | 4 |
| Year (N, [%]) | | | | | | |
| | 2014 | 8 (10.4) | 4 (5.2) | 12 (15.6) | 18 (23.4) | 48 (45.5) |
| | 2016 | 1 (1.4) | 3 (4.1) | 6 (8.1) | 17 (23.0) | 59 (63.5) |
| | 2017 | 3 (3.1) | 3 (3.1) | 19 (19.4) | 26 (26.5) | 59 (48.0) |
| | 2018 | 2 (2.1) | 2 (2.1) | 14 (14.7) | 43(45.3) | 45 (35.8) |
| | 2019 | 9 (8.7) | 7 (6.8) | 10 (9.7) | 23 (22.3) | 68 (52.4) |

[a] A stratified random sample of retailers were audited by trained fieldworkers during daylight in late spring and summer months of 2014, 2016, 2017, 2018, and 2019. Flavored products assessed included menthol cigarettes and flavored e-cigarettes, SLT, and cigarillos.

**Table 13.** Count of flavored tobacco products sold at Columbus, Ohio, tobacco retailers pre- and post-T21[a]

| | 4 vs 0-3 flavored products sold<br>aOR (99% CI) |
|---|---|
| T21 implemented | 0.36 (0.13, 1.03) |
| Year (one-year increase) | 1.29 (0.94, 1.77) |
| Convenience store or gas station | 1.96 (0.76, 5.02) |
| Census tract demographics | |
| ≥20% below poverty level | 0.25 (0.08, 0.77) |
| ≥25% black race | 0.51 (0.17, 1.53) |
| % youth ≥ county median | 1.04 (0.35, 3.11) |

Abbreviations: T21 = Tobacco 21; aOR = Adjusted odds ratio; CI = Confidence interval
[a] A stratified random sample of retailers were audited by trained fieldworkers during daylight in late spring and summer months in 2014, 2016, 2017, 2018, and 2019. Flavored products assessed included cigarettes, e-cigarettes, SLT, and cigarillos. Mixed effects logistic regression models with random intercepts were fit.

**Table 14.** Count of flavored and unflavored tobacco products advertised outside of Columbus, Ohio, tobacco retailers pre- and post-T21[a]

| | Multiplicative change in count (99% CI) |
|---|---|
| T21 implemented | 1.39 (1.02, 1.90) |
| Year (one-year increase) | 0.78 (0.67, 0.90) |
| Convenience store or gas station | 1.10 (0.68, 1.78) |
| Census tract demographics | |
| ≥20% below poverty level | 0.74 (0.40, 1.37) |
| ≥25% black race | 1.36 (0.76, 2.46) |
| % youth > county median | 1.53 (0.87, 2.69) |

Abbreviations: T21 = Tobacco 21; CI = Confidence interval

[a] A stratified random sample of retailers were audited by trained fieldworkers during daylight in late spring and summer months in 2016, 2017, 2018, and 2019. Exterior advertisements for menthol and non-menthol cigarettes; flavored and unflavored e-cigarettes, SLT, and cigarillos; large cigars; and hookah were assessed. Mixed effects Poisson regression models with random intercepts and robust standard errors were fit.

**Table 15.** Count of tobacco products with interior or exterior price promotions at Columbus, Ohio, retailers pre- and post-T21[a]

| | Multiplicative change in count (99% CI) |
|---|---|
| Year (one-year increase) | |
| Post-T21 | 1.29 (0.94, 1.78) |
| Pre-T21 | 0.79 (0.58, 1.07) |
| Convenience store or gas station | 1.24 (0.80, 1.92) |
| Census tract demographics | |
| ≥20% below poverty level | 0.53 (0.29, 0.96) |
| ≥25% black race | 0.87 (0.49, 1.55) |
| % youth ≥ county median | 1.10 (0.62, 1.94) |

[a] A stratified random sample of retailers were audited by trained fieldworkers during daylight in late spring and summer months in 2016, 2017, 2018, and 2019. Interior and exterior price promotions for menthol and non-menthol cigarettes; flavored and unflavored e-cigarettes, SLT, and cigarillos; large cigars; and hookah were assessed. Mixed effects negative binomial regression models with random intercepts were fit.

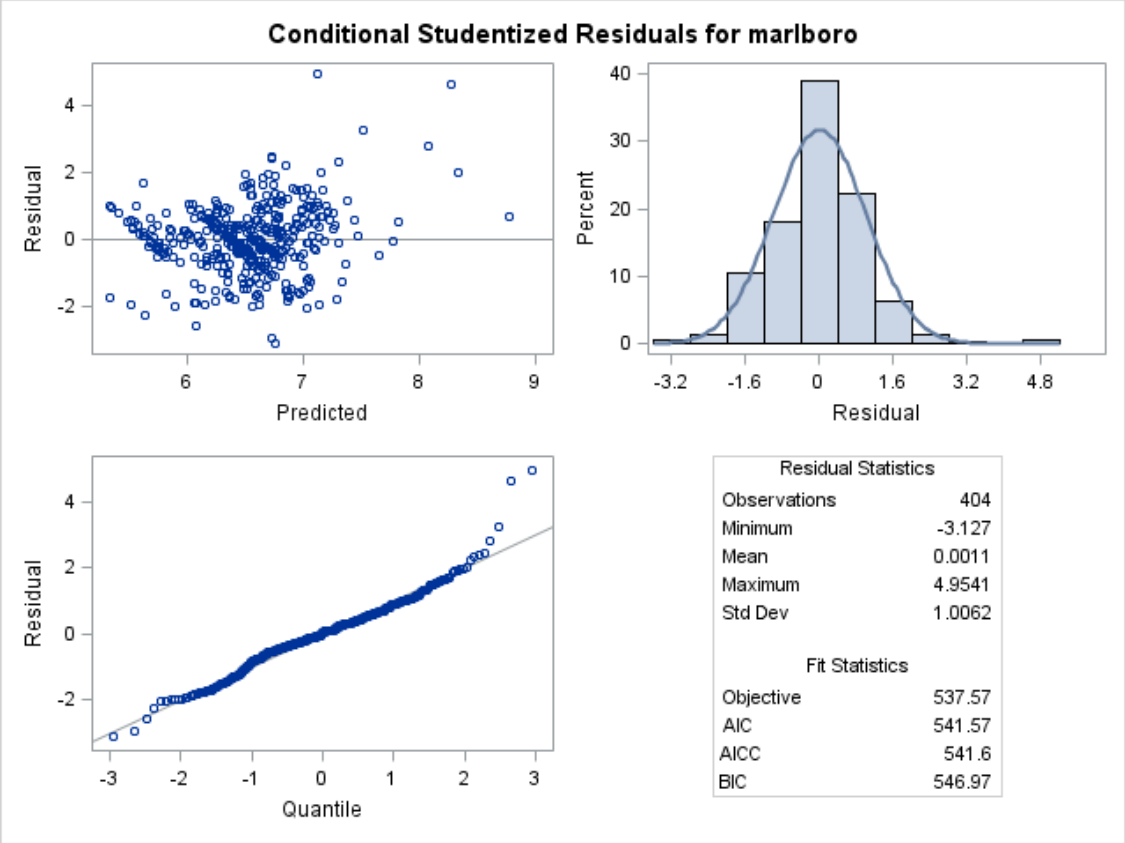


**Figure 10**. Studentized residuals plots for Marlboro price linear mixed models

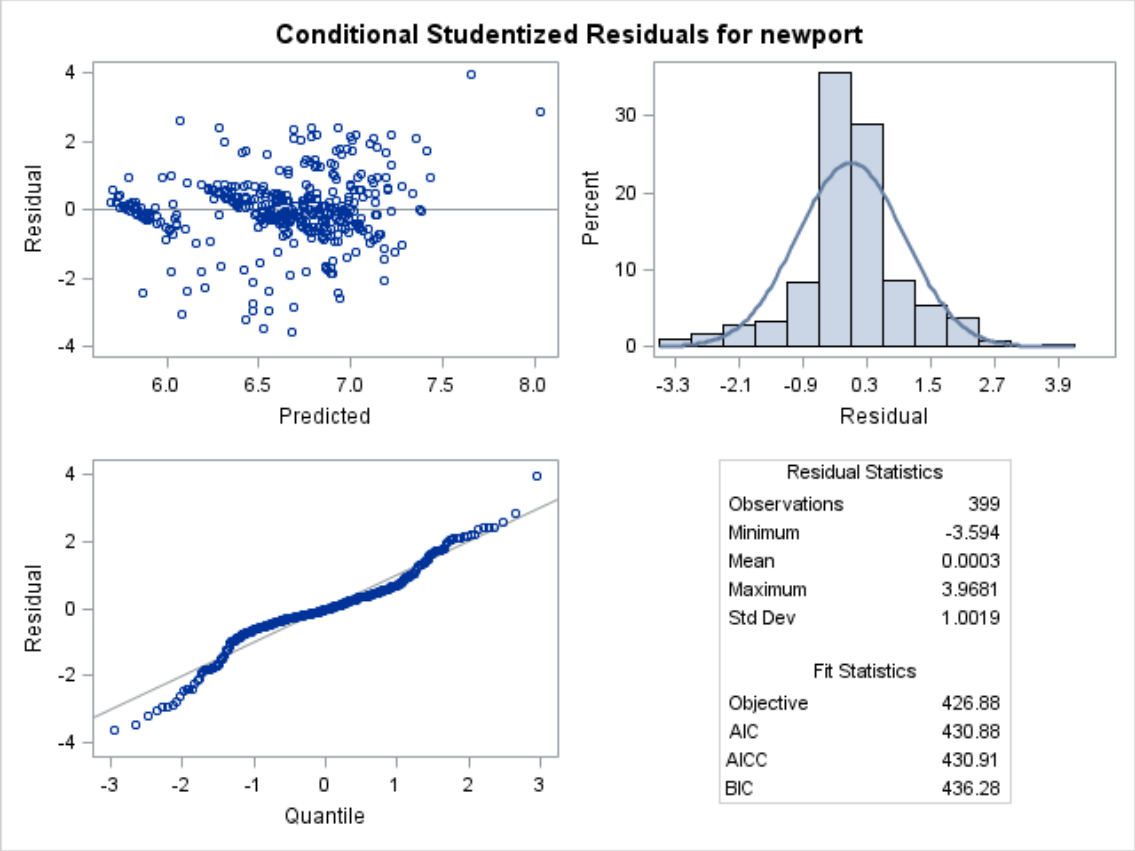


**Figure 11.** Studentized residuals plots for Newport price linear mixed models

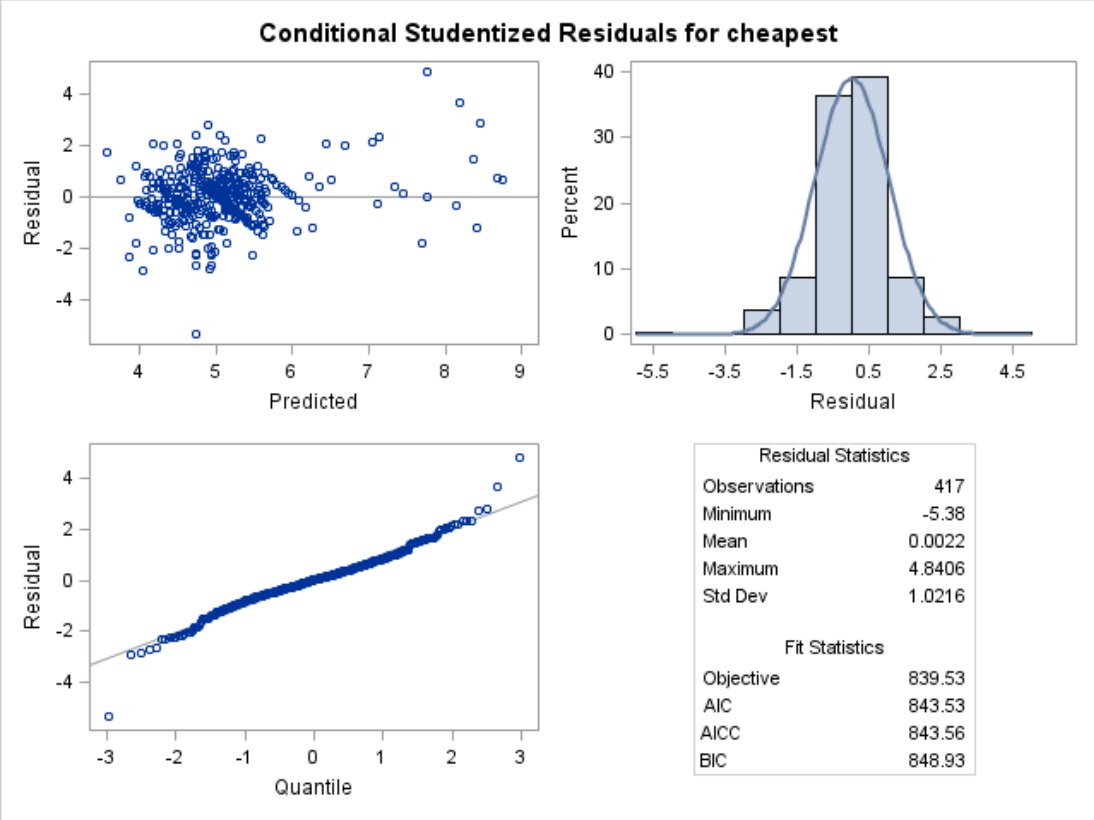


**Figure 12.** Studentized residuals plots for cheapest cigarette price linear mixed models

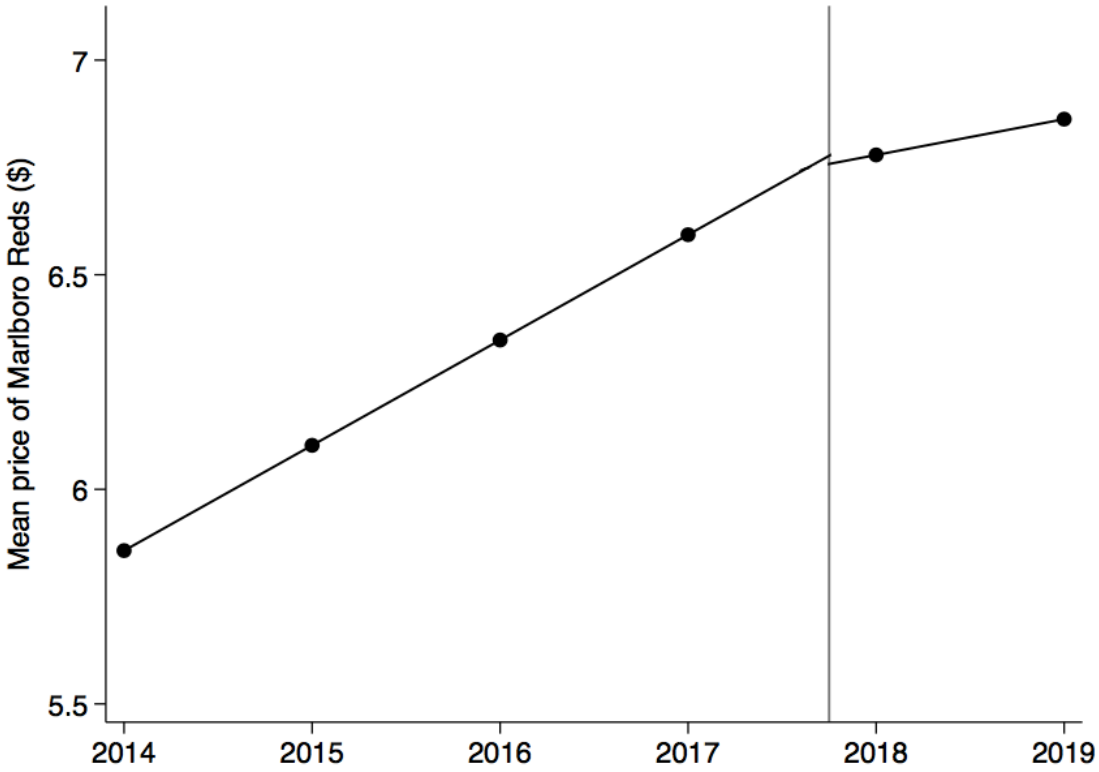


**Figure 13.** Estimated price of one pack of Marlboro Reds before and after T21 implementation, Columbus, Ohio[a]

[a] A stratified random sample of retailers were audited by trained fieldworkers during daylight in late spring and summer months of 2014, 2016, 2017, 2018, and 2019. Prices are pre-tax. Estimated mean prices were obtained from mixed effects linear regression models with random intercepts. Models controlled for store type and census tract poverty level, race, and percent youth.

