Published in final edited form as:

Psychol Addict Behav. 2019 May ; 33(3): 318–330. doi:10.1037/adb0000450.

Cigarette and E-Cigarette Use and Social Perceptions over the Transition to College: The Role of ADHD Symptoms

Melissa R. Dvorsky¹ and Joshua M. Langberg¹

¹Department of Psychology, Virginia Commonwealth University,

Abstract

Cigarette and electronic cigarette (e-cigarette) use prevalence increases during adolescence and peaks in young adulthood, with substantial increases during the transition from high school to college especially more recently for e-cigarette use. It is important to identify the underlying factors that serve as risk factors for tobacco use and social perceptions about cigarette and e-cigarette use. It is unknown whether Attention-Deficit/Hyperactivity Disorder (ADHD) symptoms are associated with social perceptions about tobacco or increased tobacco use during the high school to college transition. This three timepoint prospective longitudinal study evaluates the reciprocal relationship between ADHD symptoms and social perceptions about tobacco as well as the frequency of cigarette and e-cigarette use in a sample of 150 high school seniors ($M_{age} = 18.25$, 66.0% female, 65.3% White) across the transition to college. ADHD symptoms in high school predicted increases in e-cigarette use during the first semester of college and this association maintained through the end of the first year. ADHD symptoms predicted changes in social perceptions about cigarette and e-cigarette use after the transition to college. ADHD symptoms were predicted by social perceptions about e-cigarettes at the beginning of college. Understanding the psychosocial mechanisms underlying the pathways from ADHD symptoms to e-cigarette use may advance tobacco use etiology and prevention efforts, which is important considering the rapid growth in e-cigarette use among emerging adults.

Keywords

Attention-Deficit/Hyperactivity Disorder; e-cigarettes; tobacco use; adolescents; emerging adults

In 2017, 20% of high school students reported current use of tobacco products (CDC, 2018). In college, over 60% of students have tried at least one tobacco product, with about one-third having used in the past 30 days (Rigotti et al., 2000). While the prevalence of traditional cigarette smoking among U.S. adolescents has declined in recent years, the use of alternative forms of tobacco (e.g., e-cigarettes, smokeless tobacco) is rapidly growing in popularity among adolescents and young adults (CDC, 2018). Among U.S. high school students, the prevalence of past 30-day use of e-cigarettes increased 10-fold from 1.5% in 2011 to 16.0% in 2015, and this exceeded the prevalence of traditional cigarette smoking (9.3%; Singh et

¹ Correspondence concerning this article should be addressed to Melissa R. Dvorsky, University of California, San Francisco, Department of Psychiatry, 401 Parnassus Avenue, Box 0984, San Francisco, CA 94313-0984. Melissa.Dvorsky@ucsf.edu.

No findings from this dataset have been previously published or are in other submitted articles to date. We are not simultaneously submitting this manuscript elsewhere and no significant portions have been published previously.

al., 2016). Epidemiologic studies demonstrate that the prevalence of tobacco use increases with age and peaks during emerging adulthood (ages 17 to 25; Palmer et al., 2009), and particularly during the transition to college (Johnston et al., 2015). About half of all college students have tried alternative tobacco products, such as e-cigarettes, cigars, or hookah, with about 20% using in the past 30 days (Eissenberg et al., 2008).

Although young people who use e-cigarettes often believe they are less harmful than traditional cigarettes (Amrock et al., 2016), use of e-cigarettes has been shown to increase risk for subsequent cigarette smoking initiation, escalation, and nicotine dependence among adolescents and young adults (Soneji et al., 2017). This is of grave concern given that tobacco use is associated with a host of negative health outcomes, such as cancer and other substance use (USDHHS, 2016). The U.S. Surgeon General recently classified the increase in e-cigarette use among adolescents and young adults as a major public health concern (Murthy et al., 2017).

The transition from high school to college is associated with rapid developmental changes as well as heightened risk for escalating tobacco use (Cooke et al., 2016; Spindle et al., 2017). This developmental period is characterized by changes in social contexts that involve increased freedom and decreased support from parents, teachers, and other adults (Arnett, 2016). These changes can lead to increased mental health symptoms, risk behavior, and substance abuse, including tobacco use, particularly in the college context (Arnett, 2005). Indeed, several studies have demonstrated that substance use escalates the most substantially during the first year of college (Berg et al., 2018) and these increases begin to slow or become more stable starting in year two (Arria et al., 2016; Caldeira et al., 2012; Spindle et al., 2017). Further, the mental health, risk behaviors, and substance use habits established early in college predict lasting adult behaviors (Gotham et al., 1997; Jackson et al., 2005). Indeed, the majority of adult smokers begin using tobacco during adolescence or young adulthood, making these developmental periods important for understanding the factors that influence tobacco use long-term. The developmental context of the end of high school and beginning of college also co-occurs with the age (18 years) when purchasing tobacco products becomes legal. Taken together, the onset of these changes and new experiences makes studying tobacco risk across this transitional period an important area of research.

Research focused on tobacco use (the vast majority of which has focused on cigarette smoking, not e-cigarettes) in high school and college has identified a number of important risk factors including: knowledge and expectancies (Morrell et al., 2016), mental health symptoms including ADHD (Rodriguez et al., 2008), and social contextual factors (Noland et al., 2016). Tobacco and substance use primarily occur in social contexts (Stockdale et al., 2005), and social influences (e.g., perceived norms, social desirability) are one of the most robust predictors of cigarette and e-cigarette use in adolescence (Liu et al., 2017).

Social Perceptions about Tobacco Use

Social perceptions about tobacco use are strongly associated with adolescents' and emerging adults' own use as well as unhealthy smoking outcome expectancies (Morrell et al., 2016). Social perceptions about tobacco use, broadly defined, includes perceived harm of smoking;

perceived prevalence of use; perceived social desirability and/or acceptability of use; attitudes toward peers or family members smoking; exposure to tobacco in media; and exposure to friends, peer groups, or family members who smoke (Agarwal et al., 2018; Gibson et al., 2018; Noland et al., 2016; Stockdale et al., 2005). The term “maladaptive social perceptions” is used in the present study to characterize unhealthy or risky perceptions about tobacco use (e.g., that peers are tolerant, that tobacco use is socially desirable) which are strongly associated with use among adolescents and young adults (e.g., Noland et al., 2016). Much less is known about the effects of maladaptive social perceptions on e-cigarette use (see Gibson et al., 2018 for a review); however, college students report higher acceptance of using e-cigarette in public spaces relative to traditional cigarettes (Lee et al., 2017).

To date, much of the research examining social influences and the role of maladaptive social perceptions on tobacco use is based on developmental socialization theories including the social development model (SDM; Catalano et al., 1996). SDM is an integration of several theories including social learning theory (Bandura, 1977), social-cognitive theory (Bandura, 1986), and social control theory (Hirschi, 1969), which emphasize that social cues for various risk behaviors are associated with increased adoption of those behaviors, with numerous studies demonstrating this with traditional cigarettes (see Liu et al., 2017 for a review), and recent studies supporting this with e-cigarettes (Agarwal et al., 2018; King et al., 2015). Specifically, the perception tobacco use is socially normative, that peers are tolerant of tobacco and/or that tobacco use is socially desirable significantly heightens the risk for individuals’ own disinhibition and initiation of tobacco use (Agarwal et al., 2018; Noland et al., 2016). An important commonality of these theoretical perspectives is the emphasis on bidirectional associations between social perceptions and risk behavior (e.g., Dishion & Owen, 2002; Mercken et al., 2010), such that social perceptions can influence risk behavior and conversely, that risk behavior impacts social perceptions and the selection of friends. Unfortunately, we know little about what factors drive maladaptive social perceptions for cigarettes and e-cigarettes, including whether certain individuals, such as those with elevated inattention, impulsivity, and hyperactivity are at greater risk for maladaptive perceptions. Such information is likely to have valuable implications for identifying which adolescents and young adults are most at risk to start smoking and what interventions may best target these maladaptive social perceptions.

