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Risk Factors Associated with Subsequent Initiation of Cigarettes and E-cigarettes in Adolescence: A Structural Equation Modeling Approach

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Abstract

Background—Previous youth tobacco research has identified multiple correlated risk factors for initiation of cigarette and e-cigarette use; whether these factors are independently associated with initiation is not known, due to challenges with disentangling the independent effects of these correlated risk factors.

Methods—Students in 11th/12th grade enrolled in the Southern California Children's Health Study were surveyed in 2014 (baseline) and again in 2015 (N=1553). Structural equation models (SEM) were developed to investigate associations of susceptibility, marketing, and the social environment (as latent factors), and other tobacco use at baseline with cigarette or e-cigarette initiation between baseline and follow-up. Analyses were restricted to baseline never cigarette users (N=1293) for models evaluating cigarette initiation, and to never e-cigarette users (N=1197) for models evaluating e-cigarette initiation.

Results—In fully-adjusted prospective SEM models, latent factors for cigarette susceptibility, marketing, and the social environment, along with ever e-cigarette use and ever hookah use at baseline were independently associated with cigarette initiation between baseline and follow-up ($P < 0.05$). Similarly, latent factors for e-cigarette susceptibility, marketing, and the social environment, along with ever hookah use at baseline were associated with e-cigarette initiation

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CONTRIBUTORS

Dr. Kintz and Ms. Liu formulated the research question, conducted the analyses, interpreted the results, wrote and edited the manuscript, and approved the manuscript as submitted. Drs. Chou, Urman, Berhane, Unger, and Cruz contributed to formulating the research question, interpretation of results and to editing the manuscript, and approved the manuscript as submitted. Dr. McConnell designed the study, collected data, and contributed to formulating the research question and interpretation of the results, critically reviewed the manuscript, and approved the manuscript as submitted.

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between baseline and follow-up ($P<0.05$); however, cigarette use at baseline was not associated with e-cigarette initiation in SEM models ($P=0.16$).

Conclusions—We identified independent effects of multiple risk factors in SEM models on initiation of cigarettes and e-cigarettes. E-cigarette use was associated with cigarette initiation, but cigarette use was not associated with e-cigarette initiation in fully adjusted models. Research to identify underlying causal mechanisms are warranted.

Keywords

e-cigarettes; cigarettes; adolescence; structural equation models (SEM); risk factors; prospective cohorts; longitudinal analysis; epidemiology

1. INTRODUCTION

Combustible tobacco use is the leading cause of preventable death in the United States (US Department of Health and Human Services, 2012). It is critically important to understand what risk factors independently and collectively contribute to cigarette use in adolescents and young adults in order to develop preventive strategies and regulatory policies to reduce cigarette use and the public health burden of cigarettes. Decades of tobacco control research have identified numerous environmental and psychosocial risk factors for the initiation of cigarette use among youth (US Department of Health and Human Services, 2012). However, most of the studies to date have typically evaluated only one or two key risk factors at a time, using traditional multivariate techniques. For example, self-reported susceptibility to cigarette use, exposure to tobacco marketing, and a supportive social environment (use of cigarettes in the home, friends' use of and positive attitudes toward tobacco) have all been shown to be risk factors of combustible cigarette use in separate models (U.S.

DEPARTMENT OF HEALTH AND HUMAN SERVICES, 2014; US Department of Health and Human Services, 2012). More recently, numerous studies have reported that e-cigarette use (Barrington-Trimis et al., 2016; Best et al., 2017; Bold et al., 2018; Conner et al., 2017; Hammond et al., 2017; Leventhal et al., 2016; Leventhal et al., 2015; Loukas et al., 2018; Lozano et al., 2017; Miech et al., 2017; Morgenstern et al., 2018; Primack et al., 2015; Soneji et al., 2017; Spindle et al., 2017; Treur et al., 2018; Unger et al., 2016; Wills et al., 2016a; Wills et al., 2016b; Wills et al., 2016c), cigar use (Kong et al., 2017) and hookah use (Soneji et al., 2015) have also been identified as risk factors for subsequent initiation of combustible cigarettes.