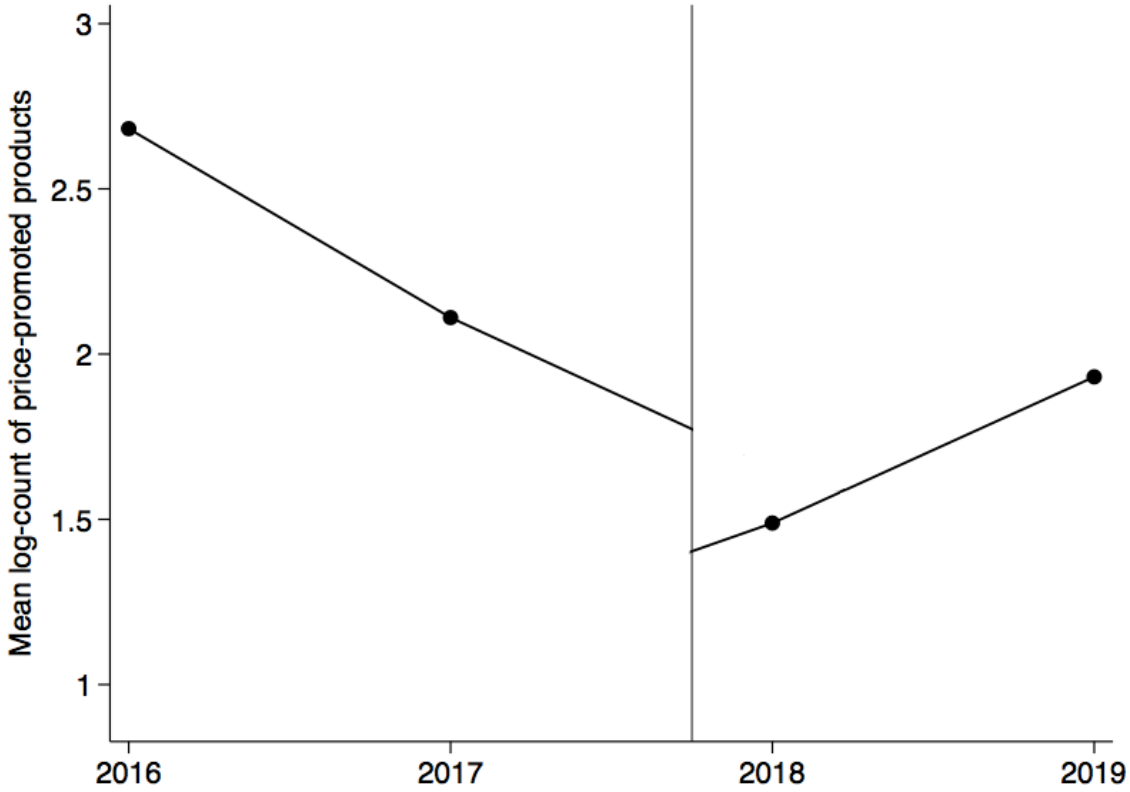


**Figure 14.** Estimated log-count of tobacco products with price promotions inside or outside of retailers before and after T21 implementation, Columbus, Ohio[a]

[a] A stratified random sample of retailers were audited by trained fieldworkers during daylight in late spring and summer months of 2016, 2017, 2018, and 2019. Estimated mean log counts of promotions were obtained from mixed effects negative binomial regression models with random intercepts. Models controlled for store type and census tract poverty level, race, and percent youth.

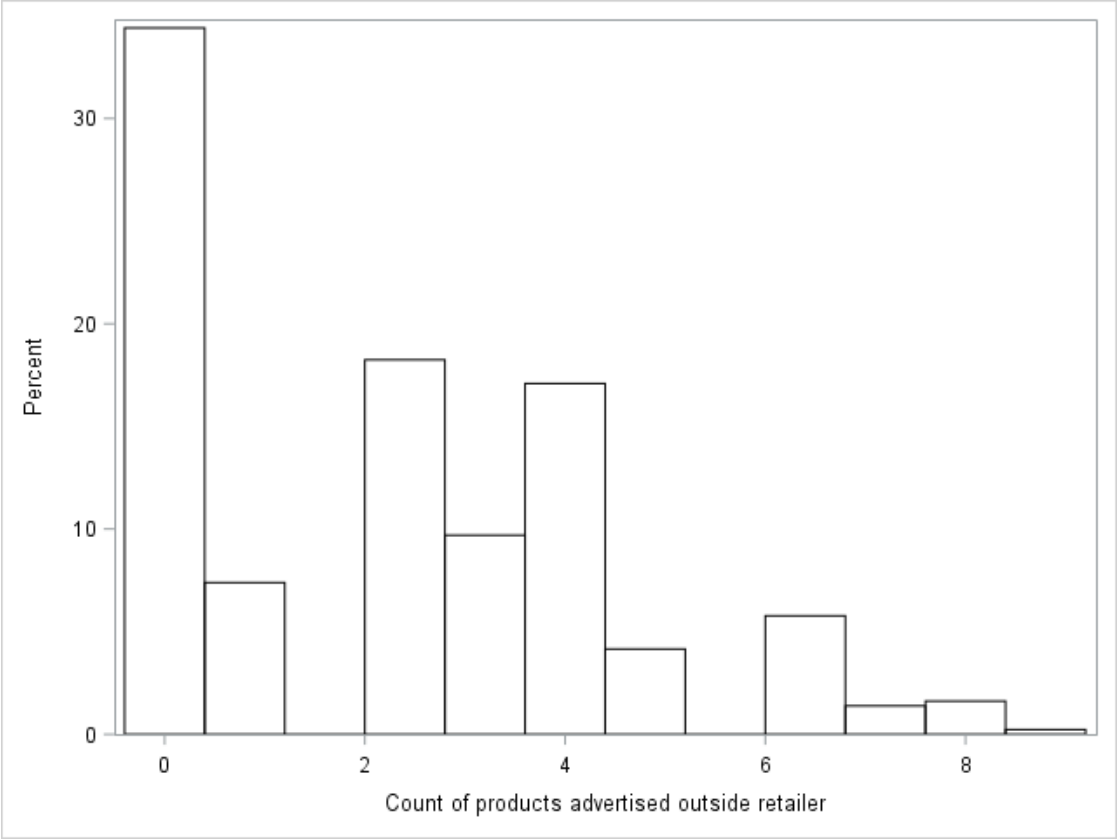


**Figure 15.** Distribution of count of tobacco products advertised outside of retailers in Columbus, Ohio[a]

[a] A stratified random sample of retailers were audited by trained fieldworkers during daylight in late spring and summer months in 2016, 2017, 2018, and 2019. Exterior advertisements for menthol and non-menthol cigarettes; flavored and unflavored e-cigarettes, SLT, and cigarillos; large cigars; and hookah were assessed.

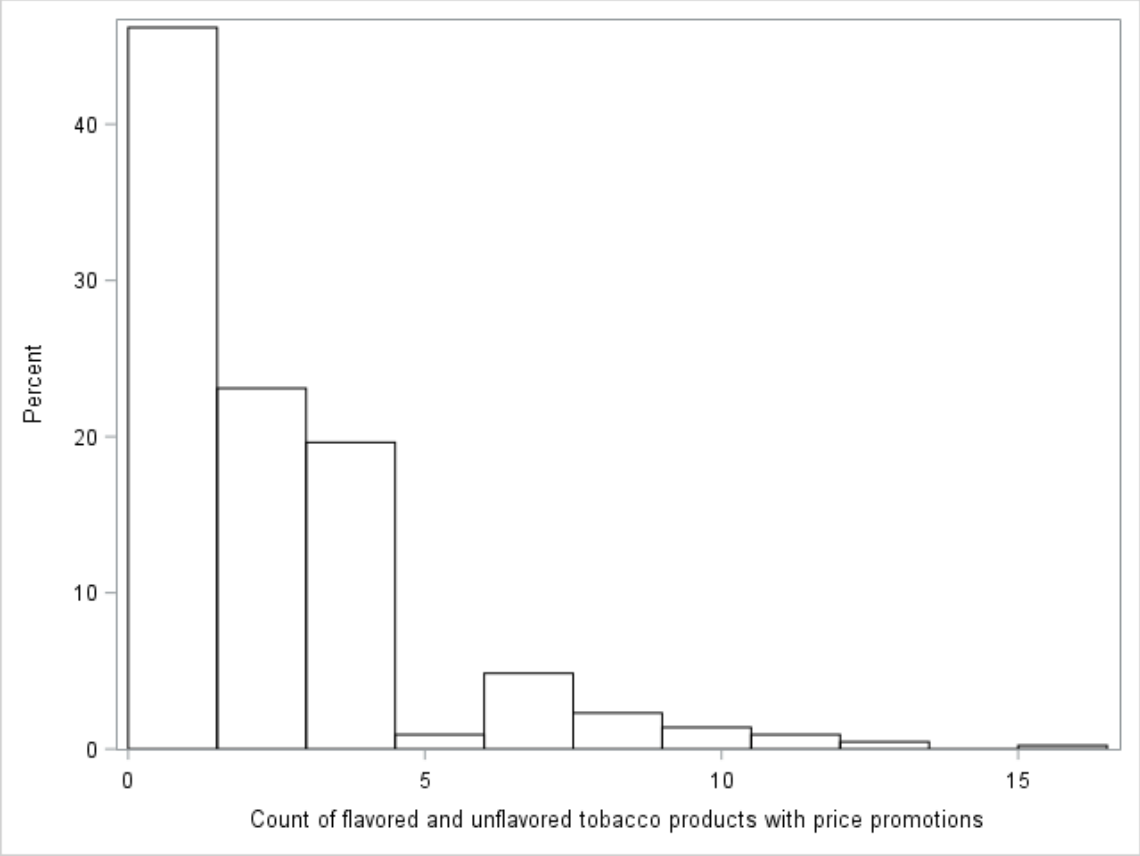


**Figure 16.** Distribution of count of tobacco products with price promotions at retailers in Columbus, Ohio[a]

[a] A stratified random sample of retailers were audited by trained fieldworkers during daylight in late spring and summer months in 2016, 2017, 2018, and 2019. Interior and exterior price promotions for menthol and non-menthol cigarettes; flavored and unflavored e-cigarettes, SLT, and cigarillos; large cigars; and hookah were assessed.

# Chapter 6. Discussion

The long-term goal of this research is to reduce the prevalence of tobacco use among adolescents in the U.S. This research was organized using the social ecological model, which describes that risk and protective factors for health behaviors occur at multiple levels of influence.[16] The advantage of using this model to study tobacco use among adolescents is that it can be used to more comprehensively 1) understand why adolescents use tobacco and 2) guide interventions to reduce tobacco use. In other words, rather than focusing on only individual-level risk factors for using tobacco products, consideration of risk factors at the community and policy levels provides additional information about the context of one's health behaviors. In the field of tobacco control, in particular, this more comprehensive focus is important because policies aiming to reduce tobacco use have been vital to the success of tobacco control in the U.S.[1]

Using the social ecological model's framework, the current research studied risk factors at the individual, community, and policy levels. In the Aim 1 study, where we focused on the individual level, we evaluated whether e-cigarette use served as a gateway to initiation of cigarettes and SLT in a cohort of adolescent males. Although several observational studies have examined this research question,[7] ours was the first to use a causal framework and the first to evaluate risk of SLT initiation, which remains a public health threat—particularly in Ohio Appalachia.[198] In the Aim 2 study, where we focused

on the community level, we described how parent-reported measures of perceived neighborhood quality were associated with boys' risk of initiating use of traditional and emerging tobacco products. Unlike the few other studies that have evaluated this research question,[103,104,211] we modeled incident rather than prevalent tobacco use and estimated risk of initiating multiple tobacco products rather than focusing on only cigarettes and e-cigarettes. In the Aim 3 study, where we focused on the policy level, we modeled trajectories in characteristics of the tobacco retail environment in a sample of Columbus, Ohio, retailers. We then evaluated whether observed trajectories changed post-T21 implementation. By studying retailers in Columbus, Ohio, we were able to observe how the retail environment changed after implementation of a strong T21 policy.

Across the three aims, we have advanced the understanding of risk factors for tobacco use among adolescents at the individual, community, and policy levels of the social ecological model. In the Aim 1 study, we identified that boys who had ever used e-cigarettes had an increased risk of initiating ever and past 30-day use of cigarettes and SLT. Because we conducted a propensity score matched analysis, the boys who had used e-cigarettes were very similar to boys who had never used e-cigarettes—with the exception of their e-cigarette use. Additionally, our use of multiple imputation to address unit nonresponse allowed us to keep boys who had a higher risk of initiating use of other tobacco products in the analytic sample. Together, the use of propensity score matching and multiple imputation demonstrated that it is reasonable to think of e-cigarettes as a "gateway" to ever and current use of other harmful tobacco products among adolescents. We provided evidence that the observed associations between e-cigarette use and use of

other tobacco products is likely driven by more than simply a common liability for using tobacco.

In the Aim 2 study, we found that boys who lived in a physically disordered neighborhood at age 10 had a greater short-term (i.e., instantaneous) risk of initiating traditional tobacco products, including cigarettes, cigars, and SLT throughout adolescence. These findings agreed with earlier literature that evaluated whether perceived neighborhood quality was associated with past year and past 30-day cigarette and e-cigarette use.[103,104] However, we did not find associations between other measures of perceived neighborhood quality and risk of traditional tobacco product initiation, nor did we find associations between perceived neighborhood quality and risk of emerging tobacco product initiation. Reasons for these null results could be related to the substantial attrition and young ages of many participants in our cohort, which resulted in reduced power and a cohort that was at lower risk of tobacco use overall. Additionally, we did not measure how stressful the boys themselves found their neighborhoods at age 10. Because some of the association between perceived neighborhood quality and tobacco use is hypothesized to be mediated by stress, it is possible that boys found other aspects of the neighborhood, such as social disorder, less stressful. Finally, it is possible that the lack of association between perceived neighborhood quality and risk of emerging tobacco product use was due to the novelty of e-cigarettes and hookah in the U.S. They might have been more difficult to obtain than traditional tobacco products, for example.

In the Aim 3 study, we detected a change in the trajectories of the price of Marlboro Reds and count of price-promoted products after T21 was implemented in

Columbus, Ohio. In both cases, the change in trajectory resulted in products being available for a lower price than they would have been if the pre-T21 trajectory had continued. We identified no change in trajectory post-T21 in availability of flavored tobacco products or count of tobacco products advertised outside of stores. These results suggest that implementation of T21 might be associated with changes to the retail environment that make at least some tobacco products more accessible to price-sensitive young adults.

## Implications for Policy

As stated above, an advantage of using the social ecological model to organize this research was that the results of these three studies can be used to inform more comprehensive tobacco control policies aiming to reduce adolescent use of tobacco products. Our findings that youth who use e-cigarettes are at greater risk of becoming ever and current users of cigarettes and SLT add additional evidence about the harm of youth e-cigarette use, which can be used to support policies that make e-cigarettes less appealing to youth. Such policies could include bans on flavors,[260] strategies to raise e-cigarette prices or raise the MLSA,[44,249] or setting other product standards that ultimately make e-cigarettes less addictive or less appealing to youth (e.g., regulating nicotine content and/or pH). Additional research that models causal associations between characteristics of e-cigarettes (e.g., specific flavors, nicotine content, or pH) and risk of initiating other tobacco products, as well as escalation of e-cigarette use from

experimentation to regular use and nicotine dependence, would be useful evidence in support of these policies.

With additional research into the mechanisms underlying the association we observed between perceived physical disorder and risk of traditional tobacco product initiation among adolescents, there could be policy implications of our findings. For example, other research has identified that density of tobacco retailers is higher in lower-SES census tracts.[32] There is evidence of increased tobacco advertising and lower tobacco prices in these census tracts as well.[30,34] If adolescents living in physically disordered neighborhoods are susceptible to using tobacco because they are stressed, these other characteristics only serve to make tobacco products more accessible. Licensing and zoning laws that limit the density of tobacco retailers or prevent them being within a certain proximity of locations frequented by youth could then be used to reduce risk of tobacco initiation for adolescents living in these neighborhoods. Additionally, strategies to raise prices (e.g., excise taxes or minimum price laws) could further reduce risk of tobacco initiation among youth.

By raising the MLSA from 18- to 21-years-old, T21 reduces the prevalence of tobacco use among youth and young adults.[249] However, we identified that it may also be associated with changes to the tobacco retail environment that ultimately make some tobacco products more affordable. These changes could be mitigated through concurrent implementation of an excise tax increase on tobacco products, minimum price laws, and/or a ban on price discounts at tobacco retailers. As none of these policies restrict speech, there are fewer legal challenges to their implementation than other tobacco

control policies.[255]Additional investigation into whether the tobacco industry increased the coupons distributed to consumers through direct mail or other sources would also be useful to support implementation of minimum price laws or coupon redemption bans. Moreover, research into how consumers actually responded to the change in trajectories in the price of Marlboro Reds and count of price-promoted tobacco products would help to frame the public health impact of the above policies.

## Implications for Future Research

Findings from this research provide direction for future research across levels of the social ecological model. At the individual level, the results of the Aim 1 study could be extended by identifying which aspects of e-cigarettes, exactly, increase the risk of initiating use of other tobacco products. As described above, these factors might be flavors, nicotine content, or pH—although it is also possible that nicotine dependence or establishment of a behavioral habit (e.g., hand-to-mouth repetition) largely drives the transition to other products. Additionally, continued study of risk and protective factors for e-cigarette use among adolescents, particularly research that includes girls, would be useful for informing prevention and cessation interventions. From the Aim 2 study, research into individual-level factors that might mediate or moderate the association we identified between physically disordered neighborhoods and risk of initiating traditional tobacco products would be informative for developing tobacco prevention programming. For example, if stress mediates this association, then interventions teaching healthy coping mechanisms that are targeted to youth living in physically disordered

neighborhoods could be a successful method to prevent initiation of traditional tobacco products. From the Aim 3 study, future research could be used to describe how individuals of different ages and socioeconomic positions respond to changes in tobacco prices post-T21 implementation. In addition to potentially providing support for price-raising policies that were described above, results of such research would identify groups of people who could be targeted with tobacco prevention or cessation interventions concurrent with the implementation of T21 policy to mitigate the effects of price-discounting strategies.

At the community level, the Aim 1 study's results could be extended by evaluating factors in the neighborhood and school environments that might mediate or moderate the causal associations we observed between e-cigarette use and initiation of cigarettes and SLT. For example, neighborhoods with increased tobacco retailer density or exterior advertising for tobacco products might provide an environment that increases adolescents' risk of transitioning from e-cigarettes to cigarettes or SLT. Conversely, schools with strong tobacco prevention programs might decrease the risk of this transition (and, ideally, decrease the risk of initiating of e-cigarettes). The Aim 2 study's results could also be extended with future work, as described above, that identifies whether some of the association between living in a physically disordered neighborhood and initiation of traditional tobacco products is due to increased tobacco retailer density or tobacco marketing in those neighborhoods. Other research that evaluates whether social norms related to tobacco use may vary according to perceived neighborhood quality, in general, would be useful to better understand the associations we observed. The Aim 3 study's

results could be extended by studying the effects of T21 in different communities—particularly if they implemented T21 at different times. These results would provide insight into whether the changes in marketing practices post-T21 that we observed in Columbus, Ohio, were in fact related to T21 policy or part of a larger change in marketing trends. Results would be even more useful if community types varied by urban and rural status, as well as by sociodemographic characteristics. As the current research used mixed models, consideration of these community characteristics could potentially lead to development of models that predict how the retail environment will change post-T21 implementation in a given community.