ADHD as a Risk for Tobacco Use and Maladaptive Social Perceptions of Use

The association between ADHD symptoms and cigarette smoking in adult populations has been well documented (Gudjonsson et al., 2012; Lee et al., 2011; Mitchell et al., 2018). National estimates suggest that low levels of ADHD symptoms are present in nearly 40% of adolescents and emerging adults (DuPaul et al., 2012; Hartung et al., 2016; Kollins et al., 2005). That is, ADHD symptoms are distributed on a continuum throughout the population (Haslam et al., 2006), and subclinical levels of ADHD symptoms impact smoking behaviors among high school and college students who do not meet diagnostic criteria for ADHD (Goldenson et al., 2018; VanEck et al., 2014). For example, ADHD symptoms measured

continuously are associated with increased tobacco use onset and escalation of use in both cross-sectional and prospective longitudinal studies (Fuemmeler et al., 2007; Rodriguez et al., 2008). Indeed, there is some evidence that tobacco use risk increases as a function of the severity of ADHD symptoms (e.g., Gudjonsson et al., 2012). In a recent study from the National Epidemiologic Survey on Alcohol and Related Conditions, each additional ADHD symptom before age 18 was associated with a greater lifetime chance of developing nicotine dependence (Ameringer & Leventhal, 2013). Using data from the National Longitudinal Study of Adolescent Health ($N = 15,197$) following adolescents into adulthood, Kollins et al. (2005) found ADHD symptoms predicted increased risk of lifetime regular smoking and younger onset of smoking, after controlling for other externalizing behaviors such as conduct problems.

It is also clear that social influences play an important role in the development of smoking for adolescents and young adults with ADHD symptoms (Tercyak et al., 2002; Wilens et al., 2008). Further, although the research is limited for adolescents and emerging adults (Glass & Flory, 2010), ADHD symptoms may influence certain social perceptions of tobacco. According to problem behavior theory, given that individuals with ADHD symptoms tend to affiliate with nonconventional peers (Bagwell et al., 2001), they may perceive greater degrees of peer use, peer tolerance and social desirability of tobacco use, increasing their risk for reduced inhibition behaviors and tobacco use (Molina & Pelham, 2014). Indeed, some studies have shown that ADHD symptoms predict adolescents' perceived peer tolerance, acceptability, and use (e.g., Marshal & Molina, 2006), suggesting that ADHD increases susceptibility to peer influence and maladaptive social perceptions about tobacco use, which also increases tobacco use. Indeed, potentially risky peer environments such as those that model disinhibition behaviors may further exacerbate ADHD related problems (Marshal et al., 2003) by reinforcing individuals own disinhibition behavior and deeming this behavior as acceptable. In other words, ADHD symptoms may become less managed in social environments where peers are smoking and/or exhibiting acceptability of smoking. However, research to date has not evaluated bidirectional influences and the potential complexity of associations between ADHD symptoms and social perceptions of cigarette and e-cigarette use is unclear. It is important to understand whether individuals with ADHD symptoms develop maladaptive social perceptions, whether their social perceptions influence their severity of symptoms, or both.

Overall, reasons for the association between ADHD symptoms and tobacco risk in adolescents and young adults remain poorly understood. Theoretically, the association could be due to several mechanisms (Glass & Flory, 2010 for a review). First, there could be a causal influence of ADHD symptoms on tobacco use. Specifically, difficulties with attention, impulsivity, and poor decision-making skills might, via mediating psychological, cognitive, and social factors, causally lead to increased tobacco use and maladaptive social perceptions about tobacco use. Alternatively, the causal relationship could run in the opposite direction, such that tobacco use and maladaptive social perceptions influence ADHD symptoms. For instance, the "self-medication hypothesis" posits that due to the stimulating effect of nicotine on the central nervous system, and potential improvements in attention and cognitive processes, individuals may use tobacco in order to alleviate their symptoms of ADHD. However, this theory has not been adequately tested among

adolescents or young adults (Glass & Flory, 2010). Another explanation for the association between ADHD symptoms and maladaptive social perceptions may be the dual process theory (Hagger et al., 2013), which identifies two cognitive systems: (a) reflective or deliberative processes, and (b) automatic implicit processes, that are responsible for bidirectional influences between social perceptions and problem behavior. In line with dual process theory, several studies have demonstrated that social environments which encourage smoking (e.g., observing others smoking, being offered a cigarette) may actually deplete self-control resources including attention, executive function, and motivation (Hagger et al., 2013; Heckman et al., 2017; Nordgren & Chou, 2011), cognitive functions that represent the underpinnings of ADHD. Indeed, there is a strong body of literature supporting the reciprocal influence of social context of smoking on executive-control behaviors, whereby social cognitions and executive-control mutually reinforce each other (Heckman et al., 2017; Nordgren & Chou, 2011). Similarly, it is also possible that the causal relationship between ADHD and tobacco use could be reciprocal, whereby ADHD symptoms and tobacco use behaviors would mutually influence each other over time and lead to a self-reinforcing process. Finally, the association could be non-causal, and merely reflect confounding factors influencing both ADHD symptoms and substance use outcomes. For example, family and peer factors may be related to both ADHD symptoms and tobacco use and could create a spurious association between the two.

Several longitudinal studies have demonstrated that ADHD symptoms are associated with traditional cigarette use (e.g., Gudjonsson et al., 2012; Kollins et al., 2005; Rodriguez et al., 2008). However, only one study known to date has examined the association with e-cigarette use. Goldenson and colleagues (2018) found that among ninth grade students, ADHD symptoms were cross-sectionally associated with e-cigarette risk but not traditional cigarettes, postulating that adolescents with elevated ADHD may be at greater risk to use e-cigarettes relative to cigarettes, since e-cigarettes violate less societal norms and many youth view them as safer and less addictive (Amrock et al., 2016). It is hypothesized that symptoms of ADHD may exacerbate the risk for e-cigarette use in a reciprocal manner over time, supporting the dual process and problem behavior theories, although to date this has only been examined cross-sectionally.

Further, no studies have directly examined the effect of tobacco use on symptoms of ADHD, with only indirect evidence supporting the self-medication hypothesis in adults (e.g., Wilens et al., 2007). Rather than studies that simply test the association in one direction, longitudinal analyses are needed to test predictive associations simultaneously in both directions while adjusting for the developmental stability of ADHD symptoms and tobacco use. Autoregressive cross-lagged path analyses of longitudinal data allow for such examinations by modeling stability paths and cross-variable associations simultaneously, but such analyses are rare in the substance use literature as studies rarely have more than two time points (Soneji et al., 2017). Clearly, more longitudinal analyses spanning multiple assessments during adolescence and emerging adulthood are needed to capture the developmental interconnections between ADHD and tobacco use and maladaptive social perceptions as well as to test the hypotheses for directionality of these associations over time. To date, no study has examined the role of ADHD symptoms as a risk for cigarette or e-cigarette use across the transition to college. In addition, examining both cigarette and e-

cigarette use in the same sample would be informative as ADHD symptoms could be differentially related to the use of these two forms of tobacco use, as well as the maladaptive social perceptions for both cigarettes and e-cigarettes.

Cigarette and E-Cigarette Use in College

To date, research on tobacco use in adolescence, young adulthood, and college settings is limited by the fact that most data are cross-sectional (Stone et al., 2012). In particular, little is known about the trajectory and patterns of cigarette and e-cigarette use and associated risks across the transition from high school to college. This is because most existing studies have followed students after they start college, often using the middle of the fall semester as a baseline. These studies fail to capture changes in tobacco use from high school to college and cannot evaluate whether pre-existing factors, present during high school, predict use in the first year of college. Notably, the few studies that have started in twelfth grade found that cigarette and e-cigarette use in high school was the strongest predictor of subsequent use one year later (e.g., Wills et al., 2016). Of note, aiding students in forming adaptive social perceptions is a common target of many college substance use prevention programs (e.g., Su et al., 2018). However, these programs have demonstrated mixed results, with some reducing students' use (Perkins et al., 2005), while others fail to demonstrate any changes in use (Wechsler et al., 2003). As such, it is important to better understand behaviors associated with maladaptive social perceptions of tobacco use.

Currently, it is unclear how risk mechanisms such as ADHD symptoms longitudinally influence young people's cigarette and e-cigarette use as well as their social perceptions about these products during the transition from high school to college. Although it is well-established that ADHD symptoms are an important risk mechanism for cigarette smoking, there is little extant research on the association between ADHD symptoms and e-cigarettes use. It remains unclear whether ADHD differentially confers risk to e-cigarette use relative to traditional cigarette use. Longitudinal research, especially starting before students arrive on campus, is needed to identify the patterns of risk associated with tobacco use.