Many of the established risk factors for combustible cigarette smoking may also be relevant to e-cigarette initiation, including a supportive social environment (Barrington-Trimis et al., 2015; Urman et al., 2018), exposure to e-cigarette marketing (Cruz et al., 2018), and self-reported susceptibility to e-cigarette use (Bold et al., 2016; Cruz et al., 2018; Farrelly et al., 2015; Mantey et al., 2016). It is less clear if combustible cigarette smoking is associated with subsequent e-cigarette use, or whether youth and young adults are using e-cigarettes to transition from or to quit cigarette use. Currently, no clinical trials have been conducted to evaluate the efficacy of e-cigarettes as a smoking cessation aid among adolescent or young adult populations. Several observational studies have had mixed results. A recent prospective analysis found that cigarette smoking was not associated with future e-cigarette use (Bold et

al., 2017); an earlier study found that cigarette use was associated with a 2-fold increase in e-cigarette initiation (Wills et al., 2016b). We recently reported that young adult cigarette smokers were substantially more likely to remain as cigarette smokers with or without concurrent e-cigarette use than to transition to exclusive e-cigarette use or quit all nicotine product use (Barrington-Trimis et al., 2018).

While these studies provide key insight into important risk factors, more comprehensive approaches are needed to evaluate the net impact of multiple correlated risk factors for cigarette or e-cigarette initiation in a single model, and to disentangle the unique contribution of each factor in the presence of other correlated risk factors. To address these gaps in the understanding of cigarette and e-cigarette initiation, we examined the influence of the social environment, marketing exposure, susceptibility to tobacco use, and use of other tobacco products on the initiation of both cigarette and e-cigarette use (independently) in a prospective study of adolescents during the transition to young adulthood. Specifically, we utilized a structural equation modeling (SEM) approach to parse the contributions of multiple correlated risk factors on cigarette and e-cigarette initiation, respectively (Figure 1).

2. METHODS

2.1 Participants

This study utilized data from the Southern California Children's Health Study (CHS), a prospective cohort study of adolescents, for which recruitment and data collection procedures have been described in detail elsewhere (Barrington-Trimis et al., 2015; McConnell et al., 2006). Briefly, students in 11th or 12th grade (mean age = 17.3 ± 0.6) were asked to complete in-classroom, paper-based questionnaires under study staff supervision from January 2014 to June 2014 (baseline for the current report; $N=2097$). Participants completed an online follow-up questionnaire between February 2015 and March 2016 after they reached 18 years of age ($N=1563$; response rate = 75%; mean age = 18.8 ± 0.6). Analyses were restricted, in respective analyses, to those who reported never having used cigarettes at baseline to examine risks of cigarette initiation ($N=1293$), and to those who had never used e-cigarette at baseline to examine risks of e-cigarette initiation ($N=1197$).

2.2 Ethics Statement

The study was approved by the University of Southern California Institutional Review Board. Participants age 18 or older provided written informed consent. Written parental informed consent and student assent were obtained for all CHS participants prior to data collection in 2014.

2.3 Measures

2.3.1 Tobacco and Alternative Tobacco Use—Participants were asked to report the age they first used e-cigarettes, cigarettes, hookah, and cigars in each survey. Participants who reported that they had never used a product were classified as “never users.” Those who reported an age of first use of a product were considered “ever users” of that product. Participants who reported no use of a product at baseline, but reported use of a product at follow-up were considered to have initiated use between baseline and follow-up.

2.3.2 Latent Variables

Susceptibility to Tobacco and Alternative Tobacco Product Use: A latent susceptibility factor for cigarette or e-cigarette use was assessed using three items as indicator variables for each product. Participants were asked the following questions separately for cigarettes and e-cigarettes with four response options (definitely not, probably not, probably yes, and definitely yes): (1) At any time in the next year do you think you will use this product?; (2) If one of your best friends were to offer you this product would you use it?; and (3) Have you ever been curious about using this product? Each item was treated as a continuous variable (e.g., ranging from 0 [definitely not] to 3 [definitely yes]).