At the policy level, future work related to Aim 1 could model the effects of different policies that aim to reduce adolescent e-cigarette use on risk of initiating cigarettes and SLT. The benefit of conducting this work would be providing further public health justification for policies aiming to reduce e-cigarette use among youth. Future work related to Aim 2 could model the effects of policies that reduce tobacco retailer density on adolescent tobacco use in differing contexts of perceived neighborhood quality. Future work related to Aim 3 could evaluate how the tobacco retail environment might change if T21 is implemented concurrently with other tobacco control policies, such as tax increases, minimum price laws, or price discounting bans.

## Limitations

Across the three aims, this research has the following limitations. The first and most important limitation was that each study was a secondary data analysis. In the ideal

Aim 1 and Aim 2 studies, we would have started following participants from earlier ages, and followed up with them more frequently, to 1) more accurately obtain their ages of initiating tobacco use and reaching tobacco use milestones like progression to current use or nicotine dependence, and 2) establish temporality of risk factors for tobacco initiation. Additionally, the ideal Aim 1 and Aim 2 studies would have included girls to improve generalizability of study results. In the ideal Aim 3 study, we would have sampled more tobacco retailers in central Ohio that were not in Columbus. This would have allowed us to better establish whether the changes we observed post-T21 implementation were related to T21 implementation or simply a change in regional trends that was simultaneous with but unrelated to T21 implementation. For all aims, it would have also been useful to have longer follow-ups, so that in Aims 1 and 2 all participants aged into young adulthood, and in Aim 3 we could have more confidence in our estimated time trends of marketing practices.

A second, but related, limitation was that all studies only took place in Ohio. Although the relatively high prevalence of tobacco use in Ohio makes it a good setting to study adolescent tobacco use,[5,53] our results would have been more generalizable if studies had included participants and retailers from different regions of the U.S. A third limitation, specific to the Aim 1 and Aim 2 studies, was that our measure of region was coarse. By dichotomizing participants by urban vs. Appalachian status, we did not capture the heterogeneity of the Appalachian region, which contains varying levels of urbanicity and rurality as well as economic distress.[193] This dichotomization could have left unmeasured confounding in our analyses.

A fourth limitation was that most data for the three studies were collected prior to the surge in JUUL use among adolescents in the U.S. In the Aim 1 and Aim 2 studies, the last time point of data collection for all participants was completed between January of 2017 and August of 2018, which was at the same time that the prevalence of JUUL use was increasing dramatically among adolescents.[6] Thus, with another year of follow-up, it is possible that results of both studies could change as a result of the increase in e-cigarette use in the cohort. Similarly, the implementation of T21 in Columbus, and therefore our post-T21 data collection period, overlapped with the increase in JUUL's market share.[168] It is possible, then, that the changes we observed in marketing practices at Columbus, Ohio, retailers were actually due to tobacco companies responding to the rapid rise of a new product.

## Conclusion

In conclusion, patterns of tobacco use are changing rapidly among adolescents in the U.S., with the prevalence of e-cigarette use soaring as the prevalence of using more traditional tobacco products continues to decrease.[3,6] The current studies evaluated risk factors for use of emerging and tobacco products in the U.S. at the individual, community, and policy levels of the social ecological model. Together, study results provide direction for future research and justification for policies to reduce adolescent tobacco use in the U.S.

Reference


1. U.S. Department of Health and Human Services. *The Health Consequences of Smoking—50 Years of Progress: A Report of the Surgeon General*. Atlanta, GA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion, Office on Smoking and Health,; 2014:1-978. https://permanent.access.gpo.gov/gpo45352/PDF version/Full report/full-report.pdf.

2. Wang TW, Asman K, Gentzke AS, et al. Tobacco Product Use Among Adults — United States, 2017. 2018;67(44):8.

3. Wang TW, Gentzke A, Sharapova S, Cullen KA, Ambrose BK, Jamal A. Tobacco Product Use Among Middle and High School Students — United States, 2011–2017. *MMWR*. 2018;67(22):629-633. doi:10.15585/mmwr.mm6722a3

4. U.S. Department of Health and Human Services. Preventing Tobacco Use among Youth and Young Adults: A Report of the Surgeon General. 2012. doi:10.1037/e603152012-001

5. Campaign for Tobacco-Free Kids. *Key State-Specific Tobacco-Related Data & Rankings*. Washington, D.C.: Campaign for Tobacco-Free Kids; 2019:1-3. https://www.tobaccofreekids.org/assets/factsheets/0176.pdf.

6. Centers for Disease Control and Prevention. *Progress Erased: Youth Tobacco Use Increased during 2017-2018*. Atlanta, GA: U.S. Department of Health and Human Services; 2019. https://www.cdc.gov/media/releases/2019/p0211-youth-tobacco-use-increased.html. Accessed May 4, 2019.

7. Soneji S, Barrington-Trimis JL, Wills TA, et al. Association Between Initial Use of e-Cigarettes and Subsequent Cigarette Smoking Among Adolescents and Young Adults: A Systematic Review and Meta-analysis. *JAMA Pediatrics*. 2017;171(8):788-797. doi:10.1001/jamapediatrics.2017.1488

8. Hanewinkel R, Isensee B. Risk factors for e-cigarette, conventional cigarette, and dual use in German adolescents: A cohort study. *Preventive Medicine*. 2015;74:59-62. doi:10.1016/j.ypmed.2015.03.006

9. Leventhal AM, Strong DR, Sussman S, et al. Psychiatric comorbidity in adolescent electronic and conventional cigarette use. *Journal of Psychiatric Research*. 2016;73:71-78. doi:10.1016/j.jpsychires.2015.11.008

10. Shahab L, Goniewicz ML, Blount BC, et al. Nicotine, Carcinogen, and Toxin Exposure in Long-Term E-Cigarette and Nicotine Replacement Therapy Users: A Cross-sectional Study. *Annals of Internal Medicine*. 2017;166(6):390. doi:10.7326/M16-1107

11. Yuan M, Cross SJ, Loughlin SE, Leslie FM. Nicotine and the adolescent brain. *Journal of Physiology*. 2015;593(16):3397-3412. doi:10.1113/JP270492

12. Dwyer JB, McQuown SC, Leslie FM. The dynamic effects of nicotine on the developing brain. *Pharmacology & Therapeutics*. 2009;122(2):125-139. doi:10.1016/j.pharmthera.2009.02.003

13. Conrad M, Gorka SM, Kassel J. Smoking's effects on respiratory sinus arrhythmia in adolescent smokers. *International Journal of Psychophysiology*. 2015;97(1):8-13. doi:10.1016/j.ijpsycho.2015.05.002

14. Chen J-M, Hwang B-F, Chen Y-C, Lee YL. Active smoking, environmental tobacco smoke and bronchitic symptoms among adolescents in Taiwan: A prospective cohort study. *Preventive Medicine*. 2014;65:116-121. doi:10.1016/j.ypmed.2014.05.007

15. Tomar SL, Winn DM, Swango PA, Giovino GA, Kleinman DV. Oral Mucosal Smokeless Tobacco Lesions among Adolescents in the United States. *Journal of Dental Research*. 1997;76(6):1277-1286. doi:10.1177/00220345970760060701

16. Sallis JF, Owen N, Fisher EB. Ecological Models of Health Behavior. In: Glanz K, Rimer BK, Viswanath K, eds. *Health Behavior and Health Education: Theory, Research, and Practice*. 4th ed. San Francisco, CA: Jossey-Bass; 2008:465-485.

17. Fryar CD, Merino MC, Hirsch R, Porter KS. *Smoking, Alcohol Use, and Illicit Drug Use Reported by Adolescents Aged 12-17 Years: United States, 1999-2004.*; 2009:1-23. http://www.ncbi.nlm.nih.gov/pubmed/19634304.

18. Poonawalla IB, Kendzor DE, Owen MT, Caughy MO. Family income trajectory during childhood is associated with adolescent cigarette smoking and alcohol use. *Addictive Behaviors*. 2014;39(10):1383-1388. doi:10.1016/j.addbeh.2014.05.005

19. Hampson SE, Andrews JA, Severson HH, Barckley M. Prospective Predictors of Novel Tobacco and Nicotine Product Use in Emerging Adulthood. *Journal of Adolescent Health*. 2015;57(2):186-191. doi:10.1016/j.jadohealth.2015.04.015

20. Soneji S, Sargent J, Tanski S. Multiple tobacco product use among US adolescents and young adults. *Tobacco Control*. 2016;25(2):174-180. doi:10.1136/tobaccocontrol-2014-051638

21. Doran N, Sanders PE, Bekman NM, et al. Mediating Influences of Negative Affect and Risk Perception on the Relationship Between Sensation Seeking and Adolescent Cigarette Smoking. *Nicotine & Tobacco Research*. 2011;13(6):457-465. doi:10.1093/ntr/ntr025

22. Urberg KA, Degirmencioglu SM, Pilgrim C. Close Friend and Group Influence on Adolescent Cigarette Smoking and Alcohol Use. *Developmental Psychology*. 1997;33(5):834-844.

23. Maxwell KA. Friends: The Role of Peer Influence Across Adolescent Risk Behaviors. *Journal of Youth and Adolescence*. 2002;31(4):267-277.

24. Villanti A, Boulay M, Juon H-S. Peer, parent and media influences on adolescent smoking by developmental stage. *Addictive Behaviors*. 2011;36:133-136. doi:10.1016/j.addbeh.2010.08.018

25. Liao Y, Huang Z, Huh J, Pentz MA, Chou C-P. Changes in Friends' and Parental Influences on Cigarette Smoking From Early Through Late Adolescence. *Journal of Adolescent Health*. 2013;53(1):132-138. doi:10.1016/j.jadohealth.2013.01.020

26. Huang GC, Unger JB, Soto D, et al. Peer Influences: The Impact of Online and Offline Friendship Networks on Adolescent Smoking and Alcohol Use. *Journal of Adolescent Health*. 2014;54(5):508-514. doi:10.1016/j.jadohealth.2013.07.001

27. Mays D, Gilman SE, Rende R, Luta G, Tercyak KP, Niaura RS. Parental Smoking Exposure and Adolescent Smoking Trajectories. *PEDIATRICS*. 2014;133(6):983-991. doi:10.1542/peds.2013-3003

28. Kravitz-Wirtz N. A discrete-time analysis of the effects of more prolonged exposure to neighborhood poverty on the risk of smoking initiation by age 25. *Soc Sci Med*. 2016;148:79-92. doi:10.1016/j.cogdev.2010.08.003.Personal

29. Yerger VB, Przewoznik J, Malone RE. Racialized Geography, Corporate Activity, and Health Disparities: Tobacco Industry Targeting of Inner Cities. *Journal of Health Care for the Poor and Underserved*. 2007;18(4A):10-38. doi:10.1353/hpu.2007.0120

30. Henriksen L, Andersen-Rodgers E, Zhang X, et al. Neighborhood Variation in the Price of Cheap Tobacco Products in California: Results From Healthy Stores for a Healthy Community. *Nicotine & Tobacco Research*. 2017;19(11):1330-1337. doi:10.1093/ntr/ntx089

31. Yu D, Peterson NA, Sheffer MA, Reid RJ, Schnieder JE. Tobacco outlet density and demographics: Analysing the relationships with a spatial regression approach. *Public Health*. 2010;124(7):412-416. doi:10.1016/j.puhe.2010.03.024

32. Rodriguez D, Carlos HA, Adachi-mejia AM, Berke EM, Sargent JD. Predictors of tobacco outlet density nationwide: a geographic analysis. *Tobacco Control*. 2013;22(5):349-355. doi:10.1136/tobaccocontrol-2011-050120.Predictors

33. Siahpush M, Jones PR, Singh GK, Timsina LR, Martin J. Association of availability of tobacco products with socio-economic and racial/ethnic characteristics of neighbourhoods. *Public Health*. 2010;124(9):525-529. doi:10.1016/j.puhe.2010.04.010

34. Barbeau EM, Wolin KY, Naumova EN, Balbach E. Tobacco advertising in communities: Associations with race and class. *Preventive Medicine*. 2005;40(1):16-22. doi:10.1016/j.ypmed.2004.04.056

35. Novak SP, Reardon SF, Raudenbush SW, Buka SL. Retail tobacco outlet density and youth cigarette smoking: A propensity-modeling approach. *American Journal of Public Health*. 2006;96(4):670-676. doi:10.2105/AJPH.2004.061622

36. Paynter J, Edwards R. The impact of tobacco promotion at the point of sale: A systematic review. *Nicotine and Tobacco Research*. 2009;11(1):25-35. doi:10.1093/ntr/ntn002

37. Spanopoulos D, Britton J, McNeill A, Ratschen E, Szatkowski L. Tobacco display and brand communication at the point of sale: Implications for adolescent smoking behaviour. *Tobacco Control*. 2014;23(1):64-69. doi:10.1136/tobaccocontrol-2012-050765

38. Lipperman-Kreda S, Grube JW, Friend KB, Mair C. Tobacco Outlet Density, Retailer Cigarette Sales without ID Checks, and Enforcement of Underage Tobacco Laws: Associations with Youths' Cigarette Smoking and Beliefs. *Addiction*. 2016;111(3):525-532. doi:10.1111/add.13179.Tobacco

39. Loomis BR, Kim AE, Busey AH, Farrelly MC, Willett JG, Juster HR. The density of tobacco retailers and its association with attitudes toward smoking, exposure to point-of-sale tobacco advertising, cigarette purchasing, and smoking among New York youth. *Preventive Medicine*. 2012;55(5):468-474. doi:10.1016/j.ypmed.2012.08.014

40. Schleicher NC, Johnson TO, Fortmann SP, Henriksen L. Tobacco outlet density near home and school: Associations with smoking and norms among US teens. *Preventive Medicine*. 2016;91:287-293. doi:10.1016/j.ypmed.2016.08.027.Tobacco

41. Pechmann C, Levine L, Loughlin S, Leslie F. Impulsive and Self-Conscious: Adolescents' Vulnerability to Advertising and Promotion. *Journal of Public Policy & Marketing*. 2005;24(2):202-221. doi:10.1509/jppm.2005.24.2.202

42. Shadel WG, Tharp-Taylor S, Fryer CS. How does exposure to cigarette advertising contribute to smoking in adolescents? The role of the developing self-concept and identification with advertising models. *Addictive Behaviors*. 2009;34(11):932-937. doi:10.1016/j.addbeh.2009.05.014

43. Ross H, Chaloupka FJ. The effect of cigarette prices on youth smoking. *Health Economics*. 2003;12(3):217-230. doi:10.1002/hec.709

44. van Hasselt M, Kruger J, Han B, et al. The relation between tobacco taxes and youth and young adult smoking: What happened following the 2009 U.S. federal tax increase on cigarettes? *Addictive Behaviors*. 2015;45:104-109. doi:10.1016/j.addbeh.2015.01.023

45. Tworek C, Yamaguchi R, Kloska DD, et al. State-level tobacco control policies and youth smoking cessation measures. *Health Policy*. 2010;97(2-3):136-144. doi:10.1016/j.healthpol.2010.04.009

46. H.R. 2 -- 111th Congress. *Children's Health Insurance Program Reauthorization Act of 2009*.; 2009. https://www.congress.gov/111/plaws/publ3/PLAW-111publ3.pdf.

47. H.R. 3979 -- 98th Congress. *Comprehensive Smoking Education Act*.; 1984. https://www.gpo.gov/fdsys/pkg/STATUTE-98/pdf/STATUTE-98-Pg2200.pdf.

48. H.R. 1256 — 111th Congress. *Family Smoking Prevention and Tobacco Control Act*.; 2009. https://www.gpo.gov/fdsys/pkg/PLAW-111publ31/pdf/PLAW-111publ31.pdf.

49. Food and Drug Administration. *Deeming Tobacco Products To Be Subject to the Federal Food, Drug, and Cosmetic Act, as Amended by the Family Smoking Prevention and Tobacco Control Act; Restrictions on the Sale and Distribution of Tobacco Products and Required Warning Statements for Tobacco Products*. FDA; 2016. https://www.federalregister.gov/documents/2016/05/10/2016-10685/deeming-tobacco-products-to-be-subject-to-the-federal-food-drug-and-cosmetic-act-as-amended-by-the.

50. Campaign for Tobacco-Free Kids. *State Cigarette Excise Tax Rates & Rankings*. Washington, D.C.: Campaign for Tobacco-Free Kids; 2018. https://www.tobaccofreekids.org/assets/factsheets/0097.pdf. Accessed June 13, 2019.

51. Johnston LD, O'Malley PM, Miech RA, Bachman JG, Schulenberg JE. *Monitoring the Future National Survey Results on Drug Use, 1975-2015: Overview, Key Findings on Adolescent Drug Use*. Ann Arbor, MI: Institute for Social Research, The University of Michigan; 2016:1-673. http://www.monitoringthefuture.org/pubs/monographs/mtf-overview2015.pdf. Accessed July 4, 2018.

52. Jamal A, Gentze A, Hu S, et al. Tobacco Use Among Middle and High School Students - United States, 2011-2016. *Morbidity and Mortality Weekly Report*. 2017;66(23):597-603. doi:10.15585/mmwr.mm6623a1

53. Ohio Department of Health. *Ohio Youth Tobacco Survey Results for 2016*.; 2018.

54. Withers N, Low L, Holgate S, Clough J. The Natural History of Respiratory Symptoms in a Cohort of Adolescents. *Am J Respir Crit Care Med*. 1998;158:352-357.

55. Mak K-K, Ho RC-M, Day JR. The Associations of Asthma Symptoms With Active and Passive Smoking in Hong Kong Adolescents. *Respiratory Care*. 2012;57(9):1398-1404. doi:10.4187/respcare.01548

56. Gold DR, Wang X, Wypij D, Speizer FE, Ware JH, Dockery DW. Effects of Cigarette Smoking on Lung Function in Adolescent Boys and Girls. *New England Journal of Medicine*. 1996;335(13):931-937. doi:10.1056/NEJM199609263351304

57. Hedman L, Bjerg A, Sundberg S, Forsberg B, Ronmark E. Both environmental tobacco smoke and personal smoking is related to asthma and wheeze in teenagers. *Thorax*. 2011;66(1):20-25. doi:10.1136/thx.2010.143800

58. Raherison C, Baldi I, Tunon-De-Lara J-M, Taytard A, Annesi-Maesano I. Asthma phenotypes according to the timing of smoking onset in young adults. *Int J Tuberc Lung Dis*. 2003;7(1):84-92.