Current Study

This study will address several gaps in the extant literature by considering the influence of ADHD symptoms on multiple tobacco use outcomes (cigarette use, e-cigarette use, maladaptive social perceptions of cigarette and e-cigarette use). The current study uses cross-lagged path analyses on three waves of data from high school to the end of the first year of college. Our aim was to investigate the directionality and magnitude of the associations between ADHD symptoms and tobacco use as well as maladaptive social perceptions about tobacco use across this developmental transition. Specifically, we examined the developmental course across the transition from high school (T1 = spring semester high school) to college (T2 = fall semester college; T3 = spring semester college) and pathways from ADHD symptoms to tobacco use and maladaptive social perceptions of tobacco use. Further, to assess the self-medication hypothesis and dual process theories, we examine the potential influence of tobacco use and maladaptive social perceptions on subsequent ADHD symptoms. More broadly, we were also interested in examining the

stability of cigarette use, e-cigarette use, tobacco social perceptions, and symptoms of ADHD changed over the transition to college. In order to remove potential confounding factors, analyses adjusted for key covariates (i.e., gender, college type, living situation, family history of smoking, and peer smoking behavior). A strength of the cross-lagged modeling approach used in the present study is that it allows for simultaneously testing each of the theoretical explanations about direction of associations between ADHD and tobacco use and maladaptive social perceptions including potential bidirectional and reciprocal pathways. In light of the well-established link between ADHD symptoms and traditional cigarette smoking, we hypothesized that ADHD symptoms would be a significant risk for both cigarettes and e-cigarettes during the transition to college. Given mixed evidence to date supporting the self-medication hypothesis in samples of adults with ADHD, we did not have a hypothesis on whether cigarette and e-cigarette use would predict subsequent ADHD symptoms. Finally, in line with social developmental, dual process, and problem behavior theories, we hypothesized a reciprocal process between ADHD symptoms and maladaptive social perceptions, such that ADHD symptoms would exacerbate the risk for maladaptive social perceptions in high school and early college, which subsequently encourages individuals to seek out social environments that models reduced inhibition and deems this behavior as acceptance, and in turn reinforces an individuals' own disinhibition and increased ADHD symptoms.

Method

Participants

Participants were 150 adolescents in twelfth grade (ages 17–19 years; *Mage* = 18.25, *SD* = .33) who reported plans to continue to college the following fall. Participants were two-thirds female (*N* = 99) and most participants self-identified as White (65.3%), with the remaining participants Black (17.3%), Asian (6.7%), American Indian/Alaska Native (1.3%), or Multiracial (5.3%); 4.0% of participants identified as Hispanic/Latino. Once started college, twenty-six participants (17.3%) attended a community college or 2-year associate program and the remaining majority attended a 4-year university (82.7%). Most participants attended an in-state college or university (76.0%) and most lived on campus (78.7%) while a few (21.3%) lived at home with their parents. 53.3% of participants' parents had a college degree. Consistent with ADHD prevalence estimates ranging from 9 to 13% among high school students (Visser et al., 2014) and 6 to 8% among college students (Eagan et al., 2014), 10.0% to 10.7% of participants in this study self-reported currently taking medication for ADHD across time points. Further, mean total scores of ADHD symptom severity ranged from 11.26 to 11.57 across waves (see Table 1), which is also consistent with existing normative data on ADHD symptomatology among college students (DuPaul et al., 2001; Garnier-Dykstra et al., 2010; Heiligenstein et al., 1999; McKee et al., 2008). As expected, across waves students who reported taking medication for ADHD reported significantly higher levels of ADHD symptomatology (*M*s from 18.38 to 23.13) compared to those who were not taking ADHD medication (*M*s from 10.14 to 10.44). Given that ADHD symptom levels and medication rates are consistent with past research in college populations (e.g., DuPaul et al., 2001; Garnier-Dykstra et al., 2010) all participants are included in the current analyses to increase generalizability to college populations broadly.

Procedure

All procedures were approved by the Institutional Review Board. Surveys assessing mental health and substance use were administered once every 6 months beginning at the end of 12th grade (spring 2016) and continued through the end of the first year of college (spring 2017). Participants were recruited during the spring semester of their twelfth-grade year from four local high schools in the mid-Atlantic area the United States. At four high schools, school personnel distributed study flyers to all families of students in twelfth grade students with plans to continue to college or university in the following fall. Schools also included recruitment information in their regular contacts (e.g., newsletters) with parents. Flyers stated that the study is seeking to examine “how students transition from high school to college”. This ensured that all twelfth-grade students continuing to college had the opportunity to participate. Recruitment flyers were directed towards parents and adolescents since some adolescents in the study were not yet 18 years old at recruitment. Students and parents who were interested in the study were directed to the study website. The study website provided an overview of the study, contact information for study investigator, IRB, and downloadable copies of the informed consent. Prior to completing the survey, participants were provided with an explanation of the study, student participants provided informed consent/assent online (depending on age), and their parents/guardians provided electronic consent. After providing consent/assent, participants were directed to the online survey in REDCap (Research Electronic Data Capture). A multi-component assessment of substance use and related behaviors and risk mechanisms occurred at three time points spanning one year, from the spring of their senior year of high school to the spring of their first year of college. Participants were compensated in gift cards for their time and effort in completing the survey: \$50 at T1, \$60 at T2 and \$70 for completing the final measures at T3.

Measures

Tobacco use.—At each wave, items based on the Monitoring the Future (MTF; Johnston et al., 2015) survey assessed current frequency of use for both cigarettes and e-cigarettes by asking how many days they used in the past 30-days (“I did not use,” “Once or twice,” “A few days,” “A couple days a week,” “Three times a week,” and “Daily or almost daily”).

Maladaptive social perceptions about tobacco use.—Using items from recent studies measuring adolescents’ perceptions of the social acceptability, tolerance, and desirability of cigarette and e-cigarette use (e.g., Gibson et al., 2018), participants answered five questions about their social perceptions of cigarettes and the same five questions but specific to e-cigarettes (10 total items). Example items include “Do you think young people who smoking cigarettes have more friends?” and “Do you think young people smoking e-cigarettes having more friends?” Items were rated on a four-point Likert scale ranging from 0 (Definitely not) to 3 (Definitely yes). The total sum score of these items was used as rating of the perceived social desirability of (a) smoking cigarettes (range 0–15) and (b) using e-cigarettes (range 0–15) in the present study ($\alpha = .83-.95$).

ADHD symptoms.—ADHD symptoms were assessed using the self-report of current symptoms version of the *Barkley Adult ADHD Rating Scale-IV* (BAARS-IV; Barkley,

2011). The BAARS-IV includes the 18 *DSM* symptoms of ADHD. Each item was rated using a four-point scale (0 = *never or rarely*, 3 = *very often*). The total sum score (range 0–54) was used for the present study ($\alpha=.90$).

Covariates.—Factors that have previously been shown to be associated with ADHD symptoms and tobacco use were included as a priori covariates to prevent confounding of key associations (e.g., Berg et al., 2018; Stone et al., 2012). Specifically, participants' gender, living arrangements (i.e., living at home vs. on campus dorm), university type (i.e., 2-year vs. 4-year college), family history of smoking (i.e., “Does anyone in your immediate family have a history of smoking cigarettes?” [yes/no]), and peer smoking behavior (“In the last 30 days, how many of your five closest friends have smoked cigarettes?” [no friends vs. one or more friends]) were examined as potential predictors of tobacco outcomes in each of the models.

Analytic Plan

Four bivariate autoregressive cross-lagged (ARCL) models were fitted separately for (a) cigarette use, (b) e-cigarette use, (c) social perceptions about cigarette use, and (d) social perceptions about e-cigarette use with ADHD symptoms across the three study waves, adjusting for covariates. These models were tested within a structural equation model framework to investigate the directional influence of ADHD symptoms with later smoking behavior and perceptions, controlling for prior tobacco use or perceptions, or vice versa during the transition to college. Residual correlations at each wave were also specified to examine the concurrent correlations between ADHD symptoms and smoking behavior or perceptions, unexplained by the cross-lagged associations.