Marketing: A latent factor for exposure to cigarette or e-cigarette marketing was assessed using five marketing questions as indicator variables for each tobacco product. Participants were asked the following questions separately for cigarettes and e-cigarettes: (1) When you are using the Internet, how often do you see ads for this product?; (2) When you are reading newspapers or magazines, how often do you see ads for this product?; (3) When you go to a convenience store, supermarket, or gas station, how often do you see ads for this product?; (4) During the past 30 days, how often did you see an ad for this product that was outdoors on a billboard or could be seen from outside a store?; and (5) When you watch TV or go to the movies, how often do you see actors using this product? Since the marketing indicator variables were well distributed across the range of response options, each was treated as a continuous variable from 1–6 based on response (I do not use the marketing channel, never, rarely, sometimes, most of the time, and always).

Social Environment: A latent factor for the cigarette or e-cigarette social environment was assessed using three social environment questions as indicator variables for each product. Participants were asked the following questions, separately for cigarettes and e-cigarettes: (1) How would your best friends act toward you if you used this product? (very unfriendly, unfriendly, friendly, or very friendly, treated as a continuous variable [0–3]). (2) How many of your four closest friends use this product? (response options=0–4 friends, treated as a continuous variable [0–4]; responses of “not sure” were treated as missing in the analysis). (3) Does anyone who lives with you now use this product? (yes/no).

2.3.3 Sociodemographic characteristics—Self-administered questionnaires completed by parents of participants assessed gender, ethnicity (Hispanic white, non-Hispanic white, and other), and parental education (highest level of education of either parent: High school diploma or less, some college, college diploma or above), which were included as additional covariates (McConnell et al., 2006).

2.3.4 Statistical Analysis—Chi-square tests were used to evaluate the odds of cigarette or e-cigarette initiation by each sociodemographic characteristic and by baseline tobacco product use in separate models. Structural equation modeling (SEM) was used to examine the associations of latent factors (susceptibility, marketing, and social environment) and observed variables (ever use of cigarette or e-cigarette, hookah, and cigar at baseline, gender, ethnicity, and parental education) with initiation of e-cigarette or cigarette use (in separate models). The zero-ordered correlations for the latent factor indicator variables, baseline use

of other tobacco products, and cigarette or e-cigarette initiation at follow-up were first evaluated using Pearson product moment coefficients for continuous-continuous, point-biserial coefficients for continuous-dichotomous, and phi coefficients for dichotomous-dichotomous observed variables. SEM models were then specified separately for cigarette and e-cigarette initiation (Figure 1). The minimally adjusted model only included three latent factors (social environment, susceptibility to tobacco use, exposure to marketing) specific to the outcome tobacco product, and baseline cigarette use for e-cigarette initiation model or baseline e-cigarette use for the cigarette initiation model. The maximally adjusted model additionally included ever hookah or cigar use at baseline as well as gender, ethnicity, parental education. Models were estimated using robust weighted least squares (WLSMV) (Muthén and Muthén, 1998–2015). The variances for each factor were set to 1 to get estimates for each indicator variable. Model estimates were standardized to factors and dependent variables (MPlus STDY method) (Muthén and Muthén, 1998–2015) and P-values were reported. A level of significance of $\alpha < 0.05$ was used in all statistical analyses. The goodness-of-fit of the model to the data was assessed using a chi-square goodness-of-fit test statistic, comparative fit index (CFI), and the root square error of approximation (RMSEA). Minimal CFIs of 0.90 were required for model acceptance, and values of 0.95 or greater were accepted as an indication of good model fit. RMSEAs of less than 0.06 were accepted as indicators of a good fitting model (Bentler, 1990; Browne and Cudeck, 1993; Hu and Bentler, 1998).

Missing data rates were generally low for tobacco product use, susceptibility, marketing, several social environment variables, and sociodemographic characteristics (<3%). Higher missing data rates were observed for friends' use of cigarettes or e-cigarettes due to responses of "not sure", which were treated as missing data (6% for both cigarette and e-cigarette). Parental education was missing for 10% of the entire sample. As such, a missing parental education category was used for the analysis. Missing data were handled by the full information maximum likelihood (FIML) estimation in Mplus. FIML estimates coverage of missing data at the covariance matrix level and uses all possible data points during the analysis (Allison, 2003). Sensitivity analyses evaluated differences in key sociodemographic characteristics for those who did (vs. did not) complete the follow-up survey (Supplemental Table 1). Analyses were performed using SAS 9.4 (SAS, 2013) and Mplus 7.4 (Muthén and Muthén, 1998–2015).