59. Yoo S, Kim HB, Lee SY, et al. Effect of active smoking on asthma symptoms, pulmonary function, and BHR in adolescents. *Pediatric Pulmonology*. 2009;44(10):954-961. doi:10.1002/ppul.21066

60. Prokhorov AV, Emmons KM, Pallonen UE, Tsoh JY. Respiratory Response to Cigarette Smoking among Adolescent Smokers: A Pilot Study. *Preventive Medicine*. 1996;25(5):633-640. doi:10.1006/pmed.1996.0099

61. Berenson GS, Srinivasan SR, Bao W, Newman WP, Tracy RE, Wattigney WA. Association between Multiple Cardiovascular Risk Factors and Atherosclerosis in Children and Young Adults. *New England Journal of Medicine*. 1998;338(23):1650-1656. doi:10.1056/NEJM199806043382302

62. McGill HC, McMahan CA, Herderick EE, et al. Effects of Coronary Heart Disease Risk Factors on Atherosclerosis of Selected Regions of the Aorta and Right Coronary Artery. *Arteriosclerosis, Thrombosis, and Vascular Biology*. 2000;20(3):836-845. doi:10.1161/01.ATV.20.3.836

63. Zieske AW, McMahan CA, McGill HC, et al. Smoking is associated with advanced coronary atherosclerosis in youth. *Atherosclerosis*. 2005;180(1):87-92. doi:10.1016/j.atherosclerosis.2004.10.039

64. Porges SW. Orienting in a defensive world: Mammalian modifications of our evolutionary heritage. A Polyvagal Theory. *Psychophysiology*. 1995;32(4):301-318.

65. Schroeder EB, Liao D, Chambless LE, Prineas RJ, Evans GW, Heiss G. Hypertension, Blood Pressure, and Heart Rate Variability: The Atherosclerosis Risk in Communities (ARIC) Study. *Hypertension*. 2003;42(6):1106-1111. doi:10.1161/01.HYP.0000100444.71069.73

66. Tonhajzerova I, Mokra D, Visnovcova Z. Vagal function indexed by respiratory sinus arrhythmia and cholinergic anti-inflammatory pathway. *Respiratory Physiology & Neurobiology*. 2013;187(1):78-81. doi:10.1016/j.resp.2013.02.002

67. Gorka SM, Nelson BD, Sarapas C, et al. Relation Between Respiratory Sinus Arrythymia and Startle Response During Predictable and Unpredictable Threat. *Journal of Psychophysiology*. 2013;27(2):95-104. doi:10.1027/0269-8803/a000091

68. Malone KM, Waternaux C, Haas GL, Cooper TB, Li S, Mann JJ. Cigarette Smoking, Suicidal Behavior, and Serotonin Function in Major Psychiatric Disorders. *American Journal of Psychiatry*. 2003;160(4):773-779. doi:10.1176/appi.ajp.160.4.773

69. Bang SJ, Commons KG. Age-dependent effects of initial exposure to nicotine on serotonin neurons. *Neuroscience*. 2011;179:1-8. doi:10.1016/j.neuroscience.2011.01.032

70. Cowen P. Serotonin and depression: pathophysiological mechanism or marketing myth? *Trends in Pharmacological Sciences*. 2008;29(9):433-436. doi:10.1016/j.tips.2008.05.004

71. Wu LT, Anthony JC. Tobacco smoking and depressed mood in late childhood and early adolescence. *American Journal of Public Health*. 1999;89(12):1837-1840. doi:10.2105/AJPH.89.12.1837

72. Pedersen W, von Soest T. Smoking, nicotine dependence and mental health among young adults: a 13-year population-based longitudinal study. *Addiction*. 2009;104(1):129-137. doi:10.1111/j.1360-0443.2008.02395.x

73. Goodman E, Capitman J. Depressive Symptoms and Cigarette Smoking Among Teens. *Pediatrics*. 2000;106(4):748-755.

74. Duncan B, Rees DI. Effect of Smoking on Depressive Symptomatology: A Reexamination of Data from the National Longitudinal Study of Adolescent Health. *American Journal of Epidemiology*. 2005;162(5):461-470. doi:10.1093/aje/kwi219

75. Chen VC-H, Kuo C-J, Wang T-N, et al. Suicide and Other-Cause Mortality after Early Exposure to Smoking and Second Hand Smoking: A 12-Year Population-Based Follow-Up Study. Hashimoto K, ed. *PLOS ONE*. 2015;10(7):e0130044. doi:10.1371/journal.pone.0130044

76. Brown RA, Lewinsohn PM, Seeley JR, Wagner EF. Cigarette Smoking, Major Depression, and Other Psychiatric Disorders among Adolescents. *Journal of the American Academy of Child & Adolescent Psychiatry*. 1996;35(12):1602-1610. doi:10.1097/00004583-199612000-00011

77. Munafò MR, Hitsman B, Rende R, Metcalfe C, Niaura R. Effects of progression to cigarette smoking on depressed mood in adolescents: evidence from the National Longitudinal Study of Adolescent Health. *Addiction*. 2008;103(1):162-171. doi:10.1111/j.1360-0443.2007.02052.x

78. Reynolds B, Fields S. Delay discounting by adolescents experimenting with cigarette smoking: Adolescents experimenting with smoking. *Addiction*. 2012;107(2):417-424. doi:10.1111/j.1360-0443.2011.03644.x

79. Richardson CG, Edalati H. Application of a Brief Measure of Delay Discounting to Examine the Relationship Between Delay Discounting and the Initiation of Substance Use Among Adolescents. *Substance Use & Misuse*. 2016;51(4):540-544. doi:10.3109/10826084.2015.1126740

80. Mann JJ, Haas GL. Toward a Clinical Model of Suicidal Behavior in Psychiatric Patients. *Am J Psychiatry*. 1999;156(2):181-189.

81. Fergusson DM, Beautrais AL, Horwood LJ. Vulnerability and resiliency to suicidal behaviours in young people. *Psychological Medicine*. 2003;33:61-73. doi:10.1017/S0033291702006748

82. Hockenberry JM, Timmons EJ, Vander Weg M. Smoking, parent smoking, depressed mood, and suicidal ideation in teens. *Nicotine & Tobacco Research*. 2010;12(3):235-242. doi:10.1093/ntr/ntp199

83. Zhan W, Dierker LC, Rose JS, Selya A, Mermelstein RJ. The Natural Course of Nicotine Dependence Symptoms Among Adolescent Smokers. *Nicotine & Tobacco Research*. 2012;14(12):1445-1452. doi:1100.1.1009933//nttrr//nttss003311

84. Dierker L, Hedeker D, Rose J, Selya A, Mermelstein R. Early emerging nicotine dependence symptoms in adolescence predict daily smoking in young adulthood. *Drug and Alcohol Dependence*. 2015;151:267-271. doi:10.1016/j.drugalcdep.2015.03.009

85. Lanza ST, Vasilenko SA. New methods shed light on age of onset as a risk factor for nicotine dependence. *Addictive Behaviors*. 2015;50:161-164. doi:10.1016/j.addbeh.2015.06.024

86. Hu M-C, Griesler PC, Schaffran C, Wall MM, Kandel DB. Trajectories of criteria of nicotine dependence from adolescence to early adulthood. *Drug and Alcohol Dependence*. 2012;125(3):283-289. doi:10.1016/j.drugalcdep.2012.03.001

87. McConnell R, Barrington-Trimis JL, Wang K, et al. Electronic Cigarette Use and Respiratory Symptoms in Adolescents. *American Journal of Respiratory and Critical Care Medicine*. 2017;195(8):1043-1049. doi:10.1164/rccm.201604-0804OC

88. Wang MP, Ho SY, Leung LT, Lam TH. Electronic Cigarette Use and Respiratory Symptoms in Chinese Adolescents in Hong Kong. *JAMA Pediatrics*. 2016;170(1):89-91. doi:10.1001/jamapediatrics.2015.3024

89. Cho JH, Paik SY. Association between Electronic Cigarette Use and Asthma among High School Students in South Korea. Fehrenbach H, ed. *PLOS ONE*. 2016;11(3):e0151022. doi:10.1371/journal.pone.0151022

90. Bahelah R, Ward KD, Ben Taleb Z, et al. Determinants of progression of nicotine dependence symptoms in adolescent waterpipe smokers. *Tobacco Control*. June 2018:tobaccocontrol-2018-054244. doi:10.1136/tobaccocontrol-2018-054244

91. DiFranza JR, Sweet M, Savageau JA, Ursprung WWS. The assessment of tobacco dependence in young users of smokeless tobacco. *Tobacco Control*. 2012;21(5):471-476. doi:10.1136/tc.2011.043810

92. Post A, Gilljam H, Rosendahl I, Bremberg S, Rosaria Galanti M. Symptoms of nicotine dependence in a cohort of Swedish youths: a comparison between

smokers, smokeless tobacco users and dual tobacco users. *Addiction*. 2010;105(4):740-746. doi:10.1111/j.1360-0443.2009.02852.x

93. Vogel EA, Ramo DE, Rubinstein ML. Prevalence and correlates of adolescents' e-cigarette use frequency and dependence. *Drug and Alcohol Dependence*. 2018;188:109-112. doi:10.1016/j.drugalcdep.2018.03.051

94. Apelberg BJ, Corey CG, Hoffman AC, et al. Symptoms of Tobacco Dependence Among Middle and High School Tobacco Users. *American Journal of Preventive Medicine*. 2014;47(2):S4-S14. doi:10.1016/j.amepre.2014.04.013

95. Flay B. Understanding environmental, situational and intrapersonal risk and protective factors for youth tobacco use: The theory of triadic influence. *Nicotine & Tobacco Research*. 1999;1(S):S111-S114. doi:10.1080/14622299050011911

96. Dalton MA, Sargent JD, Beach ML, et al. Effect of viewing smoking in movies on adolescent smoking initiation: A cohort study. *Lancet*. 2003;362:281-285. doi:10.1016/S0140-6736(03)13970-0

97. National Cancer Institute. *The Role of Media in Promoting and Reducing Tobacco Use*. Bethesda, MD; 2008.

98. Nunez-Smith M, Wolf E, Huang HM, et al. Media exposure and tobacco, illicit drugs, and alcohol use among children and adolescents: A systematic review. *Substance Abuse*. 2010;31(3):174-192. doi:10.1080/08897077.2010.495648

99. Dal Cin S, Stoolmiller M, Sargent JD. When movies matter: Exposure to smoking in movies and changes in smoking behavior. *Journal of Health Communication*. 2012;17(1):76-89. doi:10.1080/10810730.2011.585697

100. Yang F, Salmon CT, Pang JS, Cheng WJ. Media exposure and smoking intention in adolescents: A moderated mediation analysis from a cultivation perspective. *Journal of Health Psychology*. 2015;20(2):188-197. doi:10.1177/1359105313501533

101. Bandura A. *Social Foundations of Thought and Action: A Social Cognitive Theory.* Englewood Cliffs, NJ: Prentice-Hall, Inc; 1986.

102. Hoffman BR, Sussman S, Unger JB, Valente TW. Peer Influences on Adolescent Cigarette Smoking: A Theoretical Review of the Literature. *Substance Use & Misuse*. 2006;41(1):103-155. doi:10.1080/10826080500368892

103. Wen X, Shenassa ED. Interaction between parenting and neighborhood quality on the risk of adolescent regular smoking. *Nicotine and Tobacco Research*. 2012;14(3):313-322. doi:10.1093/ntr/ntr215

104. Shih RA, Parast L, Pedersen ER, et al. Individual, peer, and family factor modification of neighborhood-level effects on adolescent alcohol, cigarette, e-cigarette, and marijuana use. *Drug and Alcohol Dependence*. 2017;180(October 2016):76-85. doi:10.1016/j.drugalcdep.2017.07.014

105. University of Minnesota. Adolescence: Developing independence and identity. In: *Introduction to Psychology*. University of Minnesota Libraries Publishing; 2015:Minneapolis, MN.

106. Distefan JM, Gilpin EA, Sargent JD, Pierce JP. Do movie stars encourage adolescents to start smoking? Evidence from California. *Preventive medicine*. 1999;28(1):1-11. doi:10.1006/pmed.1998.0409

107. Tickle JJ, Sargent JD, Dalton M a, Beach ML, Heatherton TF. Favourite movie stars, their tobacco use in contemporary movies, and its association with adolescent smoking. *Tobacco control*. 2001;10(1):16-22. doi:10.1136/tc.10.1.16

108. Barrington-Trimis JL, Urman R, Berhane K, et al. E-Cigarettes and Future Cigarette Use. *PEDIATRICS*. 2016;138(1):e20160379-e20160379. doi:10.1542/peds.2016-0379

109. Higgins ST, Kurti AN, Redner R, et al. A literature review on prevalence of gender differences and intersections with other vulnerabilities to tobacco use in the United States, 2004–2014. *Preventive Medicine*. 2015;80:89-100. doi:10.1016/j.ypmed.2015.06.009

110. Palamar JJ, Zhou S, Sherman S, Weitzman M. Hookah Use Among US High School Seniors. *PEDIATRICS*. 2014;134(2):227-234. doi:10.1542/peds.2014-0538

111. Audrain-McGovern J, Rodriguez D, Leventhal AM. Gender differences in the relationship between affect and adolescent smoking uptake: Gender differences. *Addiction*. 2015;110(3):519-529. doi:10.1111/add.12797

112. Ajzen I. The theory of planned behavior. *Organizational Behavior and Human Decision Processes*. 1991;50(2):179-211. doi:10.1016/0749-5978(91)90020-T

113. Grogan S, Conner M, Fry G, Gough B, Higgins A. Gender differences in smoking: A longitudinal study of beliefs predicting smoking in 11–15 year olds. *Psychology & Health*. 2009;24(3):301-316. doi:10.1080/08870440701746586

114. Elmore KC, Scull TM, Kupersmidt JB. Media as a "Super Peer": How Adolescents Interpret Media Messages Predicts Their Perception of Alcohol and Tobacco Use Norms. *Journal of Youth and Adolescence*. 2017;46(2):376-387. doi:10.1007/s10964-016-0609-9

115. Branstetter SA, Blosnich J, Dino G, Nolan J, Horn K. Gender differences in cigarette smoking, social correlates and cessation among adolescents. *Addictive Behaviors*. 2012;37(6):739-742. doi:10.1016/j.addbeh.2012.02.007

116. Nemeth JM, Liu ST, Klein EG, Ferketich AK, Kwan M-P, Wewers ME. Factors Influencing Smokeless Tobacco Use in Rural Ohio Appalachia. *Journal of Community Health*. 2012;37(6):1208-1217. doi:10.1007/s10900-012-9556-x

117. Roberts AL, Rosario M, Calzo JP, Corliss HL, Frazier L, Austin SB. Masculine Boys, Feminine Girls, and Cancer Risk Behaviors: An 11-Year Longitudinal Study. *Journal of Adolescent Health*. 2014;55(3):373-379. doi:10.1016/j.jadohealth.2014.02.020

118. Proctor C, Barnett JA, Muilenburg J. Investigating Race, Gender, and Access to Cigarettes in an Adolescent Population. *American Journal of Health Behavior*. 2012;36(4):513-521. doi:10.5993/AJHB.36.4.8

119. Abar CC, Jackson KM, Colby SM, Barnett NP. Common and unique parenting predictors of adolescent tobacco and alcohol use. *Addictive Behaviors*. 2014;39(10):1528-1532. doi:10.1016/j.addbeh.2014.06.003

120. Mathur C, Erickson DJ, Stigler MH, Forster JL, Finnegan JR. Individual and neighborhood socioeconomic status effects on adolescent smoking: A multilevel cohort-sequential latent growth analysis. *American Journal of Public Health*. 2013;103(3):543-548. doi:10.2105/AJPH.2012.300830

121. Soteriades ES, DiFranza JR. Parent's Socioeconomic Status, Adolescents' Disposable Income, and Adolescents' Smoking Status in Massachusetts. *American Journal of Public Health*. 2003;93(7):1155-1160. doi:10.2105/AJPH.93.7.1155

122. Karriker-Jaffe KJ. Neighborhood socioeconomic status and substance use by U.S. adults. *Drug and Alcohol Dependence*. 2013;133(1):212-221. doi:10.1016/j.drugalcdep.2013.04.033

123. Miech RA, O'Malley PM, Johnston LD, Patrick ME. E-Cigarettes and the Drug Use Patterns of Adolescents. *Nicotine & Tobacco Research*. 2016;18(5):654-659. doi:10.1093/ntr/ntv217

124. Currie C, Molcho M, Boyce W, Holstein B, Torsheim T, Richter M. Researching health inequalities in adolescents: The development of the Health Behaviour in School-Aged Children (HBSC) Family Affluence Scale. *Social Science & Medicine*. 2008;66(6):1429-1436. doi:10.1016/j.socscimed.2007.11.024

125. Simon P, Camenga DR, Kong G, et al. Youth E-cigarette, Blunt, and Other Tobacco Use Profiles: Does SES Matter? *Tobacco Regulatory Science*. 2017;3(1):115-127. doi:10.18001/TRS.3.1.12

126. Simon P, Camenga DR, Morean ME, et al. Socioeconomic status and adolescent e-cigarette use: The mediating role of e-cigarette advertisement exposure. *Preventive Medicine*. 2018;112:193-198. doi:10.1016/j.ypmed.2018.04.019

127. Ellickson PL, Orlando M, Tucker JS, Klein DJ. From Adolescence to Young Adulthood: Racial/Ethnic Disparities in Smoking. *American Journal of Public Health*. 2004;94(2):293-299. doi:10.2105/AJPH.94.2.293

128. Kandel D, Schaffran C, Hu M-C, Thomas Y. Age-related differences in cigarette smoking among whites and African-Americans: Evidence for the crossover hypothesis. *Drug and Alcohol Dependence*. 2011;118(2-3):280-287. doi:10.1016/j.drugalcdep.2011.04.008