All analyses were run in *MPlus 8* (Muthén & Muthén, 2017) and used the maximum likelihood estimation with robust standard errors (MLR) which computes mean-adjusted maximum likelihood estimates for non-normally distributed data and is recommended for small and medium sample sizes (Muthén & Muthén, 2017). In order to evaluate the goodness-of-fit, χ^2 goodness-of-fit indices were considered. Incremental fit indices including the Comparative Fit Index (CFI; values >0.90), and Root Mean Square Error of Approximation (RMSEA; values >0.08) were also examined for adequate model fit (Hu & Bentler, 1999; Wang & Wang, 2012).

All longitudinal autoregressive cross-lagged models were tested with equality constraints to determine the extent to which within-construct and cross-construct effects were significantly different across time. A series of hierarchally nested models were examined to determine which path coefficients can or cannot be constrained. Equality constraints were placed on each set of parameters (i.e., first autoregressive paths, then cross-lagged paths) and the more restrictive model was compared to the previous model using the Satorra-Bentler Chi-Square difference test (S-B χ^2) and comparison of model fit indices to evaluate whether path constraints result in decremented fit in order to test for stability across time (Wang & Wang, 2012).

Missing data.—Extensive efforts were made to minimize attrition and missing data, and 85% of the initial sample provided data at all three assessments used in the present analyses.

There were no missing data at T1. Approximately 11% ($n = 16$) participants were missing data at T2 and approximately 13% ($n = 20$) were missing data at T3, with 10% ($n = 15$) missing data at both T2 and T3. Of those missing data at T2, 10% ($n = 2$) were missing data because they dropped out of college and therefore did not complete the survey; and of those missing at T3 ($n = 15$), 20% ($n = 3$) were missing data because they dropped out of college and were no longer attending a university. An additional 4 students left their original college program to attend another university, however these students were retained in the analyses. Students who missed *any* of the two follow-up waves ($n = 21$) did not differ from those with complete data at *both* follow-up waves ($n = 129$) on total ADHD symptoms, tobacco use, or social perceptions of tobacco use at any wave, as well as the baseline demographic variables ($ps > .10$). In model estimation, missing data were handled with maximum likelihood estimates using MLR, which accommodate missing data allowing the analysis to make use of all available data so that any participant with at least one time point can be included in the analysis (Wang & Wang, 2012).

Results

Frequency of Use

In the spring of twelfth grade (T1), 4.0% of students had smoked a cigarette at least once in the past 30 days and 13.3% had used e-cigarettes at least once in the past 30 days. By the fall of their first year of college (T2) this increased to 8.2% of students who had reported smoking cigarettes at least once and 20.9% that had used e-cigarettes at least once in the last 30 days. By the following spring (T3), 10.8% reported using cigarettes and 22.3% were using e-cigarettes at least once in the last 30 days. Depending upon the timepoint of interest, between 18.2–26.5% of participants reported using both e-cigarettes and cigarettes at least once in the past 30 days.

Correlations between ADHD Symptoms and Tobacco Use and Perceptions Variables

Descriptive statistics and bivariate correlations among all of the tobacco use behaviors, social perceptions of use, and ADHD symptoms across all three time points are presented in Table 1. ADHD symptoms were associated with traditional cigarette use (r s from .16-.23, within time; r s from .13-.20, across time), although this was slightly higher for e-cigarette use (r s from .20-.25, within time; r s from .17-.24, across time). ADHD symptoms were positively associated with maladaptive social perceptions about both cigarettes (r s from .12-.23, within time; r s from .11-.31, across time) and e-cigarettes (r s from .19-.23, within time; r s from .13-.37, across time).

Cross-Lagged Models of ADHD Symptoms and Cigarette and E-Cigarette Use

In the model examining the longitudinal association and reciprocal effects of cigarette smoking and ADHD symptoms across the transition to college, when homogeneity constraints were added to the stability and autoregressive paths, this did not result in significant detriment to model fit (Table 2). The final model (see Figure 1) included all equality constraints for predicting cigarette use, $\chi^2(23)=39.612$, $p=.004$, CFI=.937, RMSEA=.100. Significant stability of ADHD symptoms and cigarette use was observed

across timepoints. Family history of smoking was the only covariate significantly associated with cigarette use, only at T1 ($\beta=.217$, $p=.020$).

The best fitting model for e-cigarette use and ADHD symptoms (see Figure 2) was with equality constraints retained to the autoregressive paths for ADHD symptoms and the cross-lagged paths from e-cigarettes to ADHD symptoms, $\chi^2(21)=34.563$, $p=.026$, CFI=.963, RMSEA=.082. Simply, the impact of time from T1 to T2 did not equate to that of T2 on T3. ADHD symptoms at T1 predicted e-cigarette smoking at T2 ($\beta=.206$, $p<.001$) and this effect was even stronger from T2 to T3 ($\beta=.350$, $p<.001$). The only significant covariate was attending a 2-year college was associated with increased e-cigarette use at T1 ($\beta=.262$, $p=.013$).

Cross-Lagged Models for Social Perceptions of Cigarette and E-Cigarette Use

For the model examining social perceptions of cigarette use, the model with equality constraints to only the stability paths for ADHD led to the best fit to the data for predicting social perceptions of cigarette use ($\chi^2(20)=32.369$, $p=.009$, CFI=.935, RMSEA=.097 (see Figure 3). Social perceptions at T1 predicted ADHD symptoms at T2 ($\beta=.146$, $p=.014$) and this association was even stronger between T2 to T3 ($\beta=.222$, $p=.007$). Living at home with parents was the only covariate associated with maladaptive social perceptions about cigarette use at T2 and T3 ($\beta=.146-.226$, $p<.05$).

The best fitting model for social perceptions of e-cigarette use was with only stability paths for ADHD: $\chi^2(20)=30.060$, $p=.036$, CFI=.950, RMSEA=.078 (see Figure 4). Simply, ADHD symptoms were significantly stable and predictive over time; however, social perceptions of e-cigarette use were not. ADHD symptoms at T1 predicted social perceptions about e-cigarette use at T2 ($\beta=.139$, $p=.023$) and this effect was even stronger from T2 to T3 ($\beta=.347$, $p<.001$). Increased maladaptive social perceptions for e-cigarettes at T2 was also reciprocally predicted subsequent increased ADHD symptom severity at T3 ($\beta=.152$, $p=.008$). Having a close friend who used e-cigarettes was the only covariate associated with increased maladaptive social perceptions about e-cigarettes at T2 and T3 ($\beta=.145-.221$, $p<.05$).

Discussion

There is a wealth of evidence suggesting that adolescents with ADHD symptoms are at increased risk for smoking traditional cigarettes (Mitchell et al., 2018; Wilens et al., 2008), and that smoking not only continues but also often increases for those who enter college (e.g., Gudjonsson et al., 2012). However, most prior research has been limited by cross-sectional data and a focus solely on traditional cigarette use, and little is known about the direction of effects between ADHD symptoms and e-cigarette use behaviors and maladaptive social perceptions across the transition to college. The present study investigated the longitudinal associations of cigarette use and e-cigarette use frequency as well as social perceptions about traditional cigarette use and e-cigarette use with ADHD symptoms from high school to college. There was a substantial increase in the prevalence of e-cigarette use from the end of high school to the first semester of college. Whereas 13.3% of the students reported any past month use during high school, this rose to 20.9% during the

first semester of college. The rate of students' traditional cigarette use also doubled from high school (4.0%) to the first semester of college (8.2%), however the overall prevalence of use was considerably lower relative to e-cigarettes. We also found that ADHD symptoms in high school predicted increased risk for e-cigarette use in college and this effect was even greater after the transition to college.

The autoregressive cross-lagged models revealed a consistent pattern in which ADHD symptoms and e-cigarette use in high school predicted increased frequency of e-cigarette use in college, even when previous ADHD symptoms and e-cigarette use as well as potential confounding psychosocial covariates (i.e., family history of use, friend use, gender, college type, and living situation) known to be associated with tobacco use were controlled. The strength of the effect of ADHD symptoms in predicting increased e-cigarette use frequency was even greater across the fall to spring of the first year of college. Put another way, the residual change in ADHD symptoms across the transition (i.e., from T1 to T2) was associated with even greater increased risk for greater e-cigarette use by the end of the first year of college (T3). Further, although increased ADHD symptoms predicted subsequent increased e-cigarette use frequency in line with problem behavior theory, e-cigarette use was not associated with subsequent ADHD symptoms. Thus, the self-medication hypothesis was not supported for cigarette nor e-cigarette use in the present sample given that there was no evidence that using either traditional cigarettes or e-cigarettes was associated with subsequent decreases (or alleviation) of ADHD symptoms in the present sample. Additionally, significant stability was observed for ADHD symptoms and smoking behaviors across waves. This finding is consistent with previous studies noting the consistency and persistence of ADHD symptom severity across adolescents into emerging adulthood (Lee et al., 2008; Norwalk et al., 2009) and it underscores the importance of adjusting for autoregressive (stability) effects when examining the complex associations between ADHD symptoms with tobacco use and social perceptions.