3. RESULTS

Among never cigarette users at baseline (N=1293), 16.4% initiated cigarette use between baseline and follow-up (Table 1). E-cigarette, hookah, and cigar use at baseline were strongly associated with cigarette initiation in unadjusted models (OR_{e-cigarette}: 4.91, 95% CI: 3.42–7.05; OR_{hookah}: 4.10, 95% CI: 2.94–5.73; OR_{cigar}: 5.29, 95% CI: 3.06–9.15, respectively). Males were also more likely to initiate cigarette use (unadjusted OR=1.67; 95% CI: 1.23–2.25), but no associations were observed for ethnicity or parental education.

Among never e-cigarette users at baseline (N=1197), 26.5% initiated e-cigarette use between baseline and follow-up (Table 1). Cigarette, hookah, and cigar use at baseline were strongly associated with e-cigarette initiation in unadjusted models (OR_{cigarette}: 3.46, 95% CI: 2.07–

5.79; OR_{hookah}: 5.85, 95% CI: 4.06–8.43; OR_{cigar}: 4.25, 95% CI: 2.15–8.42, respectively). Gender, ethnicity, and parental education were not associated with e-cigarette initiation.

No differences between those who were included in analyses or lost to follow-up were observed for e-cigarette use, hookah use, or cigar use (Supplemental Table 1). Those lost to follow up were more likely to be male, Hispanic White (vs. Non-Hispanic White), and had parents with less than a high school education (or data on parental education was missing). In addition, among the sample of e-cigarette never users at baseline, baseline cigarette use was more common among those lost to follow-up.

3.1 Cigarette Initiation SEM

For cigarette initiation, zero-order correlation coefficients ranged from 0.47–0.63 for susceptibility measures, 0.23–0.44 for marketing measures, 0.03–0.23 for social environment measures, and 0.31–0.42 for use of other tobacco products at baseline (Supplemental Table 2a).

In SEM models, e-cigarette use at baseline, marketing, and social environment factors were associated with cigarette initiation at follow-up in both the minimally adjusted ($P_s < 0.05$) and maximally adjusted ($P_s < 0.05$) models (Table 2). In addition, hookah use at baseline ($P < 0.001$) and gender ($p = 0.01$) were associated with cigarette initiation in the maximally adjusted model ($P < 0.001$); ethnicity, parental education, and cigar use were not associated with cigarette initiation. Significant correlations were observed between cigarette susceptibility and marketing factors ($r = 0.13$, $P < 0.001$), and susceptibility and social environment factors ($r = .60$, $P < 0.001$), but not marketing and social environment factors ($r = 0.09$, $P = 0.08$). The R^2 for ever-use of cigarettes at follow-up in the minimally adjusted model was 0.209 ($P < 0.001$), and in the maximally adjusted model was 0.259 ($P < 0.001$). Both the minimally adjusted (Chi-square goodness of fit=178.92, d.f.=57, $P < 0.01$; CFI=0.95; RMSEA=0.04) and the maximally adjusted (Chi-square goodness of fit=322.94, d.f.=121, $P < 0.01$; CFI=0.99; RMSEA=0.04) models fit the data well.

3.2 E-cigarette Initiation SEM

For e-cigarette initiation, zero-order correlations coefficients ranged from 0.52–0.68 for susceptibility indicators, 0.23–0.49 for marketing measures, 0.19–0.30 for social environment measures, and 0.23–0.31 for use of other tobacco products at baseline (Supplemental Table 2b).