129. Wallace JM, Bachman JG, O'Malley PM, Schulenberg JE, Cooper SM, Johnston LD. Gender and ethnic differences in smoking, drinking and illicit drug use among American 8th, 10th and 12th grade students, 1976-2000. *Addiction*. 2003;98(2):225-234. doi:10.1046/j.1360-0443.2003.00282.x

130. Smith C, Denton ML, Faris R, Regnerus M. Mapping American Adolescent Religious Participation. *Journal for the Scientific Study of Religion*. 2002;41(4):597-612. doi:10.1111/1468-5906.00148

131. Clark PI, Scarisbrick-Hauser A, Gautam SP, Wirk SJ. Anti-tobacco socialization in homes of African-American and white parents, and smoking and nonsmoking parents. *Journal of Adolescent Health*. 1999;24(5):329-339. doi:10.1016/S1054-139X(98)00117-7

132. Ellickson PL, Perlman M, Klein DJ. Explaining racial/ethnic differences in smoking during the transition to adulthood. *Addictive Behaviors*. 2003;28(5):915-931. doi:10.1016/S0306-4603(01)00285-4

133. Keyes KM, Vo T, Wall M, et al. Racial/ethnic differences in use of alcohol, tobacco, and marijuana: Is there a cross-over from adolescence to adulthood? *Soc Sci Med*. 2015;124:132-141. doi:10.1016/j.socscimed.2014.11.035.Racial/ethnic

134. Reynolds B, Richards JB, Horn K, Karraker K. Delay discounting and probability discounting as related to cigarette smoking status in adults. *Behavioural Processes*. 2004;65(1):35-42. doi:10.1016/S0376-6357(03)00109-8

135. Audrain-McGovern J, Rodriguez D, Tercyak KP, Epstein LH, Goldman P, Wileyto EP. Applying a Behavioral Economic Framework to Understanding Adolescent

Smoking. *Psychology of Addictive Behaviors*. 2004;18(1):64-73. doi:10.1037/0893-164X.18.1.64

136. Reynolds B, Patak M, Shroff P, Penfold RB, Melanko S, Duhig AM. Laboratory and self-report assessments of impulsive behavior in adolescent daily smokers and nonsmokers. *Experimental and Clinical Psychopharmacology*. 2007;15(3):264-271. doi:10.1037/1064-1297.15.3.264

137. Reynolds B, Patak M, Shroff P. Adolescent smokers rate delayed rewards as less certain than adolescent nonsmokers. *Drug and Alcohol Dependence*. 2007;90(2-3):301-303. doi:10.1016/j.drugalcdep.2007.04.008

138. Audrain-McGovern J, Rodriguez D, Epstein LH, Cuevas J, Rodgers K, Wileyto EP. Does delay discounting play an etiological role in smoking or is it a consequence of smoking? *Drug and Alcohol Dependence*. 2009;103(3):99-106. doi:10.1016/j.drugalcdep.2008.12.019

139. Zuckerman M. *Behavioral Expressions and Biosocial Bases of Sensation Seeking*. New York: Cambridge University Press; 1994.

140. Hu M-C, Davies M, Kandel DB. Epidemiology and Correlates of Daily Smoking and Nicotine Dependence Among Young Adults in the United States. *American Journal of Public Health*. 2006;96(2):299-308. doi:10.2105/AJPH.2004.057232

141. Helstrom A, Hutchison K, Bryan A. Motivational enhancement therapy for high-risk adolescent smokers. *Addictive Behaviors*. 2007;32(10):2404-2410. doi:10.1016/j.addbeh.2007.02.009

142. Audrain-McGovern J, Rodriguez D, Kassel JD. Adolescent smoking and depression: evidence for self-medication and peer smoking mediation. *Addiction*. 2009;104(10):1743-1756. doi:10.1111/j.1360-0443.2009.02617.x

143. Wills TA, Knight R, Williams RJ, Pagano I, Sargent JD. Risk Factors for Exclusive E-Cigarette Use and Dual E-Cigarette Use and Tobacco Use in Adolescents. *PEDIATRICS*. 2015;135(1):e43-e51. doi:10.1542/peds.2014-0760

144. Creamer MR, Portillo GV, Clendennen SL, Perry CL. Is Adolescent Poly-tobacco Use Associated with Alcohol and Other Drug Use? *American Journal of Health Behavior*. 2016;40(1):117-122. doi:10.5993/AJHB.40.1.13

145. Camenga DR, Kong G, Cavallo DA, et al. Alternate Tobacco Product and Drug Use Among Adolescents Who Use Electronic Cigarettes, Cigarettes Only, and Never Smokers. *Journal of Adolescent Health*. 2014;55(4):588-591. doi:10.1016/j.jadohealth.2014.06.016

146. Leeman RF, Hoff RA, Krishnan-Sarin S, Patock-Peckham JA, Potenza MN. Impulsivity, Sensation-Seeking, and Part-Time Job Status in Relation to Substance Use and Gambling in Adolescents. *Journal of Adolescent Health*. 2014;54(4):460-466. doi:10.1016/j.jadohealth.2013.09.014

147. Stanger C, Ryan SR, Fu H, et al. Delay discounting predicts adolescent substance abuse treatment outcome. *Experimental and Clinical Psychopharmacology*. 2012;20(3):205-212. doi:10.1037/a0026543

148. Leung RK, Toumbourou JW, Hemphill SA. The effect of peer influence and selection processes on adolescent alcohol use: a systematic review of longitudinal studies. *Health Psychology Review*. 2014;8(4):426-457. doi:10.1080/17437199.2011.587961

149. Tucker JS, de la Haye K, Kennedy DP, Green HD, Pollard MS. Peer Influence on Marijuana Use in Different Types of Friendships. *Journal of Adolescent Health*. 2014;54(1):67-73. doi:10.1016/j.jadohealth.2013.07.025

150. Kerr DCR, Tiberio SS, Capaldi DM. Contextual risks linking parents' adolescent marijuana use to offspring onset. *Drug and Alcohol Dependence*. 2015;154:222-228. doi:10.1016/j.drugalcdep.2015.06.041

151. Barnett TE, Curbow BA, Weitz JR, Johnson TM, Smith-Simone SY. Water Pipe Tobacco Smoking Among Middle and High School Students. *American Journal of Public Health*. 2009;99(11):2014-2019. doi:10.2105/AJPH.2008.151225

152. Dutra LM, Glantz SA. Electronic Cigarettes and Conventional Cigarette Use Among US Adolescents: A Cross-sectional Study. *JAMA Pediatrics*. 2014;168(7):610. doi:10.1001/jamapediatrics.2013.5488

153. Bold KW, Kong G, Camenga DR, et al. Trajectories of E-Cigarette and Conventional Cigarette Use Among Youth. *Pediatrics*. 2018;141(1):e20171832. doi:10.1542/peds.2017-1832

154. East K, Hitchman SC, Bakolis I, et al. The Association Between Smoking and Electronic Cigarette Use in a Cohort of Young People. *Journal of Adolescent Health*. 2018;62(5):539-547. doi:10.1016/j.jadohealth.2017.11.301

155. Dunbar MS, Davis JP, Rodriguez A, Tucker JS, Seelam R, D'Amico EJ. Disentangling Within- and Between-Person Effects of Shared Risk Factors on E-cigarette and Cigarette Use Trajectories From Late Adolescence to Young Adulthood. *Nicotine & Tobacco Research*. October 2018. doi:10.1093/ntr/nty179

156. Park J-Y, Seo D-C, Lin H-C. E-Cigarette Use and Intention to Initiate or Quit Smoking Among US Youths. *American Journal of Public Health*. 2016;106(4):672-678. doi:10.2105/AJPH.2015.302994

157. Wills TA, Sargent JD, Gibbons FX, Pagano I, Schweitzer R. E-cigarette use is differentially related to smoking onset among lower risk adolescents. *Tobacco Control*. 2017;26(5):534-539. doi:10.1136/tobaccocontrol-2016-053116

158. Wagener TL, Floyd EL, Stepanov I, et al. Have combustible cigarettes met their match? The nicotine delivery profiles and harmful constituent exposures of second-generation and third-generation electronic cigarette users. *Tobacco Control*. 2017;26(e1):e23-e28. doi:10.1136/tobaccocontrol-2016-053041

159. Strasburger VC, Jordan AB, Donnerstein E. Children, Adolescents, and the Media: *Pediatric Clinics of North America*. 2012;59(3):533-587. doi:10.1016/j.pcl.2012.03.025

160. Gerbner G. Toward "Cultural Indicators": The analysis of mass mediated public message systems. *Audio-Visual Communication Review*. 1969;17(2):137-148. doi:10.1007/BF02769102

161. Bandura A, ed. *Self-Efficacy in Changing Societies*. New York: Cambridge University Press; 1995.

162. Cohen J. Defining Identification: A Theoretical Look at the Identification of Audiences With Media Characters. *Mass Communication and Society*. 2001;4(3):245-264. doi:10.1207/S15327825MCS0403_01

163. Tickle J, Hull J, Sargent J, Dalton M, Heatherton T. A structural equation model of social influences and exposure to media smoking on adolescent smoking. *Basic and Applied Social Psychology*. 2006;28(2):117-129. doi:10.1207/s15324834basp2802_2

164. Gidwani PP, Sobol A, DeJong W, Perrin JM, Gortmaker SL. Television Viewing and Initiation of Smoking Among Youth. *PEDIATRICS*. 2002;110(3):505-508. doi:10.1542/peds.110.3.505

165. Nan X, Zhao X. The Mediating Role of Perceived Descriptive and Injunctive Norms in the Effects of Media Messages on Youth Smoking. *Journal of Health Communication*. 2016;21(1):56-66. doi:10.1080/10810730.2015.1023958

166. Depue JB, Southwell BG, Betzner AE, Walsh BM. Encoded Exposure to Tobacco Use in Social Media Predicts Subsequent Smoking Behavior. *American Journal of Health Promotion*. 2015;29(4):259-261. doi:10.4278/ajhp.130214-ARB-69

167. Pokhrel P, Fagan P, Herzog TA, et al. Social media e-cigarette exposure and e-cigarette expectancies and use among young adults. *Addictive Behaviors*. 2018;78:51-58. doi:10.1016/j.addbeh.2017.10.017

168. Huang J, Duan Z, Kwok J, et al. Vaping versus JUULing: how the extraordinary growth and marketing of JUUL transformed the US retail e-cigarette market. *Tobacco Control*. 2019;28(2):146-151. doi:10.1136/tobaccocontrol-2018-054382

169. Oetting ER, Donnermeyer JF. Primary socialization theory: The etiology of drug use and deviance. I. *Substance Use & Misuse*. 1998;33(4):995-1026. doi:10.3109/10826089809056252

170. Simons-Morton BG, Farhat T. Recent Findings on Peer Group Influences on Adolescent Smoking. *The Journal of Primary Prevention*. 2010;31(4):191-208. doi:10.1007/s10935-010-0220-x

171. Roberts ME, Nargiso JE, Gaitonde LB, Stanton CA, Colby SM. Adolescent Social Networks: General and Smoking-Specific Characteristics Associated With Smoking. *Journal of Studies on Alcohol and Drugs*. 2015;76(2):247-254.

172. Kleinjan M, Vitaro F, Wanner B, Brug J, Van den Eijnden RJ, Engels RC. Predicting nicotine dependence profiles among adolescent smokers: the roles of personal and social-environmental factors in a longitudinal framework. *BMC Public Health*. 2012;12(1). doi:10.1186/1471-2458-12-196

173. Pampel FC, Boardman JD, Daw J, et al. Life events, genetic susceptibility, and smoking among adolescents. *Social Science Research*. 2015;54:221-232. doi:10.1016/j.ssresearch.2015.08.001

174. Fearnow M, Chassin L, Presson CC, Sherman SJ. Determinants of parental attempts to deter their children's cigarette smoking. *Journal of Applied Developmental Psychology*. 19(3):453-468.

175. Ratcliffe M, Burd C, Holder K, Fields A. *Defining Rural at the U.S. Census Bureau: American Community Survey and Geography Brief*. U.S. Department of Commerce; 2016:8.

176. Meit M, Knudson A, Gilbert T, et al. *The 2014 Update of the Rural-Urban Chartbook*. North Dakota and NORC Rural Health Reform Policy Research Center; 2014:153.

177. Befort CA, Nazir N, Perri MG. Prevalence of Obesity Among Adults From Rural and Urban Areas of the United States: Findings From NHANES (2005-2008): *Obesity Among Rural and Urban Adults*. *The Journal of Rural Health*. 2012;28(4):392-397. doi:10.1111/j.1748-0361.2012.00411.x

178. Atkins GT, Kim T, Munson J. Residence in Rural Areas of the United States and Lung Cancer Mortality. Disease Incidence, Treatment Disparities, and Stage-Specific Survival. *Annals of the American Thoracic Society*. 2017;14(3):403-411. doi:10.1513/AnnalsATS.201606-469OC

179. Byun S, Meece JL, Irvin MJ. Rural-Nonrural Disparities in Postsecondary Educational Attainment Revisited. *American Educational Research Journal*. 2012;49(3):412-437. doi:10.3102/0002831211416344

180. Caldwell JT, Ford CL, Wallace SP, Wang MC, Takahashi LM. Intersection of Living in a Rural Versus Urban Area and Race/Ethnicity in Explaining Access to Health Care in the United States. *American Journal of Public Health*. 2016;106(8):1463-1469. doi:10.2105/AJPH.2016.303212

181. Fan L, Mohile S, Zhang N, Fiscella K, Noyes K. Self-Reported Cancer Screening Among Elderly Medicare Beneficiaries: A Rural-Urban Comparison: Rural-Urban Disparities in Cancer Screening. *The Journal of Rural Health*. 2012;28(3):312-319. doi:10.1111/j.1748-0361.2012.00405.x

182. Hartley D. Rural Health Disparities, Population Health, and Rural Culture. *American Journal of Public Health*. 2004;94(10):1675-1678. doi:10.2105/AJPH.94.10.1675

183. Vander Weg MW, Cunningham CL, Howren MB, Cai X. Tobacco use and exposure in rural areas: Findings from the Behavioral Risk Factor Surveillance System. *Addictive Behaviors*. 2011;36(3):231-236. doi:10.1016/j.addbeh.2010.11.005

184. Roberts ME, Doogan NJ, Stanton CA, et al. Rural versus urban use of traditional and emerging tobacco products in the United States, 2013-2014. *American Journal of Public Health*. 2017;107(10):1554-1559. doi:10.2105/AJPH.2017.303967

185. Chang JT, Levy DT, Meza R. Trends and Factors Related to Smokeless Tobacco Use in the United States. *Nicotine & Tobacco Research*. 2016;18(8):1740-1748. doi:10.1093/ntr/ntw090

186. Singh GK, Siahpush M. Widening Rural–Urban Disparities in Life Expectancy, U.S., 1969–2009. *American Journal of Preventive Medicine*. 2014;46(2):e19-e29. doi:10.1016/j.amepre.2013.10.017

187. Coomber K, Toumbourou JW, Miller P, Staiger PK, Hemphill SA, Catalano RF. Rural Adolescent Alcohol, Tobacco, and Illicit Drug Use: A Comparison of Students in Victoria, Australia, and Washington State, United States: Rural Adolescent Substance Use. *The Journal of Rural Health*. 2011;27(4):409-415. doi:10.1111/j.1748-0361.2010.00360.x

188. Hanson CL, Novilla MLLB, Barnes MD, et al. Using the Rural-Urban Continuum to Explore Adolescent Alcohol, Tobacco, and Other Drug Use in Montana. *Journal of Child & Adolescent Substance Abuse*. 2008;18(1):93-105. doi:10.1080/15470650802544289

189. Pesko MF, Robarts AMT. Adolescent Tobacco Use in Urban Versus Rural Areas of the United States: The Influence of Tobacco Control Policy Environments. *Journal of Adolescent Health*. 2017;61(1):70-76. doi:10.1016/j.jadohealth.2017.01.019

190. Warren JC. Perceived Ease of Access to Alcohol, Tobacco, and Other Substances in Rural and Urban US Students. 2016:12.

191. Ling PM, Haber LA, Wedl S. Branding the Rodeo: A Case Study of Tobacco Sports Sponsorship. *American Journal of Public Health*. 2010;100(1):32-41. doi:10.2105/AJPH.2008.144097

192. Helme DW, Rayens MK, Kercsmar SE, et al. Rural Print Media Portrayal of Secondhand Smoke and Smoke-Free Policy. *Health Promotion Practice*. 2012;13(6):848-856. doi:10.1177/1524839911399429

193. Appalachian Regional Commission. *The Appalachian Region*. ARC https://www.arc.gov/appalachian_region/TheAppalachianRegion.asp. Accessed September 23, 2018.

194. Appalachian Regional Commission. *County Economic Status and Number of Distressed Areas in Appalachian Ohio, Fiscal Year 2019*. ARC; 2018:5. https://www.arc.gov/images/appregion/economic_statusFY2019/CountyEconomicStatusandDistressAreasFY2019Ohio.pdf. Accessed September 23, 2018.

195. Blackley D, Behringer B, Zheng S. Cancer Mortality Rates in Appalachia: Descriptive Epidemiology and an Approach to Explaining Differences in Outcomes. *Journal of Community Health*. 2012;37(4):804-813. doi:10.1007/s10900-011-9514-z

196. Wilson RJ, Ryerson AB, Singh SD, King JB. Cancer Incidence in Appalachia, 2004-2011. *Cancer Epidemiology Biomarkers & Prevention*. 2016;25(2):250-258. doi:10.1158/1055-9965.EPI-15-0946

197. Marshall JL, Thomas L, Lane NM, et al. *Creating a Culture of Health in Appalachia: Disparities and Bright Spots*. PDA Inc, The Cecil G. Sheps Center for Health Statistics, Appalachian Regional Commission; 2017. https://www.arc.gov/assets/research_reports/Health_Disparities_in_Appalachia_August_2017.pdf. Accessed September 23, 2018.