Although ADHD symptoms predicted a higher likelihood of engaging in e-cigarette use, symptom severity did not significantly predict later traditional cigarette use at any time point during the transition to college. This finding is contrary to other studies that have demonstrated a significant relationship between ADHD and cigarette smoking in adolescents and young adults (Flory et al., 2003; Wilens et al., 2008; VanEck et al., 2014). However, this finding has also been supported most recently in the only other study to examine the effect of ADHD symptoms for both e-cigarette and traditional (or combustible) cigarette use (Goldenson et al., 2018). One explanation for the association of ADHD symptoms with e-cigarettes, but not traditional cigarettes in the present study is that perhaps the characteristics associated with ADHD such as impulsivity and poor self-regulation exacerbate the maladaptive perceptions frequently held by adolescents regarding e-cigarettes (e.g., that they safer, less addictive, more socially acceptable), thereby putting individuals with elevated ADHD symptoms at greater risk for e-cigarette use. Further, the lack of association between ADHD symptoms with traditional cigarettes during the transition to college may be that other potentially confounding factors have greater salience for traditional cigarettes (e.g., conduct problems, family use), but not e-cigarettes. Another explanation is the low prevalence of traditional cigarette smoking (4–10% report cigarette use) relative to alternative forms of tobacco use such as e-cigarettes (13–22% report e-cigarette use), which

are known to be on the rise among adolescents and young adults (CDC, 2018). As such, there may be a historical cohort effect that distinguishes the current study from prior work conducted over a decade ago demonstrating a robust association of ADHD with traditional cigarette smoking for adolescents and young adults (Fuemmeler et al., 2007; Kollins et al., 2005). The lower frequencies of cigarette use in the present sample, relative to e-cigarette use frequency, may have reduced power needed to detect associations between ADHD symptoms with use of traditional cigarettes. Of note, the standardized path estimates from ADHD symptoms to cigarettes were much smaller ($\beta < .10$) than the estimates predicting e-cigarettes ($\beta = .21-.35$), suggesting that an increased sample size is unlikely to result in significant effects for cigarette used during this developmental period.

With regard to social perceptions about cigarette and e-cigarette use, ADHD symptoms demonstrated a consistent pattern predicting subsequent increased maladaptive social perceptions about both cigarettes and e-cigarettes, even when previous levels and potential confounding factors were adjusted for in the models. These findings are important given that they may suggest potential constructs or populations to target when attempting to reduce tobacco use in college students. This is consistent with the social development model and problem behavior theory, as well as other studies of college samples (i.e., conducted *after* the transition to college), which have demonstrated a significant association between ADHD and risk for maladaptive social perceptions about substance use (e.g., VanEck et al., 2014) and alcohol use (Pedersen et al., 2013). Extending previous work, this study demonstrates that ADHD symptoms in high school, *before* the transition to college (T1), were directly associated with maladaptive social perceptions *after* the transition (T2) and this effect was even greater across the first year of college (i.e., from T2 to T3). Past work has failed to take into account the direction of influence for maladaptive social perceptions about tobacco (Wilens et al., 2008), and to account for the complexity of social influences on smoking. It is important to understand whether individuals with ADHD symptoms choose to associate with peers who are similar to them and form social perceptions based on this, or whether they are influenced by their peers to use cigarettes/e-cigarettes, or both. The present study is the first to demonstrate that across the transition to college, ADHD symptoms both influence, and are influenced by, maladaptive social perceptions about e-cigarette use. ADHD symptoms during high school (T1) was associated with subsequent increased maladaptive social perceptions about e-cigarettes (T2) which in turn conferred increased risk for subsequent ADHD symptoms at the end of the first year of college (T3). This reciprocal effect between ADHD symptoms and maladaptive social perceptions about e-cigarettes is consistent with research on the dual process theory which supports that individuals in social environments cued for smoking (e.g., being offered a cigarette, observing someone smoking) depletes self-regulation resources including attention, executive functions, and motivation, which are key cognitive underpinnings of ADHD. Overall, the reciprocal effect highlights the importance of targeting both ADHD symptoms and maladaptive social perceptions during the first year of college.

Strengths of this study include the longitudinal design spanning high school and college, statistical adjustment for clinically relevant intrapersonal and environmental covariates, and examination of both traditional tobacco products (cigarettes) and alternative products (e-cigarettes) which have been rapidly growing in popularity among youth. Further, levels of

ADHD symptoms in the present sample were similar to estimates of the distribution of ADHD symptoms in a U.S. normative nationally representative adolescent sample (DuPaul et al., 1998). Despite these strengths, the present study is not without limitations. Assessments occurred in a moderately sized sample of youth who were planning to attend a 2- or 4-year university or community college. Although the current study collected data sampled from multiple high schools and students that attended 51 different universities spanning several regions of the United States, it should be noted that these findings may not generalize to other young adult populations such as non-students. For instance, these findings may not generalize to adolescents who are transitioning to work or other placements following high school. Future research should examine these associations with young adults outside the college context to examine important mechanisms of tobacco use risk for emerging adults who are not necessarily college students. It is also especially important to examine potential differences in how risk for tobacco use and ADHD symptoms manifests in varying cultural contexts within high school and college including racial/ethnic backgrounds, socioeconomic status, immigration, and parent educational backgrounds, as it is possible that these associations do not manifest similarly in all cultures, demographics and settings (Cooke et al., 2016). Unfortunately, the moderate sample size in the present study did not allow for subgroup analyses by ethnicity.

Further, ADHD symptoms were measured continuously rather than using diagnosis. As such, generalizability to high-risk youth including those with ADHD diagnoses that have persisted into late adolescence may be limited. In addition, given the size of our sample, we were unable to test the associations between ADHD symptoms with smoking behavior and ADHD symptoms with smoking perceptions simultaneously in the same model, and were likely underpowered to detect significant paths with smaller effect sizes. With a larger sample size, we may have had the power to detect paths with small-medium effect sizes like these at a statistically significant level. The psychometric properties of the items used to assess maladaptive social perceptions of tobacco use require additional evaluation. This study also used all self-reported measures, which is a frequently used measurement approach in research on ADHD and substance use. Self-report of ADHD symptoms corresponds closely with parent and spousal report for young adults (Barkley et al., 2008). Further, disclosure of problem behaviors is highest when self-report is used and when collected using a confidential online format (Richman et al., 1999), as done in this study.

Future work should examine pathways among smoking behaviors, smoking perceptions and ADHD symptoms concurrently over a greater number of days in a larger sample of youth. We examined a specific transition period that is common for many adolescents. It is possible that other patterns might emerge over other periods of development, a longer study period, or during a time of more stability. Finally, we did not examine other adverse risk mechanisms (e.g., emotion regulation, sensation seeking, executive functions) that might contribute to smoking problems.

Conclusion

Our findings contribute to the literature examining developmental trajectories of smoking behaviors, social normative beliefs and symptoms of ADHD. We highlighted the

longitudinal and reciprocal relationships among these indicators of adjustment over a period of time typically characterized by change and uncertainty for many adolescents. We found differential associations between ADHD symptoms and smoking over time. Specifically, we identified a significant association between ADHD symptoms predicting increases e-cigarette use, but not for traditional cigarette use. Further, we found a relation between ADHD symptoms in predicting cognitive perceptions about smoking cigarettes only after the transition to college. Higher ADHD symptoms predicted subsequent increases in positive social perceptions about using cigarettes and e-cigarettes in the first year of college. These results underscore the importance of studying multiple domains of tobacco use (e.g., subjective behaviors and social cognitive perceptions) to capture dimensions of smoking frequency and potential risk for future use of cigarettes and e-cigarettes. These findings have direct relevance for high school and university administrators seeking to promote successful adjustment during the transition to college. Given that substance use prevention programming has not consistently demonstrated significant reductions in use (Wechsler et al., 2003), the next steps in tobacco prevention may be to identify for whom and under what conditions targeting social perceptions may reduce tobacco use. Our findings suggest that adolescents with ADHD symptoms may benefit from these type of programs, particularly for targeting increased risk for e-cigarette use. Future prevention and intervention programs in both high school and college should consider including strategies to help youth with ADHD cope effectively with adjustment and form adaptive cognitions.