In SEM models, cigarette use at baseline and the three latent factors were all associated with e-cigarette initiation at follow-up in the minimally adjusted model (Table 3; $P < 0.008$). After adjusting for sociodemographic variables and other tobacco product use at baseline, the three latent factors were still associated with e-cigarette initiation ($P_s \leq 0.02$), but the estimated effect of cigarette use was markedly attenuated and no longer significant ($P = 0.16$). Hookah use at baseline was associated with e-cigarette initiation in the maximally adjusted model ($P < 0.001$), but no associations of demographic characteristics or cigar use with e-cigarette initiation were observed. Significant correlations were observed between all three latent factors in the maximally adjusted model. The highest correlation was between e-

cigarette susceptibility and social environment factors ($r=0.60$, $P<0.001$), followed by e-cigarette marketing and social environment factors ($r=0.25$, $P<0.001$), and e-cigarette susceptibility and marketing factors ($r=0.16$, $P<0.001$). The R^2 for ever-use of e-cigarettes at follow-up in the minimally adjusted model was 0.194 ($P<0.001$), and in the maximally adjusted model was 0.284 ($P<0.001$). Both the minimally adjusted (Chi-square goodness of fit=111.43, d.f.=57, $P<0.001$; CFI=0.97; RMSEA=0.03) and the maximally adjusted (Chi-square goodness of fit=237.53, d.f.=121, $P<0.001$; CFI=0.99; RMSEA=0.03) models fit the data well.

4. DISCUSSION

This prospective study assessed the independent effects of the tobacco social environment, exposure to tobacco marketing, susceptibility to tobacco product use, and use of other tobacco products with cigarette and e-cigarette initiation in adolescents using SEM to model all factors simultaneously. The results demonstrate that: (1) a pro-tobacco social environment, exposure to tobacco marketing, and susceptibility to tobacco product use each independently contribute to initiation of both cigarettes and e-cigarettes; (2) after accounting for the effects of these factors, e-cigarette use was significantly associated with cigarette initiation, but cigarette use was not associated with e-cigarette initiation; and (3) hookah use was strongly associated with subsequent initiation of both e-cigarette and cigarette use.

The use of SEM has several advantages relative to traditional multivariate techniques. First, while most multivariate techniques do not explicitly model measurement error, SEM statistically controls for measurement error for both independent and dependent variables by including error variance parameters in the model (Byrne, 2012; Novikova et al., 2013). Next, most multivariate techniques are designed to evaluate variables that are directly measured, which can be limiting if researchers are interested in testing underlying theoretical constructs, or latent factors. SEM allows for the estimation of these latent factors, via observed variables while accounting for measurement error. Importantly, SEM eliminates the issue of multicollinearity among covariates, which make it possible to examine effects of multiple correlated risk factors at the same time. Taken together, this allows SEM models to evaluate the effects of observed variables that are highly correlated (e.g., indicators for susceptibility to tobacco use), as well as factors that are related (e.g., susceptibility to use and a pro-tobacco social environment). Overall, an SEM approach may provide a better understanding of how risk factors, individually and collectively, influence tobacco product initiation, which can inform interventions and policy measures designed to reduce exposure to the factors that pose the greatest risk to youth tobacco initiation.

While all three factors were found to be associated with cigarette and e-cigarette initiation, the strongest association for initiation of both products was a pro-tobacco social environment. Interventions to help adolescents resist peer influences and efforts to denormalize e-cigarette and cigarette use in youth may help reverse the current high rates of use. Such programs have already been shown to be successful in reducing cigarette use among adolescents (Malone et al., 2012; Services., 2012). In addition, since cigarette and e-cigarette marketing exposure is linked with subsequent use of those products, efforts to further restrict pro-tobacco marketing, and marketing campaigns designed to deliver

preventive messages across diverse media channels to which adolescents are easily exposed (Cruz et al., 2018; Hanewinkel et al., 2011; Henriksen et al., 2010; Villanti et al., 2016) may be effective strategies to reduce adolescent tobacco use. For example, health communication interventions that use fast-paced graphics, visuals, and music to provide accurate information about the risks of tobacco product use, like the “Wake Up” campaign in California, and the FDA’s “The Real Cost” campaign, are promising platforms that may help denormalize tobacco product use, counteract tobacco marketing targeted towards youth, and ultimately reduce tobacco product initiation among young adults (California Department of Public Health, 2017; Farrelly et al., 2017; Jamal et al., 2017).