198. Centers for Disease Control and Prevention. *Smokeless Tobacco Use in the United States*. Atlanta, GA: US Department of Health and Human Services, CDC; 2018. https://www.cdc.gov/tobacco/data_statistics/fact_sheets/smokeless/use_us/index.htm. Accessed September 23, 2018.

199. Meyer MG, Toborg MA, Denham SA, Mande MJ. Cultural Perspectives Concerning Adolescent Use of Tobacco and Alcohol in the Appalachian Mountain Region. *The Journal of Rural Health*. 2008;24(1):67-74. doi:10.1111/j.1748-0361.2008.00139.x

200. Noland MP, Kryscio RJ, Riggs RS, Linville LH, Perritt LJ, Tucker TC. Use of snuff, chewing tobacco, and cigarettes among adolescents in a tobacco-producing area. *Addictive Behaviors*. 1990;15(6):517-530. doi:10.1016/0306-4603(90)90052-Y

201. Beaver P. *Rural Community in the Appalachian South*. Prospect Heights, IL: Waveland Press, Inc; 1992.

202. Curry LE, Pederson LL, Stryker JE. The changing marketing of smokeless tobacco in magazine advertisements. *Nicotine & Tobacco Research*. 2011;13(7):540-547. doi:10.1093/ntr/ntr038

203. Doubeni CA, Schootman M, Major JM, et al. Health Status, Neighborhood Socioeconomic Context, and Premature Mortality in the United States: The National Institutes of Health–AARP Diet and Health Study. *American Journal of Public Health*. 2012;102(4):680-688. doi:10.2105/AJPH.2011.300158

204. Bethea TN, Palmer JR, Rosenberg L, Cozier YC. Neighborhood Socioeconomic Status in Relation to All-cause, Cancer, and Cardiovascular Mortality in the Black Women's Health Study. *Ethnicity & Disease*. 2016;26(2):157. doi:10.18865/ed.26.2.157

205. Ford JL, Rechel M. Parental Perceptions of the Neighborhood Context and Adolescent Depression. *Public Health Nursing*. 2012;29(5):390-402. doi:10.1111/j.1525-1446.2012.01015.x

206. Mezuk B, Chaikiat Å, Li X, Sundquist J, Kendler KS, Sundquist K. Depression, neighborhood deprivation and risk of type 2 diabetes. *Health & Place*. 2013;23:63-69. doi:10.1016/j.healthplace.2013.05.004

207. Barber S, Hickson DA, Wang X, Sims M, Nelson C, Diez-Roux AV. Neighborhood Disadvantage, Poor Social Conditions, and Cardiovascular Disease Incidence Among African American Adults in the Jackson Heart Study. *American Journal of Public Health*. 2016;106(12):2219-2226. doi:10.2105/AJPH.2016.303471

208. Saelens BE, Glanz K, Frank LD, et al. Two-Year Changes in Child Weight Status, Diet, and Activity by Neighborhood Nutrition and Physical Activity Environment: Neighborhood and Child Weight Status Change. *Obesity*. 2018;26(8):1338-1346. doi:10.1002/oby.22247

209. Carroll-Scott A, Gilstad-Hayden K, Rosenthal L, et al. Disentangling neighborhood contextual associations with child body mass index, diet, and physical activity: The role of built, socioeconomic, and social environments. *Social Science & Medicine*. 2013;95:106-114. doi:10.1016/j.socscimed.2013.04.003

210. Browning CR, Soller B. Moving Beyond Neighborhood: Activity Spaces and Ecological Networks As Contexts for Youth Development. *Cityscape*. 2014;16(1):165-196.

211. Fagan AA, Wright EM, Pinchevsky GM. A Multi-level analysis of the Impact of neighborhood structural and social factors on adolescent substance use. *Drug and Alcohol Dependence*. 2015;153:180-186. doi:10.1016/j.drugalcdep.2015.05.022.A

212. Jensen M, Chassin L, Gonzales NA. Neighborhood Moderation of Sensation Seeking Effects on Adolescent Substance Use Initiation. *Journal of Youth and Adolescence*. 2017;46(9):1953-1967. doi:10.1007/s10964-017-0647-y

213. Kaestle CE, Wiles BB. Targeting high-risk neighborhoods for tobacco prevention education in schools. *American Journal of Public Health*. 2010;100(9):1708-1713. doi:10.2105/AJPH.2008.145557

214. Ennett ST, Foshee VA, Bauman KE, et al. A social contextual analysis of youth cigarette smoking development. *Nicotine & tobacco research : official journal of the Society for Research on Nicotine and Tobacco*. 2010;12(9):950-962. doi:10.1093/ntr/ntq122

215. Nowlin PR, Colder CR. The role of ethnicity and neighborhood poverty on the relationship between parenting and adolescent cigarette use. *Nicotine and Tobacco Research*. 2007;9(5):545-556. doi:10.1080/14622200701239613

216. Timberlake JM. Racial and Ethnic Inequality in the Duration of Children's Exposure to Neighborhood Poverty and Affluence. *Social Problems*. 2007;54(3):319-342. doi:10.1525/sp.2007.54.3.319

217. Frohlich KL, Potvin L, Gauvin L, Chabot P. Youth smoking initiation: disentangling context from composition. *Health & Place*. 2002;8(3):155-166. doi:10.1016/S1353-8292(02)00003-5

218. Barbeau E, Leavy-Sperounis A, Balbach E. Smoking, social class, and gender: what can public health learn from the tobacco industry about disparities in smoking? *Tobacco Control*. 2004;13(2):115-120. doi:10.1136/tc.2003.006098

219. Lipperman-Kreda S, Mair C, Grube JW, Friend KB, Jackson P, Watson D. Density and Proximity of Tobacco Outlets to Homes and Schools: Relations with Youth Cigarette Smoking. *Prevention Science*. 2014;15(5):738-744. doi:10.1007/s11121-013-0442-2

220. Henriksen L, Schleicher NC, Feighery EC, Fortmann SP. A longitudinal study of exposure to retail cigarette advertising and smoking initiation. *Pediatrics*. 2010;126(2):232-238. doi:10.1542/peds.2009-3021.A

221. Mennis J, Mason M. Tobacco outlet density and attitudes towards smoking among urban adolescent smokers. *Substance Abuse*. 2016;37(4):521-525. doi:10.1080/08897077.2016.1181135

222. Syamlal G, Jamal A, Mazurek JM. Combustible Tobacco and Smokeless Tobacco Use Among Working Adults—United States, 2012 to 2014: *Journal of Occupational and Environmental Medicine*. 2016;58(12):1185-1189. doi:10.1097/JOM.0000000000000898

223. Tobacco Control Legal Consortium. *Using Licensing and Zoning to Regulate Tobacco Retailers*. Saint Paul, MN: Tobacco Control Legal Consortium; 2016. http://publichealthlawcenter.org/sites/default/files/resources/tclc-guide-licensing-and-zoning-2016.pdf. Accessed November 19, 2018.

224. CounterTobacco.org. *How to Reduce Tobacco Retailer Density and Why*. Chapel Hill, NC: University of North Carolina https://countertobacco.org/policy/licensing-and-zoning/. Accessed July 6, 2018.

225. University of North Carolina. Tobacco Free Pharmacies. COUNTERTOBACCO.ORG. http://countertobacco.org/policy/tobacco-free-pharmacies/. Published 2018. Accessed April 15, 2018.

226. Tucker-Seely RD, Bezold CP, James P, Miller M, Wallington SF. Retail pharmacy policy to end the sale of tobacco products: what is the impact on disparity in neighborhood density of tobacco outlets? *Cancer Epidemiol Biomarkers Prev*. 2016;25(9):1305-1310. doi:10.1158/1055-9965.EPI-15-1234

227. Luke DA, Hammond RA, Combs T, et al. Tobacco Town: Computational Modeling of Policy Options to Reduce Tobacco Retailer Density. *Am J Public Health*. 2017;107(5):740-746. doi:10.1016/j.antiviral.2015.06.014.Chronic

228. Myers AE, Hall MG, Isgett LF, Ribisl KM. A Comparison of Three Policy Approaches for Tobacco Retailer Reduction. *Preventive Medicine*. 2015;74:67-73. doi:10.1021/acschemneuro.5b00094.Serotonin

229. Jin Y, Lu B, Klein EG, Berman M, Foraker RE, Ferketich AK. Tobacco-free pharmacy laws and trends in tobacco retailer density in California and Massachusetts. *American Journal of Public Health*. 2016;106(4):679-685. doi:10.2105/AJPH.2015.303040

230. Ribisl KM, Luke DA, Bohannon DL, Sorg AA, Moreland-Russell S. Reducing disparities in tobacco retailer density by banning tobacco product sales near schools. *Nicotine and Tobacco Research*. 2017. doi:10.1093/ntr/ntw185

231. Luke DA, Ribisl KM, Smith C, Sorg AA. Family smoking prevention and tobacco control act: Banning outdoor tobacco advertising near schools and playgrounds. *American Journal of Preventive Medicine*. 2011. doi:10.1016/j.amepre.2010.11.018

232. Ribisl K, Patrick R, Eidson S, Tynan M, Francis J. State Cigarette Minimum Price Laws — United States, 2009. *MMWR*. 2010;59(13):389-392.

233. McLaughlin I, Pearson A, Laird-Metke E, Ribisl K. Reducing Tobacco Use and Access Through Strengthened Minimum Price Laws. *American Journal of Public Health*. 2014;104(10):1844-1850. doi:10.2105/AJPH.2014.302069

234. Federal Trade Commission. *Federal Trade Commission Cigarette Report for 2017*. Washington, D.C.; 2019. https://www.ftc.gov/system/files/documents/reports/federal-trade-commission-cigarette-report-2017-federal-trade-commission-smokeless-tobacco-report/ftc_cigarette_report_2017.pdf. Accessed July 20, 2019.

235. Federal Trade Commission. *Federal Trade Commission Smokeless Tobacco Report for 2017*. Washington, D.C.; 2019. https://www.ftc.gov/system/files/documents/reports/federal-trade-commission-cigarette-report-2017-federal-trade-commission-smokeless-tobacco-report/ftc_smokeless_tobacco_report_2017.pdf. Accessed July 20, 2019.

236. Brock B, Carlson SC, Moilanen M, Schillo BA. Effectiveness of local policy efforts to increase the price of cheap cigars in Minnesota. *American Journal of Public Health*. 2017. doi:10.2105/AJPH.2016.303517

237. Li W, Gouveia T, Sbarra C, et al. Has Boston's 2011 cigar packaging and pricing regulation reduced availability of single-flavoured cigars popular with youth? *Tobacco Control*. 2017;26(2):135-140. doi:10.1136/tobaccocontrol-2015-052619

238. Huang J, Chriqui JF, DeLong H, Mirza M, Diaz MC, Chaloupka FJ. Do state minimum markup/price laws work? Evidence from retail scanner data and TUS-CPS. *Tobacco Control*. 2016;25(Suppl 1):i52-i59. doi:10.1136/tobaccocontrol-2016-053093

239. Feighery EC. How do minimum cigarette price laws affect cigarette prices at the retail level? *Tobacco Control*. 2005;14(2):80-85. doi:10.1136/tc.2004.008656

240. Tynan MA, Ribisl KM, Loomis BR. Impact of cigarette minimum price laws on the retail price of cigarettes in the USA. *Tobacco Control*. 2013;22(e1):e78-e85. doi:10.1136/tobaccocontrol-2012-050554

241. Golden SD, Farrelly MC, Luke DA, Ribisl KM. Comparing projected impacts of cigarette floor price and excise tax policies on socioeconomic disparities in smoking. *Tobacco Control*. 2016;25(Suppl 1):i60-i66. doi:10.1136/tobaccocontrol-2016-053230

242. Doogan NJ, Wewers ME, Berman M. The impact of a federal cigarette minimum pack price policy on cigarette use in the USA. *Tobacco Control*. March 2017:tobaccocontrol-2016-053457. doi:10.1136/tobaccocontrol-2016-053457

243. CounterTobacco.org. *Increasing Tobacco Prices through Non-Tax Approaches*. Chapel Hill, NC: University of North Carolina https://countertobacco.org/policy/licensing-and-zoning/. Accessed July 6, 2018.

244. Wang TW, Falvey K, Gammon DG, et al. Sales Trends in Price-Discounted Cigarettes, Large Cigars, Little Cigars, and Cigarillos—United States, 2011–2016. *Nicotine & Tobacco Research*. 2018;20(11):1401-1406. doi:10.1093/ntr/ntx249

245. Choi K. The associations between exposure to tobacco coupons and predictors of smoking behaviours among US youth: Table 1. *Tobacco Control*. 2016;25(2):232-235. doi:10.1136/tobaccocontrol-2014-052147

246. Lange T, Hoefges M, Ribisl KM. Regulating Tobacco Product Advertising and Promotions in the Retail Environment: A Roadmap for States and Localities. *The Journal of Law, Medicine & Ethics*. 2015;43(4):878-896. doi:10.1111/JLME.12326

247. Marynak KL, Xu X, Wang X, Holmes CB, Tynan MA, Pechacek T. Estimating the Impact of Raising Prices and Eliminating Discounts on Cigarette Smoking Prevalence in the United States. *Public Health Reports*. 2016;131(4):536-543. doi:10.1177/0033354916662211

248. Forster J. Social exchange of cigarettes by youth. *Tobacco Control*. 2003;12(2):148-154. doi:10.1136/tc.12.2.148

249. Committee on the Public Health Implications of Raising the Minimum Age for Purchasing Tobacco Products, Board on Population Health and Public Health Practice, Institute of Medicine. *Public Health Implications of Raising the Minimum Age of Legal Access to Tobacco Products*. (Bonnie RJ, Stratton K, Kwan LY, eds.). Washington, D.C.: National Academies Press; 2015. doi:10.17226/18997

250. Ahmad S, Billimek J. Limiting youth access to tobacco: Comparing the long-term health impacts of increasing cigarette excise taxes and raising the legal smoking age to 21 in the United States. *Health Policy*. 2007;80(3):378-391. doi:10.1016/j.healthpol.2006.04.001

251. Campaign for Tobacco-Free Kids. *States and Localities That Have Raised the Minimum Legal Sale Age for Tobacco Products to 21*.; 2019. https://www.tobaccofreekids.org/assets/content/what_we_do/state_local_issues/sales_21/states_localities_MLSA_21.pdf. Accessed July 18, 2019.

252. Balmert J. Raising tobacco sales age to 21: Ohio becomes latest state in national trend. *Cincinnati Enquirer*. https://www.cincinnati.com/story/news/politics/2019/07/18/raising-tobacco-sales-age-21-ohio-becomes-latest-state-national-trend/1765403001/. Published July 18, 2019. Accessed July 27, 2019.

253. Rouan R. Columbus City Council approves $195 million for health costs in 2017. *The Columbus Dispatch*. https://www.dispatch.com/content/stories/local/2016/12/12/columbus-city-council-approves-195-million-for-health-costs-in-2017.html. Published December 13, 2016. Accessed October 25, 2018.

254. Winickoff JP, McMillen R, Tanski S, Wilson K, Gottlieb M, Crane R. Public support for raising the age of sale for tobacco to 21 in the United States. *Tobacco Control*. 2015;25(3):284-288. doi:10.1136/tobaccocontrol-2014-052126

255. Berman ML. Raising the Tobacco Sales Age to 21: Surveying the Legal Landscape. *Public Health Reports*. 2016;131(2):378-381. doi:10.1177/003335491613100223

256. Schneider SK, Buka SL, Dash K, Winickoff JP, Donnell LO. Community reductions in youth smoking after raising the minimum tobacco sales age to 21. *Tobacco Control*. 2016;25(3):355-359. doi:10.1136/tobaccocontrol-2014-052207

257. Gottlieb S. *Statement from FDA Commissioner Scott Gottlieb, M.D., on Proposed New Steps to Protect Youth by Preventing Access to Flavored Tobacco Products and Banning Menthol in Cigarettes*. Washington, D.C.: U.S. Food and Drug Administration; 2018.

https://www.fda.gov/NewsEvents/Newsroom/PressAnnouncements/ucm625884.htm. Accessed November 23, 2018.

258. 124th Maine Legislture. *H.P. 1086 An Act to Make Maine's Laws Consistent with the Federal Family Smoking Prevention and Tobacco Control Act*. Vol 1560-D.; 2009. http://lldc.mainelegislature.org/Open/LDs/124/124-LD-1542.pdf. Accessed October 25, 2018.

259. Campaign for Tobacco-Free Kids. *States and Localities That Have Restricted the Sale of Flavored Tobacco Products*.; 2019. https://www.tobaccofreekids.org/assets/factsheets/0398.pdf. Accessed July 27, 2019.

260. Corey CG, Ambrose BK, Apelberg BJ, King BA. Flavored Tobacco Product Use Among Middle and High School Students — United States, 2014. *MMWR Morbidity and Mortality Weekly Report*. 2015;64(38):1066-1070. doi:10.15585/mmwr.mm6438a2

261. Lee JGL, Henriksen L, Rose SW, Moreland-Russell S, Ribisl KM. A Systematic Review of Neighborhood Disparities in Point-of-Sale Tobacco Marketing. *American Journal of Public Health*. 2015;105(9):e8-e18. doi:10.2105/AJPH.2015.302777

262. Ribisl KM, D'Angelo H, Feld AL, et al. Disparities in tobacco marketing and product availability at the point of sale: Results of a national study. *Preventive Medicine*. 2017;105:381-388. doi:10.1016/j.ypmed.2017.04.010

263. Courtemanche CJ, Palmer MK, Pesko MF. Influence of the Flavored Cigarette Ban on Adolescent Tobacco Use. *American Journal of Preventive Medicine*. 2017;52(5):e139-e146. doi:10.1016/j.amepre.2016.11.019

264. Farley SM, Johns M. New York City flavoured tobacco product sales ban evaluation. *Tobacco Control*. 2017;26(1):78-84. doi:10.1136/tobaccocontrol-2015-052418

265. Behren JV, Reynolds P, Gunier RB, et al. Residential Traffic Density and Childhood Leukemia Risk. *Cancer Epidemiology Biomarkers & Prevention*. 2008;17(9):2298-2301. doi:10.1158/1055-9965.EPI-08-0338

266. Hyland A, Ambrose BK, Conway KP, et al. Design and methods of the Population Assessment of Tobacco and Health (PATH) Study. *Tobacco Control*. 2017;26(4):371-378. doi:10.1136/tobaccocontrol-2016-052934

267. Stephenson MT, Hoyle RH, Palmgreen P, Slater MD. Brief measures of sensation seeking for screening and large-scale surveys. *Drug and Alcohol Dependence*. 2003;72(3):279-286. doi:10.1016/j.drugalcdep.2003.08.003

268. Kirby KN, Petry NM, Bickel WK. Heroin Addicts Have Higher Discount Rates for Delayed Rewards Than Non-Drug-Using Controls. *J Exp Psychol Gen*. 1999;128(1):78-87.