Acknowledgements

Funding from the Virginia Youth Tobacco Projects small grant program through the Virginia Foundation for Healthy Youth supported this project. The findings and conclusions expressed in this manuscript are those of the authors and do not necessarily reflect those of the foundation.

References

- Agarwal D, Loukas A, & Perry CL (2018). Examining College Students' Social Environment, Normative Beliefs, and Attitudes in Subsequent Initiation of Electronic Nicotine Delivery Systems. *Health Education & Behavior*, 45(4), 532–539. [PubMed: 29117720]
- Ameringer K, & Leventhal A (2013). Associations between attention deficit hyperactivity disorder symptom domains and DSM-IV lifetime substance dependence. *The American journal on addictions*, 22(1), 23–32. [PubMed: 23398223]
- Amrock S, Lee L, & Weitzman M (2016). Perceptions of e-cigarettes and noncigarette tobacco products among US youth. *Pediatrics*, 138(5), 1–10.
- Arnett J (2005). The developmental context of substance use in emerging adulthood. *Journal of drug issues*, 35(2), 235–254.
- Arnett J (2016). College students as emerging adults: The developmental implications of the college context. *Emerging Adulthood*, 4(3), 219–222.
- Arria AM, Garnier-Dykstra LM, Caldeira KM, Vincent KB, Winick ER, & O'Grady KE (2013). Drug use patterns and continuous enrollment in college: Results from a longitudinal study. *Journal of studies on alcohol and drugs*, 74(1), 71–83. [PubMed: 23200152]
- Bandura A (1977). Self-efficacy: toward a unifying theory of behavioral change. *Psychological review*, 84(2), 191. [PubMed: 847061]
- Bagwell C, Molina B, Pelham W, & Hoza B (2001). Attention-deficit hyperactivity disorder and problems in peer relations: Predictions from childhood to adolescence. *Journal of the American Academy of Child & Adolescent Psychiatry*, 40(11), 1285–1292. [PubMed: 11699802]
- Bandura A (1986). *Social foundations of thought and action*. Englewood, NJ: Prentice Hall.

- Barkley R (2011). The Barkley Adult ADHD Rating Scale-IV. Guilford Press: New York.
- Barkley R, Murphy K, & Fischer M (2008). ADHD in Adults: What the Science Says. New York, NY: Guilford Press.
- Berg CJ, Haardörfer R, Milkie V, Getachew B, Lloyd SA, Lanier A, ... & Dossantos E (2018). Cigarette use trajectories in young adults: Analyses of predictors across system levels. *Drug and alcohol dependence*, 188, 281–287. [PubMed: 29807215]
- Caldeira KM, O'Grady KE, Vincent KB, & Arria AM (2012). Marijuana use trajectories during the post-college transition: Health outcomes in young adulthood. *Drug and alcohol dependence*, 125(3), 267–275. [PubMed: 22464050]
- Centers for Disease Control and Prevention. (2018). Tobacco Use Among Middle and High School Students, 2011–2017. *Morbidity & Mortality Weekly Report*, 67(22), 629–633. [PubMed: 29879097]
- Cooke M, Nasim A, Cho S, Kendler K, Clark S, & Dick DM (2016). Predicting tobacco use across the first year of college. *American journal of health behavior*, 40(4), 484–495. [PubMed: 27338995]
- Dishion TJ, & Owen LD (2002). A longitudinal analysis of friendships and substance use: Bidirectional influence from adolescence to adulthood. *Developmental psychology*, 38(4), 480–491. [PubMed: 12090479]
- DuPaul GJ, Reid R, Anastopoulos AD, Lambert MC, Watkins MW, & Power TJ (2016). Parent and teacher ratings of attention-deficit/hyperactivity disorder symptoms: Factor structure and normative data. *Psychological Assessment*, 28(2), 214. [PubMed: 26011476]
- DuPaul GJ, Schaugency EA, Weyandt LL, Tripp G, Kiesner J, Ota K, & Stanish H (2001). Self-report of ADHD symptoms in university students: Cross-gender and cross-national prevalence. *Journal of learning disabilities*, 34(4), 370–379. [PubMed: 15503581]
- DuPaul G, Anastopoulos A, Power T, Reid R, Ikeda M, & McGoey K (1998). Parent ratings of attention-deficit/hyperactivity disorder symptoms: Factor structure and normative data. *Journal of Psychopathology and Behavioral Assessment*, 20(1), 83–102.
- Eagan K, Stolzenberg E, Ramirez J, Aragon M, & Hurtado S (2014). The American freshman: National norms fall 2014. Los Angeles, CA: Higher Education Research Institute.
- Eissenberg T, Ward K, Smith S & Maziak W (2008). Waterpipe tobacco smoking on a US College campus: prevalence and correlates. *Journal of Adolescent Health*, 42(5), 526–529. [PubMed: 18407049]
- Flory K, Milich R, Lynam D, Leukefeld C, & Clayton R (2003). Relation between childhood disruptive behavior disorders and substance use and dependence symptoms in young adulthood: Individuals with symptoms of attention-deficit/hyperactivity disorder are uniquely at risk. *Psychology of Addictive Behaviors*, 17(2), 151. [PubMed: 12814279]
- Fuemmeler BF, Kollins SH, & McClernon FJ (2007). Attention deficit hyperactivity disorder symptoms predict nicotine dependence and progression to regular smoking from adolescence to young adulthood. *Journal of pediatric psychology*, 32(10), 1203–1213. [PubMed: 17602186]
- Garnier-Dykstra LM, Pinchevsky GM, Caldeira KM, Vincent KB, & Arria AM (2010). Self-reported adult attention-deficit/hyperactivity disorder symptoms among college students. *Journal of American College Health*, 59(2), 133–136. [PubMed: 20864440]
- Gibson LA, Creamer MR, Breland AB, Giachello AL, Kaufman A, Kong G, ... & Halpern-Felsher B (2018). Measuring perceptions related to e-cigarettes: Important principles and next steps to enhance study validity. *Addictive behaviors*, 79, 219–225. [PubMed: 29175027]
- Glass K, & Flory K (2010). Why does ADHD confer risk for cigarette smoking? A review of psychosocial mechanisms. *Clinical Child & Family Psychology Review*, 13(3), 291–313. [PubMed: 20582628]
- Goldenson N, Khoddam R, Stone M, & Leventhal A (2018). Associations of ADHD Symptoms with Smoking and Alternative Tobacco Product Use Initiation During Adolescence. *Journal of pediatric psychology*, 43(6), 613–624. [PubMed: 29304219]
- Gotham H, Sher K, & Wood P (1997). Predicting stability and change in frequency of intoxication from the college years to beyond: Individual-difference and role transition variables. *Journal of abnormal psychology*, 106(4), 619. [PubMed: 9358692]