The relationship between e-cigarette and combustible cigarette use is critical to evaluating the public health implications of e-cigarettes. E-cigarettes may lead to the reduction or cessation of combustible tobacco use among adult smokers, but could also lead to combustible cigarette initiation and the renormalization of smoking among youth and young adults (Fairchild et al., 2014). A number of studies report a substantial proportion of adolescent e-cigarette users have never used conventional cigarettes, and multiple reports from a series of prospective cohort studies have found that nonsmoking youth who use e-cigarettes are at increased risk of initiating combustible cigarette smoking (Barrington-Trimis et al., 2016; Best et al., 2017; Bold et al., 2018; Conner et al., 2017; Hammond et al., 2017; Leventhal et al., 2016; Leventhal et al., 2015; Loukas et al., 2018; Lozano et al., 2017; Miech et al., 2017; Morgenstern et al., 2018; Primack et al., 2015; Soneji et al., 2017; Spindle et al., 2017; Treur et al., 2018; Unger et al., 2016; Wills et al., 2016a; Wills et al., 2016b; Wills et al., 2016c). In the SEM analysis, e-cigarette use was associated with increased risk of combustible cigarette initiation, independent of the social environment, marketing, susceptibility, other tobacco use, and demographic characteristics. This suggests the association between e-cigarette use and subsequent smoking may result from more than a shared risk for e-cigarettes and cigarettes. On the other hand, in fully adjusted SEM models, we observed a markedly attenuated and statistically non-significant association between cigarette use and e-cigarette initiation. Taken together, these findings indicate e-cigarette use may encourage future cigarette use, but cigarette use does not necessarily result in future e-cigarette use. Thus, e-cigarettes may expose more youth to tobacco products, without providing much benefit via harm reduction, ultimately resulting in a net adverse public health impact in the young adult population. The overall impact of e-cigarettes on the public health of youth and young adult populations is also dependent upon longer term use patterns. If e-cigarettes are associated with subsequent initiation but not long term cigarette use, then the adverse impact of e-cigarettes is minimized; however, emerging evidence suggests that e-cigarette use is associated not only with cigarette initiation but with progression to more frequent cigarette use patterns and a similar trajectory toward regular cigarette use (Barrington-Trimis et al., 2018; Leventhal et al., 2016). Similarly, longer term transition patterns away from cigarettes will also affect the net public health impact of e-cigarettes, however, our findings that cigarette smokers do not have any greater likelihood of initiation of e-cigarettes suggests that they are also unlikely to have greater likelihood of continued and regular e-cigarette use.

Although recent research has primarily focused on the effect of e-cigarette use on cigarette initiation in youth, and vice versa, the role of hookah in both cigarette and e-cigarette

initiation merits further investigation (Gilreath et al., 2016; Huh and Leventhal, 2016). Prospective studies have shown that hookah use was associated with cigarette initiation, current cigarette use, and higher intensity of smoking among young adults (Jaber et al., 2015; Soneji et al., 2015). In a previous cross-sectional analysis of CHS data, we observed that the prevalence of hookah use was higher than that of either e-cigarette or cigarette use in high school students (Gilreath et al., 2016). While use of all three tobacco products were correlated, we identified a group that had a pattern of both e-cigarette and hookah use that distinguished it from other patterns of polytobacco product use (Gilreath et al., 2016). In a 6-month prospective follow-up of a younger cohort enrolled in middle school, transitions to polytobacco product use were common, possibly with an intermediate transition from never tobacco use to e-cigarette and hookah use (Huh and Leventhal, 2016). In the current study, our findings of significant associations of previous e-cigarette and hookah use on the initiation of tobacco smoking were consistent with these previous reports. More research is needed to understand why e-cigarette and hookah use are strong risk factors for subsequent cigarette use in adolescents (Schneider and Diehl, 2016). Given that e-cigarettes and hookah are frequently sold and marketed in forms and flavors that may preferentially appeal to youth (Carpenter et al., 2005; Connolly, 2004; Vasiljevic et al., 2016), regulatory policies that successfully reduce youth exposure and access to these products might reduce both initiation of cigarettes and e-cigarettes, but also reduce the subsequent transition from e-cigarette to cigarette use.