269. Echeverria SE. Reliability of Self-Reported Neighborhood Characteristics. *Journal of Urban Health: Bulletin of the New York Academy of Medicine*. 2004;81(4):682-701. doi:10.1093/jurban/jth151

270. Mujahid MS, Diez Roux AV, Morenoff JD, Raghunathan T. Assessing the Measurement Properties of Neighborhood Scales: From Psychometrics to Ecometrics. *American Journal of Epidemiology*. 2007;165(8):858-867. doi:10.1093/aje/kwm040

271. Sampson RJ, Raudenbush SW. Seeing Disorder: Neighborhood Stigma and the Social Construction of "Broken Windows." *Social Psychology Quarterly*. 2004;67(4):319-342. doi:10.1177/019027250406700401

272. Sampson RJ. Neighborhoods and Violent Crime: A Multilevel Study of Collective Efficacy. *Science*. 1997;277(5328):918-924. doi:10.1126/science.277.5328.918

273. Hu L, Bentler PM. Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling: A Multidisciplinary Journal*. 1999;6(1):1-55. doi:10.1080/10705519909540118

274. Powell DA, Schafer WD. The Robustness of the Likelihood Ratio Chi-Square Test for Structural Equation Models: A Meta-Analysis. *Journal of Educational and Behavioral Statistics*. 2001;26(1):105-132. doi:10.3102/10769986026001105

275. von Hippel P, Lynch J. Efficiency Gains from Using Auxiliary Variables in Imputation. *Cornell University Library*. 2013:10.

276. Lee KJ, Carlin JB. Multiple Imputation for Missing Data: Fully Conditional Specification Versus Multivariate Normal Imputation. *American Journal of Epidemiology*. 2010;171(5):624-632. doi:10.1093/aje/kwp425

277. Johnson DR, Young R. Toward Best Practices in Analyzing Datasets with Missing Data: Comparisons and Recommendations. *Journal of Marriage and Family*. 2011;73(5):926-945. doi:10.1111/j.1741-3737.2011.00861.x

278. Rubin DB. *Multiple Imputation for Nonresponse in Surveys*. New York, NY: John Wiley & Sons, Inc.; 1987.

279. Morgan CJ. Reducing bias using propensity score matching. *Journal of Nuclear Cardiology*. 2018;25(2):404-406. doi:10.1007/s12350-017-1012-y

280. Hosmer DW, Lemeshow S, Sturdivant RX. *Applied Logistic Regression*. 3rd ed. Hoboken, New Jersey: John Wiley & Sons, Inc; 2013.

281. Costanza MC. Matching. *Preventive Medicine*. 1995;24:425-433. doi:10.1006/pmed.1995.1069

282. Othus M, Barlogie B, LeBlanc ML, Crowley JJ. Cure Models as a Useful Statistical Tool for Analyzing Survival. *Clinical Cancer Research*. 2012;18(14):3731-3736. doi:10.1158/1078-0432.CCR-11-2859

283. Greenland S. Absence of Confounding Does Not Correspond to Collapsibility of the Rate Ratio or Rate Difference: *Epidemiology*. 1996;7(5):498-501. doi:10.1097/00001648-199609000-00008

284. Jackson MC, Hastings G, Wheeler C, Eadie D, MacKintosh AM. Marketing alcohol to young people: implications for industry regulation and research policy. *Addiction*. 2000;95(12):597-608. doi:10.1080/09652140020013809

285. Cantrell J, Kreslake JM, Ganz O, et al. Marketing Little Cigars and Cigarillos: Advertising, Price, and Associations With Neighborhood Demographics. *American Journal of Public Health*. 2013;103(10):1902-1909. doi:10.2105/AJPH.2013.301362

286. Waddell EN, Sacks R, Farley SM, Johns M. Point-of-Sale Tobacco Marketing to Youth in New York State. *Journal of Adolescent Health*. 2016;59(3):365-367. doi:10.1016/j.jadohealth.2016.05.013

287. Roberts ME, Berman ML, Slater MD, Hinton A, Ferketich AK. Point-of-sale tobacco marketing in rural and urban Ohio: Could the new landscape of Tobacco products widen inequalities? *Preventive Medicine*. 2015;81:232-235. doi:10.1016/j.ypmed.2015.08.024

288. Rose SW, Myers AE, D'Angelo H, Ribisl KM. Retailer Adherence to Family Smoking Prevention and Tobacco Control Act, North Carolina, 2011. *Preventing Chronic Disease*. 2013;10. doi:10.5888/pcd10.120184

289. ESRI. *ArcGIS Desktop: Release 10*. Redlands, CA: Environmental Systems Research Institute; 2011.

290. Bishaw A. *Areas With Concentrated Poverty: 2006–2010*. Washington, D.C.: U.S. Census Bureau; 2011:10.

https://www2.census.gov/library/publications/2011/acs/acsbr10-17.pdf. Accessed November 21, 2018.

291. Fitzmaurice GM, Laird NM, Ware JH. *Applied Longitudinal Data Analysis*. 2nd ed. Hoboken, New Jersey: John Wiley & Sons, Inc; 2011.

292. *SAS Version 9.4*. Cary, NC: The SAS Institute; 2013.

293. Kokonendji CC. Over-and Underdispersion Models. In: Balakrishnan N, ed. *Methods and Applications of Statistics in Clinical Trials*. Hoboken, NJ, USA: John Wiley & Sons, Inc.; 2014:506-526. doi:10.1002/9781118596333.ch30

294. Bhatta DN, Glantz SA. Electronic Cigarette Use and Myocardial Infarction Among Adults in the US Population Assessment of Tobacco and Health. *JAHA*. 2019;8(12). doi:10.1161/JAHA.119.012317

295. Morean ME, Kong G, Cavallo DA, Camenga DR, Krishnan-Sarin S. Nicotine concentration of e-cigarettes used by adolescents. *Drug and Alcohol Dependence*. 2016;167:224-227. doi:10.1016/j.drugalcdep.2016.06.031

296. Watkins SL, Glantz SA, Chaffee BW. Association of Noncigarette Tobacco Product Use With Future Cigarette Smoking Among Youth in the Population Assessment of Tobacco and Health (PATH) Study, 2013-2015. *JAMA Pediatrics*. 2018;172(2):181. doi:10.1001/jamapediatrics.2017.4173

297. Primack BA, Soneji S, Stoolmiller M, Fine MJ, Sargent JD. Progression to traditional cigarette smoking after electronic cigarette use among US adolescents and young adults. *JAMA pediatrics*. 2015;169(11):1018-1023. doi:10.1001/jamapediatrics.2015.1742

298. Hammond D, Reid JL, Cole AG, Leatherdale ST. Electronic cigarette use and smoking initiation among youth: a longitudinal cohort study. *Canadian Medical Association Journal*. 2017;189(43):E1328-E1336. doi:10.1503/cmaj.161002

299. Etter J-F. Gateway effects and electronic cigarettes. *Addiction*. 2018;113(10):1776-1783. doi:10.1111/add.13924

300. Vanyukov MM, Tarter RE, Kirillova GP, et al. Common liability to addiction and "gateway hypothesis": Theoretical, empirical and evolutionary perspective. *Drug and Alcohol Dependence*. 2012;123:S3-S17. doi:10.1016/j.drugalcdep.2011.12.018

301. Mantey DS, Cooper MR, Clendennen SL, Pasch KE, Perry CL. E-Cigarette Marketing Exposure Is Associated With E-Cigarette Use Among US Youth. *Journal of Adolescent Health*. 2016;58(6):686-690. doi:10.1016/j.jadohealth.2016.03.003

302. Singh T, Agaku IT, Arrazola RA, et al. Exposure to Advertisements and Electronic Cigarette Use Among US Middle and High School Students. *PEDIATRICS*. 2016;137(5):e20154155-e20154155. doi:10.1542/peds.2015-4155

303. Friedman KL, Roberts ME, Keller-Hamilton B, et al. Attitudes towards tobacco, alcohol, and non-alcoholic beverage advertisement themes among adolescent boys. *Substance Use and Misuse*. 2018;53(10):1706-1714. doi:10.1080/10826084.2018.1429473

304. Evans AT, Peters E, Keller-Hamilton B, et al. Warning Size Affects What Adolescents Recall from Tobacco Advertisements. *Tobacco Regulatory Science*. 2018;4(3):79-87. doi:10.18001/TRS.4.3.7

305. RStudio Team. *RStudio: Integrated Development for R.* Boston, MA: RStudio, Inc.; 2016. http://www.rstudio.com/.

306. Verplanken B. Beyond frequency: Habit as mental construct. *British Journal of Social Psychology*. 2006;45(3):639-656. doi:10.1348/014466605X49122

307. Wills TA, Gibbons FX, Sargent JD, Schweitzer RJ. How is the effect of adolescent e-cigarette use on smoking onset mediated: A longitudinal analysis. *Psychology of Addictive Behaviors*. 2016;30(8):876-886. doi:10.1037/adb0000213

308. Skotsimara G, Antonopoulos AS, Oikonomou E, et al. Cardiovascular effects of electronic cigarettes: A systematic review and meta-analysis. *European Journal of Preventive Cardiology*. March 2019:204748731983297. doi:10.1177/2047487319832975

309. U.S. Public Health Service. A Clinical Practice Guideline for Treating Tobacco Use and Dependence: 2008 Update. *American Journal of Preventive Medicine*. 2008;35(2):158-176. doi:10.1016/j.amepre.2008.04.009

310. Hair EC, Romberg AR, Niaura R, et al. Longitudinal Tobacco Use Transitions Among Adolescents and Young Adults: 2014–2016. *Nicotine & Tobacco Research*. 2019;21(4):458-468. doi:10.1093/ntr/ntx285

311. Morean ME, Butler ER, Bold KW, et al. Preferring more e-cigarette flavors is associated with e-cigarette use frequency among adolescents but not adults. Jeyaseelan S, ed. *PLoS ONE*. 2018;13(1):e0189015. doi:10.1371/journal.pone.0189015

312. Chen JC, Das B, Mead EL, Borzekowski DLG. Flavored E-cigarette Use and Cigarette Smoking Susceptibility among Youth. *tobacco reg sci*. 2017;3(1):68-80. doi:10.18001/TRS.3.1.7

313. StataCorp. *Stata Statistical Software Version 14.2*. College Station, TX: StataCorp LP; 2015.

314. Cho JH, Paik SY. Association between Electronic Cigarette Use and Asthma among High School Students in South Korea. Fehrenbach H, ed. *PloS One*. 2016;11(3):e0151022. doi:10.1371/journal.pone.0151022

315. Wills TA, Knight R, Williams RJ, Pagano I, Sargent JD. Risk Factors for Exclusive E-Cigarette Use and Dual E-Cigarette Use and Tobacco Use in Adolescents. *PEDIATRICS*. 2015;135(1):e43-e51. doi:10.1542/peds.2014-0760

316. Hawkins SS, Bach N, Baum CF. Impact of Tobacco Control Policies on Adolescent Smoking. *Journal of Adolescent Health*. 2016;58(6):679-685. doi:10.1016/j.jadohealth.2016.02.014

317. Diez Roux AV, Mair C. Neighborhoods and health. *Annals of the New York Academy of Sciences*. 2010;1186(1):125-145. doi:10.1111/j.1749-6632.2009.05333.x

318. Rhodes JE, Jason LA. A social stress model of substance abuse. *Journal of Consulting and Clinical Psychology*. 1990;58(4):395-401.

319. Rosseel Y. lavaan: An R Package for Structural Equation Modeling. *Journal of Statistical Software*. 2012;48(2):1-36.

320. White IR, Royston P, Wood AM. Multiple imputation using chained equations: Issues and guidance for practice. *Statistics in Medicine*. 2011;30(4):377-399. doi:10.1002/sim.4067

321. Committee on the Public Health Implications of Raising the Minimum Age for Purchasing Tobacco Products, Board on Population Health and Public Health Practice, Institute of Medicine. *Public Health Implications of Raising the Minimum Age of Legal Access to Tobacco Products*. Washington, D.C.: National Academies Press; 2015. doi:10.17226/18997

322. Kessel Schneider S, Buka SL, Dash K, Winickoff JP, O'Donnell L. Community reductions in youth smoking after raising the minimum tobacco sales age to 21. *Tobacco Control*. 2016;25(3):355-359. doi:10.1136/tobaccocontrol-2014-052207

323. Dai H. Attitudes Toward Tobacco 21 Among US Youth. *Pediatrics*. 2017;140(1):e20170570. doi:10.1542/peds.2017-0570

324. Volinsky AC, Kranzler EC, Gibson LA, Hornik RC. Tobacco 21 Policy Support by U.S. Individuals Aged 13–25 Years: Evidence From a Rolling Cross-sectional

Study (2014–2017). *American Journal of Preventive Medicine*. 2018;55(1):129-131. doi:10.1016/j.amepre.2018.03.008

325. City of Columbus. Learn how the Tobacco 21 law will save lives. ND. https://www.columbus.gov/publichealth/programs/Tobacco-21/Why-Tobacco-21-/. Accessed July 16, 2019.

326. City of Columbus. Tobacco 21 Requirements. ND. https://www.columbus.gov/publichealth/programs/Tobacco-21/Tobacco-21-Requirements/. Accessed July 16, 2019.

327. City of Columbus. Enforcement and Fines. ND. https://www.columbus.gov/publichealth/programs/Tobacco-21/Enforcement-and-Fines/. Accessed July 16, 2019.

328. City of Columbus. Retail tobacco and paraphernalia sales license information. ND. https://www.columbus.gov/publichealth/programs/Tobacco-21/Retail-Tobacco-Sales-License-Information/. Accessed July 16, 2019.

329. DiFranza JR. The federal initiative to halt the sale of tobacco to children--the Synar Amendment, 1992-2000: lessons learned. *Tobacco Control*. 2005;14(2):93-98. doi:10.1136/tc.2004.009373

330. Chaloupka FJ, Cummings KM, Morley C, Horan J. Tax, price and cigarette smoking: evidence from the tobacco documents and implications for tobacco company marketing strategies. *Tobacco Control*. 2002;11(Supplement 1):i62-i72. doi:10.1136/tc.11.suppl_1.i62

331. Chaloupka FJ, Straif K, Leon ME. Effectiveness of tax and price policies in tobacco control. *Tobacco Control*. 2011;20(3):235-238. doi:10.1136/tc.2010.039982

332. Cantrell J, Huang J, Greenberg MS, Xiao H, Hair EC, Vallone D. Impact of e-cigarette and cigarette prices on youth and young adult e-cigarette and cigarette behaviour: evidence from a national longitudinal cohort. *Tobacco Control*. June 2019:tobaccocontrol-2018-054764. doi:10.1136/tobaccocontrol-2018-054764

333. Jackson KM, Janssen T, Gabrielli J. Media/Marketing Influences on Adolescent and Young Adult Substance Abuse. *Current Addiction Reports*. 2018;5(2):146-157. doi:10.1007/s40429-018-0199-6

334. Beleva Y, Pike JR, Miller S, Xie B, Ames SL, Stacy AW. Share of Advertising Voice at the Point-of-Sale and Its Influence on At-Risk Students' Use of Alternative Tobacco Products. *Nicotine & Tobacco Research*. 2019;21(7):903-910. doi:10.1093/ntr/nty152

335. Siahpush M, Shaikh R, Smith D, et al. The Association of Exposure to Point-of-Sale Tobacco Marketing with Quit Attempt and Quit Success: Results from a Prospective Study of Smokers in the United States. *International Journal of Environmental Research and Public Health*. 2016;13(2):203. doi:10.3390/ijerph13020203

336. Harrell MB, Weaver SR, Loukas A, et al. Flavored e-cigarette use: Characterizing youth, young adult, and adult users. *Preventive Medicine Reports*. 2017;5:33-40. doi:10.1016/j.pmedr.2016.11.001

337. Goldenson NI, Kirkpatrick MG, Barrington-Trimis JL, et al. Effects of sweet flavorings and nicotine on the appeal and sensory properties of e-cigarettes among young adult vapers: Application of a novel methodology. *Drug and Alcohol Dependence*. 2016;168:176-180. doi:10.1016/j.drugalcdep.2016.09.014

338. Food and Drug Administration Center for Tobacco Products. *Modifications to Compliance Policy for Certain Deemed Tobacco Products: Guidance for Industry - Draft Guidance*. U.S. Department of Health and Human Services; 2019. https://www.fda.gov/media/121384/download. Accessed July 18, 2019.

339. Opazo Breton M, Britton J, Bogdanovica I. Changes in roll-your-own tobacco and cigarette sales volume and prices before, during and after plain packaging legislation in the UK. *Tobacco Control*. May 2019:tobaccocontrol-2018-054734. doi:10.1136/tobaccocontrol-2018-054734

340. Scollo M, Zacher M, Coomber K, Bayly M, Wakefield M. Changes in use of types of tobacco products by pack sizes and price segments, prices paid and consumption following the introduction of plain packaging in Australia. *Tobacco Control*. 2015;24(Suppl 2):ii66-ii75. doi:10.1136/tobaccocontrol-2014-052071

341. Philip Morris Limited. *Commoditising Tobacco Products through Plain Packaging Will Harm Public Health, Violate Treaties, and Does Not Meet the Test of "Evidence-Based Policy."* Melbourne; 2011. http://webarchive.nla.gov.au/gov/20130329051831/http://www.yourhealth.gov.au/internet/yourhealth/publishing.nsf/Content/Phillip-Morris-Limited~Phillip-Morris-Limited-2. Accessed July 20, 2019.