- Gudjonsson G, Sigurdsson J, Sigfusdottir I, & Young S (2012). An epidemiological study of ADHD symptoms among young persons and the relationship with cigarette smoking, alcohol consumption and illicit drug use. *Journal of Child Psychology & Psychiatry*, 53(3), 304–312. [PubMed: 22066497]
- Hagger MS, Leaver E, Esser K, Leung CM, Te Pas N, Keatley DA, ... & Chatzisarantis NL (2013). Cue-induced smoking urges deplete cigarette smokers' self-control resources. *Annals of Behavioral Medicine*, 46(3), 394–400. [PubMed: 23720186]
- Hartung CM, Lefler EK, Canu WH, Stevens AE, Jaconis M, LaCount PA, ... & Willcutt EG (2016). DSM-5 and other symptom thresholds for ADHD: which is the best predictor of impairment in college students?. *Journal of attention disorders*.
- Haslam N, Williams B, Prior M, Haslam R, Graetz B, & Sawyer M (2006). The latent structure of attention-deficit/hyperactivity disorder: A taxometric analysis. *Australian and New Zealand Journal of Psychiatry*, 40(8), 639–647. [PubMed: 16866759]
- Heckman B, MacQueen D, Marquinez N, MacKillop J, Bickel W, & Brandon T (2017). Self-control depletion and nicotine deprivation as precipitants of smoking cessation failure. *Journal of consulting & clinical psychology*, 85(4), 381–396. [PubMed: 28333537]
- Heiligenstein E, Conyers LM, Berns AR, & Smith MA (1999). Preliminary normative data on DSM-IV attention deficit hyperactivity disorder in college students. *Journal of American College Health*, 46(4), 185–188.
- Hu LT, & Bentler PM (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural equation modeling*, 6(1), 1–55.
- Jackson KM, Sher KJ, & Schulenberg JE (2005). Conjoint developmental trajectories of young adult alcohol and tobacco use. *Journal of abnormal psychology*, 114(4), 612–626. [PubMed: 16351384]
- Johnston L, O'Malley P, Bachman JG, Schulenberg JE, & Miech RA (2015). Monitoring the Future national survey results on drug use, 1975–2014: Volume II, college students and adults ages 19–55. Ann Arbor: Institute for Social Research, University of Michigan.
- King AC, Smith LJ, McNamara PJ, Matthews AK, & Fridberg DJ (2015). Passive exposure to electronic cigarette (e-cigarette) use increases desire for combustible and e-cigarettes in young adult smokers. *Tobacco control*, 24(5), 501–504. [PubMed: 24848637]
- Kline R (2010) *Principles and Practice of Structural Equation Modelling*. Guilford Press: NY.
- Lee DH, Oakland T, Jackson G, & Glutting J (2008). Estimated prevalence of attention-deficit/hyperactivity disorder symptoms among college freshmen: gender, race, and rater effects. *Journal of Learning Disabilities*, 41(4), 371–384. [PubMed: 18560023]
- Lee SS, Humphreys KL, Flory K, Liu R, & Glass K (2011). Prospective association of childhood attention-deficit/hyperactivity disorder (ADHD) and substance use and abuse/dependence: a meta-analytic review. *Clinical psychology review*, 31(3), 328–341. [PubMed: 21382538]
- Lee H, Lin H, Seo D, & Lohrmann D (2017). Determinants associated with e-cigarette adoption and use intention among college students. *Addictive behaviors*, 65, 102–110. [PubMed: 27816034]
- Marshall M, & Molina B (2006). Antisocial behaviors moderate the deviant peer pathway to substance use in children with ADHD. *Journal of Clinical Child & Adolescent Psychology*, 35(2), 216–226. [PubMed: 16597217]
- Marshall M, Molina BS, & Pelham WE (2003). Childhood ADHD and adolescent substance use: an examination of deviant peer group affiliation as a risk factor. *Psychology of Addictive Behaviors*, 17(4), 293. [PubMed: 14640825]
- Mercken L, Snijders TA, Steglich C, Vartiainen E, & De Vries H (2010). Dynamics of adolescent friendship networks and smoking behavior. *Social networks*, 32(1), 72–81.
- Mitchell J, Howard A, Beledniuk K, Kennedy T, Stehli A, ... Molina BSG (2018). Cigarette Smoking Progression among Young Adults Diagnosed with ADHD in Childhood: A 16-year Longitudinal Study of Children with and without ADHD. *Nicotine & Tobacco Research*, 1, 1–10.
- Molina BS, & Pelham WE (2014). Attention-Deficit/Hyperactivity Disorder and risk of substance use disorder: Developmental considerations, potential pathways, and opportunities for research. *Annual Review of Clinical Psychology*, 10, 607–639.

- Morrell H, Lapsley D, & Halpern-Felsher B (2016). Subjective invulnerability and perceptions of tobacco-related benefits predict adolescent smoking behavior. *The Journal of Early Adolescence*, 36(5), 679–703.
- Murthy V (2017). E-cigarette use among youth and young adults: A major public health concern. *JAMA pediatrics*, 171(3), 209–210. [PubMed: 27928577]
- Muthén L, & Muthén B *Mplus User's Guide*, 8th ed., Muthén & Muthén, Los Angeles, CA
- Nichols TT, Foulds J, Yingst JM, Veldheer S, Hrabovsky S, Richie J, ... & Wilson SJ (2016). Cue-reactivity in experienced electronic cigarette users: Novel stimulus videos and a pilot fMRI study. *Brain research bulletin*, 123, 23–32. [PubMed: 26478134]
- Noland M, Ickes M, Rayens M, Butler K, Wiggins A, & Hahn E (2016). Social influences on use of cigarettes, e-cigarettes, and hookah by college students. *Journal of American College Health*, 64(4), 319–328. [PubMed: 26822236]
- Nordgren LF, & Chou EY (2011). The push and pull of temptation: The bidirectional influence of temptation on self-control. *Psychological Science*, 22(11), 1386–1390. [PubMed: 21980159]
- Norwalk K, Norvilitis J & MacLean M (2009) ADHD symptomatology and its relationship to factors associated with college adjustment. *Journal of Attention Disorders*, 13, 251–258. [PubMed: 18669877]
- Palmer R, Young S, Hopfer C, Corley R, Stallings M, Crowley T, & Hewitt J (2009). Developmental epidemiology of drug use and abuse in adolescence and young adulthood: Evidence of generalized risk. *Drug and alcohol dependence*, 102(1–3), 78–87. [PubMed: 19250776]
- Perkins H, Haines M, & Rice R (2005). Misperceiving the college drinking norm and related problems: a nationwide study of exposure to prevention information, perceived norms and student alcohol misuse. *Journal of studies on alcohol*, 66(4), 470–478. [PubMed: 16240554]
- Richman WL, Kiesler S, Weisband S, & Drasgow F (1999). A meta-analytic study of social desirability distortion in computer-administered questionnaires, traditional questionnaires, and interviews. *Journal of applied psychology*, 84(5), 754–775.
- Rigotti NA, Lee JE, & Wechsler H (2000). US college students' use of tobacco products: results of a national survey. *Jama*, 284(6), 699–705. [PubMed: 10927777]
- Rodriguez D, Tercyak K, & Audrain-McGovern J (2008). Effects of inattention and hyperactivity/impulsivity symptoms on development of nicotine dependence from mid adolescence to young adulthood. *Journal of Pediatric Psychology*, 33(6), 563–575. [PubMed: 17956929]
- Singh T, Arrazole R, Corey C, et al. (2016). Tobacco use among middle and high school students—2011–2015. *Morbidity and mortality weekly report*, 65(14), 361–367. [PubMed: 27077789]
- Soneji S, Barrington-Trimis J, Wills T, et al. (2017). Association between initial use of e-cigarettes and subsequent cigarette smoking among adolescents and young adults: a systematic review and meta-analysis. *JAMA pediatrics*, 171(8), 788–797. [PubMed: 28654986]
- Spindle TR, Hiler M, Cooke M, Eissenberg T, Kendler K, & Dick D (2017). Electronic cigarette use and uptake of cigarette smoking: a longitudinal examination of US college students. *Addictive behaviors*, 67, 66–72. [PubMed: 28038364]
- Stockdale M, Dawson-Owens H, & Sagrestano L (2005). Social, attitudinal, and demographic correlates of adolescent vs college-age tobacco use initiation. *American Journal of Health Behavior*, 29(4), 311–323. [PubMed: 16006228]
- Stone A, Becker L, Huber A, & Catalano R (2012). Review of risk and protective factors of substance use and problem use in emerging adulthood. *Addictive behaviors*, 37, 747–775. [PubMed: 22445418]
- Su J, Hancock L, Wattenmaker A, Alshagra M,...& Adkins A (2018). Evaluating the effect of a campus-wide social norms marketing intervention on alcohol-use perceptions, consumption, and blackouts. *Journal of American College Health*, 66(3), 219–224. [PubMed: 28937942]
- Tercyak K, Lerman C, & Audrain J (2002). Association of ADHD symptoms with levels of cigarette smoking in a community sample of adolescents. *Journal of the American Academy of Child & Adolescent Psychiatry*, 41(7), 799–805. [PubMed: 12108804]
- US Department of Health and Human Services. (2016). E-cigarette use among youth and young adults. A report of the Surgeon General. Atlanta, GA: US 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.