This analysis is subject to some limitations. First, 25% of the sample were lost to follow up, and significant differences in retention were observed by gender, race and parental education ($P < 0.05$, Supplemental Table 1). We cannot rule out the possible role of selection bias; however, the estimated effects were robust to adjustment for these characteristics. Second, the indicator variables for the latent variables in each SEM model were product specific. However, it is likely that susceptibility, marketing, and social environment factors are not product specific, but rather are influenced by multiple tobacco products. In addition, this study specifically examines risk factors for cigarette or e-cigarette initiation. Future studies should investigate factors associated with longer term and heavier use patterns as this data is made available. Moreover, future analyses could additionally examine bidirectional associations of the risk factors of this study with tobacco product use. The analyses adjust for many important factors, but additional risk factors for initiation, such as risk-taking and mental health, were not available. Overall, the variance accounted for by variables included in each model was relatively low; thus, other unmeasured variables may account for a greater proportion of cigarette or e-cigarette initiation. SEM is a useful tool for modeling multiple important risk factors in a single model, and our approach is amenable to inclusion of a wider range of established risk factors to gain a broader insight into how all potential risks influence cigarette and e-cigarette initiation. Finally, the current analyses did not explicitly assess whether young adults were using e-cigarettes to quit smoking cigarettes.

Conclusion

The analytical approach using SEM successfully identified independent effects of tobacco use, product-specific susceptibility, marketing exposure, and the social environment on initiation of cigarettes and e-cigarettes. Results support the hypothesis that e-cigarette use is

associated with subsequent cigarette initiation in the presence of other strong risk factors for initiation, but provide little evidence of an association of cigarette use at baseline with initiation of e-cigarette use. Research to identify underlying mechanisms of these associations are warranted.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Dr. Barrington-Trimis designed the study, collected data, and contributed to formulating the research question and interpretation of the results, provided oversight and mentorship to the first-author regarding the scope and design of the manuscript, critically reviewed the manuscript, and approved the manuscript as submitted.

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HIGHLIGHTS

- In SEM models, multiple independent risk factors – including e-cigarettes – were associated with cigarette initiation.
- Multiple risk factors were also associated with e-cigarette initiation.
- Notably, cigarette use was not associated with e-cigarette initiation in fully-adjusted SEM models.

Figure 1. Conceptual Model of Cigarette (or E-Cigarette) Initiation at follow-up in association with three product specific latent factors at baseline, baseline tobacco product use, and sociodemographic variables

Conceptual model of cigarette (or e-cigarette) susceptibility, cigarette (or e-cigarette) marketing, and cigarette (or e-cigarette) social environment latent factors, e-cigarette (or cigarette), hookah, and cigar use, and demographic variables at baseline on cigarette (or e-cigarette) initiation at follow-up. Squares represent observed variables, circles represent

latent variables. Covariance estimates for all factors and covariates were included but not all were shown in the model for graphic simplicity.

Table 1.

Descriptive frequencies for e-cigarette and cigarette initiation at baseline

Characteristic		E-Cigarette Initiation (N=1197)			Cigarette Initiation (N=1293)		
		No (n= 837)	Yes (n= 327)	Odds Ratios	No (n= 1058)	Yes (n= 208)	Odds Ratios
		N(%)	N(%)	(95% CI)	N(%)	N(%)	(95% CI)
Cigarette use (baseline)							
	No	809 (73.5)	292 (26.5)	Ref	1058 (83.6)	208 (16.4)	--
	Yes	28 (44.4)	35 (55.6)	3.46 (2.07, 5.79)	--	--	
E-cigarette use (baseline)							
	No	837 (71.9)	327 (28.1)	--	965 (87.3)	141 (12.8)	Ref
	Yes	--	--		92 (58.2)	66 (41.8)	4.91 (3.42, 7.05)
Hookah use (baseline)							
	No	783 (77.07)	233 (22.93)	Ref	923 (87.7)	130 (12.4)	Ref
	Yes	54 (36.49)	94 (63.51)	5.85 (4.06, 8.43)	135 (63.4)	78 (36.6)	4.10 (2.94, 5.73)
Cigar use (baseline)							
	No	823 (73.0)	304 (27.0)	Ref	1029 (85.0)	181 (15.0)	Ref
	Yes	14 (38.9)	22 (61.1)	4.25 (2.15, 8.42)	29 (51.8)	27 (48.2)	5.29 (3.06, 9.15)
Gender							
	Female	461 (73.1)	170 (26.9)	Ref	576 (86.9)	87 (13.1)	Ref
	Male	376 (70.5)	157 (29.5)	1.13 (0.88, 1.46)	482 (79.9)	121 (20.1)	1.66 (1.23, 2.25)
Ethnicity							
	Non-Hispanic white	308 (70.32)	130 (29.68)	Ref	399 (81.43)	91 (18.57)	Ref
	Hispanic white	398 (70.82)	164 (29.18)	0.98 (0.74, 1.28)	507 (84.08)	96 (15.92)	0.83 (0.61, 1.14)
	Other	131 (79.88)	33 (20.12)	0.60 (0.39, 0.92)	152 (87.86)	21 (12.14)	0.61 (0.36, 1.01)
Parental Education							
	High School or less	201 (71.0)	82 (29.0)	0.99 (0.70, 1.41)	256 (84.5)	47 (15.5)	0.86 (0.57, 1.29)
	Some college	241 (70.9)	99 (29.1)	Ref	308 (82.4)	66 (17.6)	Ref
	College or above	310 (72.9)	115 (27.1)	0.90 (0.66, 1.24)	389 (83.3)	78 (16.7)	0.94 (0.65, 1.34)
	Missing	85 (73.3)	31 (26.7)	0.89 (0.55, 1.42)	105 (86.1)	17 (13.9)	0.76 (0.42, 1.35)