342. Freeman B, Chapman S, Rimmer M. The case for the plain packaging of tobacco products. *Addiction*. 2008;103(4):580-590. doi:10.1111/j.1360-0443.2008.02145.x

343. Winickoff JP, Hartman L, Chen ML, Gottlieb M, Nabi-Burza E, DiFranza JR. Retail Impact of Raising Tobacco Sales Age to 21 Years. *Am J Public Health*. 2014;104(11):e18-e21. doi:10.2105/AJPH.2014.302174

344. Watson KA, Gammon DG, Loomis BR, Juster HR, Anker E. Trends in Cigarette Advertising, Price-Reducing Promotions, and Policy Compliance in New York State Licensed Tobacco Retailers, 2004 to 2015. *American Journal of Health Promotion*. 2018;32(8):1679-1687.

345. Doogan NJ, Cooper S, Quisenberry AJ, et al. The role of travel distance and price promotions in tobacco product purchase quantity. *Health & Place*. 2018;51:151-157. doi:10.1016/j.healthplace.2018.03.009

346. Kasza KA, Ambrose BK, Conway KP, et al. Tobacco-Product Use by Adults and Youths in the United States in 2013 and 2014. *New England Journal of Medicine*. 2017;376(4):342-353. doi:10.1056/NEJMsa1607538

347. Ling PM, Glantz SA. Why and how the tobacco industry sells cigarettes to young adults: Evidence from industry documents. *American Journal of Public Health*. 2002;92(6):908-916. doi:10.2105/AJPH.92.6.908

348. Vallone D, Cantrell J, Bennett M, et al. Evidence of the Impact of the truth FinishIt Campaign. *Nicotine & Tobacco Research*. 2018;20(5):543-551. doi:10.1093/ntr/ntx119

# Appendix A. Measures

## SA1 & SA2 Measures

*Items asked to male youth*

1. Have you ever tried cigarette smoking, even one or two puffs?

- 1) Yes
- 2) No
- DON'T KNOW
- REFUSED

2. How old were you when you first tried cigarette smoking, even one or two puffs? Please enter age in years in the space provided.

|__|__|
DON’T KNOW
REFUSED

3. When was the last time you smoked a cigarette, even one or two puffs? Would you say...

- 1) Earlier today
- 2) Yesterday
- 3) Not yesterday or today but sometime during the past 7 days
- 4) Not during the past 7 days but sometime during the past 30 days
- 5) Not during the past 30 days but sometime during the past 6 months
- 6) Not during the past 6 months but sometime during the past year
- 7) 1 to 4 years ago
- 8) 5 or more years ago
- DON'T KNOW
- REFUSED

4. Have you ever used an e-cigarette, such as Smoking Everywhere, NJOY, Blu or Vapor King, even one or two times?

- 1) Yes
- 2) No
- DON'T KNOW
- REFUSED

5. How old were you when you first tried an e-cigarette, even one or two times? Please enter age in years.

|__|__|
DON’T KNOW
REFUSED

6. Have you ever smoked a cigar, cigarillo, or filtered cigar, even one or two puffs?

- 1) Yes
- 2) No
- DON'T KNOW
- REFUSED

7. How old were you when you first tried a [cigar|cigarillo/filtered cigar], even one or two puffs? Please enter age in years.

|__|__|
DON’T KNOW
REFUSED

8. Have you ever smoked tobacco in a hookah, even one or two puffs?

- 1) Yes
- 2) No
- DON'T KNOW
- REFUSED

9. How old were you when you first tried a hookah, even one or two puffs? Please enter age in years.

|__|__|
DON’T KNOW
REFUSED

10. Have you ever used any of the following smokeless tobacco products, even one or two times?

| | 1) Yes | 2) No | DON'T KNOW | REFUSED |
|---|---|---|---|---|
| Snus Pouches | o | o | o | o |
| Loose snus, moist snuff, dip, spit, or chewing tobacco | o | o | o | o |

11. How old were you when you first tried [snus|smokeless tobacco], even one or two times? Please enter age in years.

|__|__|
DON'T KNOW
REFUSED

12. When was the last time you used snus pouches, even one or two times? Would you say?

- o 1) Earlier today
- o 2) Yesterday
- o 3) Not yesterday or today but sometime during the past 7 days
- o 4) Not during the past 7 days but something during the past 30 days
- o 5) Not during the past 30 days but sometime during the past 6 months
- o 6) Not during the past 6 months but sometime during the past year
- o 7) 1 to 4 years ago
- o 8) 5 or more years ago
- o DON'T KNOW
- o REFUSED

13. When was the last time you used smokeless tobacco, even one or two times? Would you say...

- 1) Earlier today
- 2) Yesterday
- 3) Not yesterday or today but sometime during the past 7 days
- 4) Not during the past 7 days but sometime during the past 30 days
- 5) Not during the past 30 days but sometime during the past 6 months
- 6) Not during the past 6 months but sometime during the past year
- 7) 1 to 4 years ago
- 8) 5 or more years ago
- DON'T KNOW
- REFUSED

14. Have you ever used alcohol?

- 1) Yes
- 2) No
- DON'T KNOW
- REFUSED

15. About how old were you when you first started drinking, not counting small tastes or sips of alcohol? Please enter age in years in the space provided.

|__|__|
DON'T KNOW
REFUSED

16. Have you ever used marijuana, hash, THC, or grass?

1 Yes
2 No
DON'T KNOW
REFUSED

17. About how old were you when you first started using marijuana, hash, THC, or grass? Please enter age in years.

|__|__|
DON'T KNOW
REFUSED

18. The next questions are about things some people like to do. Please tell me how much you agree or disagree with the following statements.
I would like to explore strange places. Do you…
1 Strongly disagree
2 Disagree
3 Neither agree nor disagree
4 Agree
5 Strongly agree
-8 DON'T KNOW
-7 REFUSED

19. I like to do frightening things. Do you…
1 Strongly disagree
2 Disagree
3 Neither agree nor disagree
4 Agree
5 Strongly agree
-8 DON'T KNOW
-7 REFUSED

20. I like new and exciting experiences, even if I have to break the rules. Do you…
1 Strongly disagree
2 Disagree
3 Neither agree nor disagree
4 Agree
5 Strongly agree
-8 DON'T KNOW
-7 REFUSED

21. I prefer friends who are exciting and unpredictable. Do you…
1 Strongly disagree
2 Disagree
3 Neither agree nor disagree
4 Agree
5 Strongly agree
-8 DON'T KNOW
-7 REFUSED

22. You will now read a list of 9 choices between two money rewards. Please circle the reward you would prefer; the smaller reward today, or the larger reward in the specified

number of days. **You will not receive the rewards that you choose, but we want you to make your decisions as though you were really going to get the rewards you choose.** The choices you make are completely up to you. Please select the option that you prefer, not what you think others would want you to choose. We do not expect you to choose one particular reward over another.

| | Today | | Future |
|---|---|---|---|
| Would you prefer | $55 today | or | $75 in 61 days? |
| Would you prefer | $31 today | or | $85 in 7 days? |
| Would you prefer | $78 today | or | $80 in 162 days? |
| Would you prefer | $67 today | or | $75 in 119 days? |
| Would you prefer | $69 today | or | $85 in 91 days? |
| Would you prefer | $80 today | or | $85 in 157 days? |
| Would you prefer | $33 today | or | $80 in 14 days? |
| Would you prefer | $54 today | or | $80 in 30 days? |
| Would you prefer | $41 today | or | $75 in 20 days? |

DON'T KNOW
REFUSED

23. What is your race? Choose all that apply.

1 White
2 Black or African American
3 Native American, American Indian or Alaska Native
4 Native Hawaiian or Other Pacific Islander
5 Other: _____
DON'T KNOW
REFUSED

24. What is your date of birth?

MM/DD/YYYY

*Items asked to parents/guardians*

1. What is the highest grade or level of school you completed?

- ❑ Less than high school
- ❑ Some high school, no diploma
- ❑ GED
- ❑ High school graduate—diploma
- ❑ Some college but no degree

- ❑ Associate degree—occupational/vocational
- ❑ Associate degree—academic program
- ❑ Bachelor's degree (ex: BA, AB, BS)
- ❑ Master's degree (ex: MA, MS, MEng, Med, MSW)
- ❑ Professional school degree (ex: MD, DDS, DVM, JD)
- ❑ Doctorate degree (ex: PhD, EdD)
- ❑ DON'T KNOW
- ❑ REFUSED

2. How many current tobacco users over 18 years of age are in your household?

____PERSONS
- ❑ DON'T KNOW
- ❑ REFUSED

3. Did you live with [boy] or in the same neighborhood as he did when he was 10?
   1 Yes
   2 No → SKIP TO END
   -8 DON'T KNOW → SKIP TO END
   -7 REFUSED → SKIP TO END

Finally, I'd like to ask you a few questions about the neighborhood [boy] lived in on his tenth birthday (probe 5th grade if necessary). Please say whether you strongly agree, agree, neither agree nor disagree, disagree, or strongly disagree.

4. Many people in your neighborhood were afraid to go outside at night.

1 Strongly agree
2 Agree
3 Neither agree nor disagree
4 Disagree
5 Strongly disagree
-8 DON'T KNOW
-7 REFUSED

5. There were areas of this neighborhood where everyone knows "trouble" is expected.

1 Strongly agree
2 Agree
3 Neither agree nor disagree
4 Disagree
5 Strongly disagree
-8 DON'T KNOW

-7 REFUSED

6. You’re taking a big chance if you walk in this neighborhood alone after dark.
1 Strongly agree
2 Agree
3 Neither agree nor disagree
4 Disagree
5 Strongly disagree
-8 DON’T KNOW
-7 REFUSED

7. I felt safe walking in this neighborhood.
1 Strongly agree
2 Agree
3 Neither agree nor disagree
4 Disagree
5 Strongly disagree
-8 DON’T KNOW
-7 REFUSED

8. Violence was a problem in this neighborhood.
1 Strongly agree
2 Agree
3 Neither agree nor disagree
4 Disagree
5 Strongly disagree
-8 DON’T KNOW
-7 REFUSED

9. I felt safe from crime in this neighborhood.
1 Strongly agree
2 Agree
3 Neither agree nor disagree
4 Disagree
5 Strongly disagree
-8 DON’T KNOW
-7 REFUSED

10. This was a close-knit neighborhood.
1 Strongly agree
2 Agree
3 Neither agree nor disagree
4 Disagree

5 Strongly disagree
-8 DON'T KNOW
-7 REFUSED

11. People in that neighborhood were willing to help their neighbors.
1 Strongly agree
2 Agree
3 Neither agree nor disagree
4 Disagree
5 Strongly disagree
-8 DON'T KNOW
-7 REFUSED

12. People in that neighborhood generally didn't get along with each other.
1 Strongly agree
2 Agree
3 Neither agree nor disagree
4 Disagree
5 Strongly disagree
-8 DON'T KNOW
-7 REFUSED

13. People in that neighborhood shared the same values.
1 Strongly agree
2 Agree
3 Neither agree nor disagree
4 Disagree
5 Strongly disagree
-8 DON'T KNOW
-7 REFUSED

14. People in that neighborhood could be trusted.
1 Strongly agree
2 Agree
3 Neither agree nor disagree
4 Disagree
5 Strongly disagree
-8 DON'T KNOW
-7 REFUSED

15. Still thinking about the neighborhood [boy] [lived in when he was 10|currently lives in], please say whether the following characteristics of that neighborhood were a big problem, somewhat of a problem, or not a problem.

16. How much of a problem was litter, broken glass, or trash on the sidewalks and streets?

1 A big problem
2 Somewhat of a problem
3 Not a problem
-8 DON'T KNOW
-7 REFUSED

17. How much of a problem was graffiti on buildings and walls?

1 A big problem
2 Somewhat of a problem
3 Not a problem
-8 DON'T KNOW
-7 REFUSED

18. How much of a problem was vacant or deserted houses or storefronts?

1 A big problem
2 Somewhat of a problem
3 Not a problem
-8 DON'T KNOW
-7 REFUSED

19. How much of a problem was drinking in public?

1 A big problem
2 Somewhat of a problem
3 Not a problem
-8 DON'T KNOW
-7 REFUSED

20. How much of a problem was people selling or using drugs?

1 A big problem
2 Somewhat of a problem
3 Not a problem
-8 DON'T KNOW
-7 REFUSED

21. How much of a problem was groups of teenagers or adults hanging out in the neighborhood and causing trouble?

1 A big problem

2 Somewhat of a problem
3 Not a problem
-8 DON'T KNOW
-7 REFUSED

22. How much of a problem was noise in the neighborhood?
1 A big problem
2 Somewhat of a problem
3 Not a problem
-8 DON'T KNOW
-7 REFUSED

23. How much of a problem was yelling or fighting?
1 A big problem
2 Somewhat of a problem
3 Not a problem
-8 DON'T KNOW
-7 REFUSED

SA3 Measures

. Type of Store

- Convenience store without gas
- Gas convenience store (e.g. 7-Eleven, Exxon, Speedway, Duke & Duchess, BP, Marathon)
- Drug store/pharmacy (e.g. Walgreens, Rite Aid)
- Beer, wine, or liquor store
- Grocery store (e.g. small market/deli/produce market) or supermarket (e.g. Stop & Shop, Kroger, Big Bear, IGA)
- Mass merchandiser (e.g. Walmart, Costco, BJ's, Sam's Club) or discount store (e.g. Dollar General, Family Dollar)
- Tobacco shop (e.g. cigar shops)
- Bar or restaurant
- Hookah Cafe
- Vape shop
- Drive-Through
- Other

*Display This Question:*

*If Type of Store = Other*

2. If "other" type of store, specify:

_____

3. External Ads: Which products are advertised outside the store (on windows/doors, building, sidewalk, parking lot or elsewhere)? Reminder--advertisements can be with or without prices.

- ☐ Cigarettes, non-menthol
- ☐ Cigarettes, menthol
- ☐ E-Cigarettes, unflavored
- ☐ E-Cigarettes, flavored
- ☐ Chew, snuff, or snus, unflavored
- ☐ Chew, snuff, or snus, flavored
- ☐ Cigarillos/Little Cigars, unflavored
- ☐ Cigarillos/Little Cigars, flavored
- ☐ Large Cigars
- ☐ Hookah
- ☐ On! nicotine crystals
- ☐ Non-branded (e.g, "the best cigars in town")
- ☐ No External Ads

4. External Promotions: Which products have promotions outside the store (on windows/doors, building, sidewalk, parking lot or elsewhere)? Reminder--promotions are offering a special/cheaper price.

- ☐ Cigarettes, non-menthol
- ☐ Cigarettes, menthol
- ☐ E-Cigarettes, unflavored
- ☐ E-Cigarettes, flavored
- ☐ Chew, snuff, or snus, unflavored
- ☐ Chew, snuff, or snus, flavored
- ☐ Cigarillos/Little Cigars, unflavored
- ☐ Cigarillos/Little Cigars, flavored
- ☐ Large Cigars
- ☐ Hookah
- ☐ On! nicotine crystals
- ☐ No External Promotions

5. What products are sold here?

- ☐ Cigarettes, non-menthol
- ☐ Cigarettes, menthol
- ☐ E-Cigarettes, unflavored
- ☐ E-Cigarettes, flavored
- ☐ Chew, snuff, or snus, unflavored
- ☐ Chew, snuff, or snus, flavored
- ☐ Cigarillos/Little Cigars, unflavored
- ☐ Cigarillos/Little Cigars, flavored
- ☐ Large Cigars
- ☐ Hookah, unflavored
- ☐ Hookah, flavored
- ☐ Hookah that is nicotine free
- ☐ Heat Not Burn Products (e.g., Revo)
- ☐ On! nicotine crystals
- ☐ No Tobacco Products Sold

6. What products are promoted inside the store?

- ☐ Cigarettes, non-menthol
- ☐ Cigarettes, menthol
- ☐ E-Cigarettes, unflavored
- ☐ E-Cigarettes, flavored
- ☐ Chew, snuff, or snus, unflavored
- ☐ Chew, snuff, or snus, flavored
- ☐ Cigarillos/Little Cigars, unflavored
- ☐ Cigarillos/Little Cigars, flavored
- ☐ Large Cigars
- ☐ Hookah
- ☐ On! nicotine crystals
- ☐ No Inside Promotions


7. Are any of these products being sold?

- Marlboro Reds
- Newport Green Full Flavor
- Blu disposable e-cigarette (magnificent menthol variety)
- None

*Display This Question:*

*If Are any of these products being sold? = Marlboro Reds*

8. Marlboro Red advertised price:

_____

*Display This Question:*

*If Are any of these products being sold? = Newport Green Full Flavor*

9. Newport Green Full Flavor advertised price:

_____

*Display This Question:*

*If Are any of these products being sold? = Blu disposable e-cigarette (magnificent menthol variety)*

10. Blu disposable e-cig advertised price:

_____

*Display This Question:*

*If What products are sold here? = Cigarettes, non-menthol*

*Or What products are sold here? = Cigarettes, menthol*

11. Cheapest cigarette pack in the store:

_____

## Appendix B. Proof of Distribution-Level Balance Being Acceptable for Estimating the Average Treatment Effect

### Estimation of Treatment Effect

**Model B1**. In the model below, the value of some outcome, Y, depends on treatment assignment, T, covariates, X, and random error.

$$Y = \beta_0 + \beta_1 T + \beta_2 \boldsymbol{X} + \varepsilon$$

This model can be written as the following two expectations:

$$E(Y|T = 1) = \beta_0 + \beta_1 + \beta_2 \overline{\boldsymbol{X}}_{T=1}$$

$$E(Y|T = 0) = \beta_0 + \beta_2 \overline{\boldsymbol{X}}_{T=0}$$

The average treatment effect, then, can be estimated by calculating E(Y|T=1) – E(Y|T=0). As this quantity depends on the mean of X, not individual values of X, achieving distribution-level balance is acceptable for estimating the average treatment effect.