VanEck K, Markle R, Dattilo L, & Flory K (2014). Do peer perceptions mediate the effects of ADHD symptoms and conduct problems on substance use for college students? *Psychology of Addictive Behaviors*, 28(2), 431–44252. [PubMed: 24955667]

Visser S, Danielson M, Bitsko R, Holbrook J, Kogan M, et al. (2014). Trends in the parent-report of health care provider-diagnosed and medicated ADHD: United States, 2003–2011. *Journal of the American Academy of Child & Adolescent Psychiatry*, 53(1), 34–46. [PubMed: 24342384]

Wang J, & Wang X (2012). *Structural equation modeling: Applications using Mplus*. John Wiley & Sons.

Wechsler H, Nelson T, Lee J, Seibring M, Lewis C, & Keeling R (2003). Perception and reality: a national evaluation of social norms marketing interventions to reduce college students' heavy alcohol use. *Journal of studies on alcohol*, 64(4), 484–494. [PubMed: 12921190]

Wilens T, Adamson J, Sgambati S, Whitley J, Santry A, et al. (2007). Do individuals with ADHD self-medicate with cigarettes and substances of abuse? Results from a controlled family study of ADHD. *The American Journal on Addictions*, 16, 14–23. [PubMed: 17453603]

Wilens T, Vitulano M, Upadhyaya H, Adamson J, Sawtelle R, Utzinger L, et al. (2008). Cigarette smoking associated with attention deficit hyperactivity disorder. *The Journal of Pediatrics*, 153(3), 414–419. [PubMed: 18534619]

Figure 1.

Autoregressive cross-lagged path model for ADHD symptoms and frequency of cigarette use. Statistically significant standardized path coefficients (and standard errors) are shown with solid lines and dotted lines represent a non-significant path. Covariates and cross-sectional correlations were included in the model but are omitted from the figure to reduce complexity.

Figure 2.
Autoregressive cross-lagged path model for ADHD symptoms and frequency of e-cigarette use.

Figure 3. Autoregressive cross-lagged path model for ADHD symptoms and social perceptions about cigarette use.

Figure 4. Autoregressive cross-lagged path model for ADHD symptoms and social perceptions about e-cigarette use.

Table 1.

Correlations among study variables

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Cigarette Use T1		.57***	.52***	.24**	.32***	.40***	.10	.02	.22**	.07	.03	.20*	.16*	.14	.13
2. Cigarette Use T2			.69***	.33***	.35***	.40***	.01	.24**	.30**	.11	.07	.17*	.14	.23**	.20*
3. Cigarette Use T3				.28**	.30***	.42***	.02	.22*	.32***	.12	.08	.21*	.14	.20*	.23**
4. E-Cigarette Use T1					.55***	.61***	.09	.04	.03	.07	.05	.02	.20*	.22*	.18*
5. E-Cigarette Use T2						.77***	.16*	.24**	.36***	.09	.15	.34***	.17*	.25**	.18*
6. E-Cigarette Use T3							.05	.20*	.32***	.07	.18*	.27**	.17*	.24**	.23**
7. Perceptions of Cigarettes T1								.20*	.46***	.53***	.16	.49***	.12	.23**	.11
8. Perceptions of Cigarettes T2									.34***	.11	.76***	.22*	.15	.23**	.17*
9. Perceptions of Cigarettes T3										.15	.22*	.76***	.14	.31***	.18*
10. Perceptions of E-Cigarettes T1											.20*	.29***	.19*	.22**	.13
11. Perceptions of E-Cigarettes T2												.27**	.17*	.21**	.20*
12. Perceptions of E-Cigarettes T3													.17*	.37***	.23*
13. ADHD Symptoms T1														.65***	.57***
14. ADHD Symptoms T2															.68***
15. ADHD Symptoms T3															
Mean	.24	.29	.36	.34	.45	.51	.18	.25	.24	.56	.56	.61	11.57	11.26	11.50
SD	.05	.11	.13	.14	.21	.23	.46	.55	.56	.51	.54	.65	8.94	8.09	8.16

Note. T1 = spring of senior year of high school. T2 = fall of first year of college. T3 = spring of first year of college.

* $p < .05$.

** $p < .01$.

*** $p < .001$

Table 2.

Comparison of Model Constraints for the Longitudinal Associations between ADHD symptoms and Cigarette and E-Cigarette Use and Social Perceptions

Model	χ^2	df	CFI	RMSEA	90% CI	Satorra-Bentler χ^2	Decision
<i>Cigarette Use and ADHD Symptoms</i>							
<i>Unconstrained Model</i>							
Auto-regressive paths:	32.988	19	.945	.105	(.056, .154)	--	
a) ADHD	34.747	20	.943	.104	(.056, .151)	$\chi^2(1) = 1.736, p = .188$	Retain
b) Cig	34.771	21	.946	.098	(.050, .144)	$\chi^2(1) = 0.371, p = .542$	Retain
c) ADHD $\rightarrow$ Cig	36.574	22	.943	.097	(.051, .143)	$\chi^2(1) = 1.790, p = .181$	Retain
d) Cig $\rightarrow$ ADHD	39.612	23	.937	.100	(.055, .144)	$\chi^2(1) = 2.793, p = .095$	Retain
<i>E-Cigarette Use and ADHD Symptoms</i>							
Unconstrained	31.064	19	.967	.082	(.027, .129)	--	
Auto-regressive paths:	34.472	20	.961	.086	(.037, .132)	$\chi^2(1) = 3.357, p = .066$	Retain
b) E-Cig	65.398	21	.885	.144	(.106, .184)	$\chi^2(1) = 30.391, p < .001$	Reject
c) ADHD $\rightarrow$ E-Cig	43.498	21	.940	.104	(.061, .146)	$\chi^2(1) = 8.6421, p = .003$	Reject
d) E-Cig $\rightarrow$ ADHD	34.563	21	.963	.082	(.031, .127)	$\chi^2(1) = 0.123, p = .726$	Retain
<i>Social Perceptions about Cigarette Use and ADHD Symptoms</i>							
Unconstrained	31.944	19	.933	.102	(.052, .151)	--	
Auto-regressive paths:	32.369	20	.935	.097	(.047, .145)	$\chi^2(1) = 0.494, p = .482$	Retain
b) Soc Perc	36.696	21	.918	.109	(.062, .156)	$\chi^2(1) = 4.166, p = .041$	Reject
c) ADHD $\rightarrow$ Soc Perc	41.622	21	.903	.115	(.071, .160)	$\chi^2(1) = 8.799, p = .003$	Reject
d) Soc Perc $\rightarrow$ ADHD	43.174	21	.896	.119	(.075, .163)	$\chi^2(1) = 10.259, p = .001$	Reject
<i>Social Perceptions about E-Cigarette Use and ADHD Symptoms</i>							
Unconstrained	29.828	19	.947	.083	(.028, .132)	--	
Auto-regressive paths:	30.060	20	.950	.078	(.020, .126)	$\chi^2(1) = 0.328, p = .567$	Retain
b) Soc Perc	34.742	21	.935	.087	(.038, .132)	$\chi^2(1) = 4.444, p = .035$	Reject
c) ADHD $\rightarrow$ Soc Perc	37.582	21	.924	.095	(.049, .139)	$\chi^2(1) = 7.045, p = .008$	Reject

Model	χ^2	df	CFI	RMSEA	90% CI	Satorra-Bentler χ^2	Decision
d) Soc Perc → ADHD	41.734	21	.907	.105	(.061, .148)	$\chi^2 (1) = 10.912, p = .001$	Reject

Note. Models presented above are hierarchically nested such that constraints retained (or rejected) at initial steps are retained (or rejected) for the subsequent models. The first model is the unconstrained (base) model. *Model A* = Homogeneity constraints to the stability paths of ADHD over time. *Model B* = Homogeneity constraints to the stability paths of tobacco use outcome over time. *Model C* = Homogeneity constraints to the cross-lagged paths of ADHD to either cigarettes or e-cigarettes (use or perceptions). *Model D* = Homogeneity constraints to the cross-lagged paths of cigarette/e-cigarette use and perceptions to ADHD. Bolded models are the final model retained. CFI = Comparative Fit Index. RMSEA = Root Mean Square Error of Approximation. df = degrees of freedom. Soc Perc = social perceptions of either cigarette or e-cigarette use.