Table 2.

Relationship between baseline susceptibility, marketing and social environment with subsequent cigarette Initiation at follow-up

	Minimally Adjusted ^{ac}	Maximally Adjusted ^{bc}
Ever Use of E-Cigarettes at baseline	0.236 (P<0.001)	0.141 (P<0.001)
F1 (Susceptibility to cigarettes)	0.137 (P=0.045)	0.139 (P=0.049)
F2 (Marketing [cigarettes])	0.131 (P=0.004)	0.129 (P=0.004)
F3 (Social Environment [cigarettes])	0.213 (P=0.02)	0.199 (P=0.04)
Ever Use of Hookah at baseline		0.163 (P<0.001)
Ever Use of Cigars at baseline		0.060 (P=0.11)
Parent Education		
High School or less		−0.015 (P=0.80)
Some College		Ref
College or more		0.005 (P=0.93)
Missing		−0.042 (P=0.38)
Ethnicity		
Non-Hispanic White		Ref
Hispanic White		−0.049 (P=0.36)
Other		−0.063 (P=0.21)
Male		0.102 (P=0.01)

^a: Effects of three latent factors and e-cigarette use at baseline on cigarette initiation at follow-up

^b: Effects of three latent factors, e-cigarette, cigar, and hookah use, and demographic variables at baseline on cigarette initiation at follow-up

^c: Parameter coefficients in probit link are standardized using MPlus STDY estimation method

Table 3.

Relationship between baseline susceptibility, marketing and social environment with subsequent e-cigarette Initiation at follow-up

	Minimally Adjusted ^{ac}	Maximally Adjusted ^{bc}
Ever Use of Cigarettes at baseline	0.127 (P=0.001)	0.056 (P=0.16)
F1 (Susceptibility to e-cigarettes)	0.160 (P=0.008)	0.137 (P=0.022)
F2 (Marketing [e-cigarettes])	0.136 (P=0.003)	0.121 (P=0.007)
F3 (Social Environment [e-cigarettes])	0.236 (P=0.003)	0.246 (P=0.002)
Ever Use of Hookah at baseline		0.288 (P<0.001)
Ever Use of Cigars at baseline		0.020 (P=0.64)
Parent Education		
High School or less		0.012 (P=0.80)
Some College		Ref
College or more		0.025 (P=0.59)
Missing		-0.009 (P=0.83)
Ethnicity		
Non-Hispanic White		Ref
Hispanic White		0.015 (P=0.75)
Other		-0.071 (P=0.09)
Male		0.005 (P=0.89)

^a: Effects of three latent factors and cigarette use at baseline on e-cigarette initiation at follow-up

^b: Effects of three latent factors, cigarette, cigar, and hookah use, and demographic variables at baseline on e-cigarette initiation at follow-up

^c: Parameter coefficients in probit link are standardized using MPlus STDY estimation method