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Role of Mental Health in the Association Between E-Cigarettes and Cannabis Use

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Abstract

Introduction: E-cigarette use may be associated prospectively with subsequent cannabis use among U.S. adolescents. However, it remains unclear whether this association differs by individual mental health status. This longitudinal study examines effect modifications by mental health status.

Methods: The first 4 waves (2013–2017) of the Population Assessment of Tobacco and Health Study were analyzed in 2020. Adolescents (aged 12–17 years) who reported never using cannabis at baseline waves were included. Waves 1–3 were each considered as baseline for their 12-month follow-up waves. Generalized estimating equations were used to evaluate the effect modification of internalizing mental health (IMH) and externalizing mental health (EMH) problems on the associations between baseline past 30–day e-cigarette use and past 30–day cannabis use at follow-up, controlling for individual characteristics and state recreational cannabis laws.

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Credit Statement

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Results: Baseline e-cigarette use was significantly associated with cannabis use at follow-up (AOR=4.81, 95% CI=2.93, 7.90). Adolescents with high severity of IMH/EMH problems were significantly more likely to initiate cannabis use. However, current e-cigarette users who reported high severity of IMH symptoms were less likely to initiate cannabis use (AOR=2.51, 95% CI=0.92, 6.83) compared with those who reported low severity of IMH problems (AOR=8.84, 95% CI=4.19, 18.65). There were no differences by severity of EMH problems.

Conclusions: Baseline e-cigarette use and endorsement of severe IMH/EMH problems were significantly associated with subsequent cannabis use among U.S. adolescents. Efforts to reduce youth vaping and improve youth mental health could help curb cannabis initiation. Tailored interventions may be warranted for e-cigarette-using adolescents with IMH problems.

INTRODUCTION

In 2020, the prevalence of current e-cigarette use was 19.6% among high school students and 4.7% among middle school students in the U.S.[1] Despite possible existence of common cause confounding, a growing body of longitudinal studies indicated that e-cigarette use was associated with subsequent cannabis initiation among adolescents.[2–5] A recent meta-analysis, which analyzed 18 cross-sectional and 3 longitudinal studies, found that the pooled odds of cannabis use among adolescents who used e-cigarettes were 3.5 times the corresponding odds for adolescents who did not use e-cigarettes (AOR=3.47, 95% CI=2.63, 4.59).[6]

However, this overall association between e-cigarette use and subsequent cannabis initiation may mask important differences among vulnerable population subgroups, particularly those with mental health problems. Mental health problems are generally categorized into 2 broad categories: internalizing mental health (IMH) and externalizing mental health (EMH) problems.[7] IMH problems are characterized as inner-directed and consist of anxiety, depressive, and somatic symptoms; EMH problems are outer-directed and feature symptoms that include emotional dysregulation, impulsivity, and oppositional behavior.[7,8] The evidence regarding the prospective association between IMH problems and substance use remains mixed.[9–14] Some studies suggested that adolescents with IMH problems are more likely to use substances to cope with stress/anxiety. By contrast, other studies found that these youth tend to be more socially isolated and may have less access to cannabis products, suggesting that IMH problems may be moderately protective against adolescent substance use.[9,13,15] The literature on EMH disorders is much more consistent, with current evidence suggesting a strong and robust association between EMH problems and adolescent substance use.[9–12,16] Current evidence also suggests that both IMH and EMH problems are associated with e-cigarette initiation.[17] Among adolescents who use e-cigarettes, those who experience more severe mental health conditions may be more motivated to use substances in an effort to cope with their symptoms, which could increase their likelihood of transitioning from e-cigarette use to cannabis use. Consequently, exploring the patterns and associations of e-cigarette use and cannabis use among adolescents who report mental health problems is warranted.

In addition to mental health, adolescent cannabis use may be influenced by state cannabis laws, which was not accounted for in most studies examining the association between e-cigarettes and cannabis use. Compared with medical cannabis laws, the legalization of recreational cannabis use for adults aged ≥21 years may have stronger potential of increasing social acceptability of adolescent cannabis use and product accessibility and availability.[18,19] With an increasing number of U.S. states legalizing adult recreational cannabis use, it is critically important to consider the policy impacts on adolescents' cannabis use behaviors. Population-based longitudinal studies that take into account the impact of the policy environment are needed.

The objective of this longitudinal study is to investigate whether the prospective association between e-cigarette use and cannabis use differs by IMH and EMH status among U.S. adolescents, controlling for individual characteristics and state recreational cannabis laws. This study aims to examine: (1) the strength of the association between baseline e-cigarette use, IMH/EMH problems, as well as other covariates, and cannabis use at follow-up; and (2) the role of IMH/EMH in the association between e-cigarette use and cannabis use. It is hypothesized that e-cigarette use and more severe IMH/EMH problems at baseline would be associated with an elevated risk of initiating cannabis use at the follow-up, and the association between baseline e-cigarette use and the onset of cannabis use at follow-ups would be stronger among those who reported more severe IMH/EMH problems.

METHODS

Study Sample/Population

This study used data from the Waves 1–4 youth cohort (2013–2017) of the Population Assessment of Tobacco and Health (PATH) Study. A multistage, stratified probability youth sample was selected to represent the non-institutionalized population in the U.S.[20] Further details on study design, sampling, response rates, imputation, and data collection procedures are available in the PATH Study user guide.[21] The Georgia State University IRB exempted this study from review.

This study followed an approach used by the PATH Study research team to treat each of the first 3 waves as a baseline for their corresponding 12-month follow-up waves, and stacked baseline covariates with cannabis use status at the corresponding follow-up wave.[22,23] For instance, Wave 2 served as the 12-month follow-up for Wave 1 and the baseline for Wave 3. This approach is used to examine associations between baseline characteristics and outcomes at follow-up, which is different from classical panel data analysis.[24] The corresponding all-wave weights for the youth cohort (aged 12–17 years) were used to produce nationally representative estimates.[21] The all-wave weights were restricted to Wave 1 respondents who completed all follow-up surveys or the shadow sample (aged 9–11 years) who completed at ≥1 interview at follow-up waves while they were aged 12–17 years.[21] The target population was youth who never used cannabis, and the study sample was composed of respondents who reported having never used cannabis at the baseline waves. As illustrated in Appendix Figure 1, this study included 5,049 youth at Wave 1, 6,522 youth at Wave 2, and 7,888 youth at Wave 3.

Measures

The primary outcome was the self-reported past 30–day (P30D) use of cannabis at follow-up among adolescents (aged 12–17 years) who had never used cannabis at baseline. The exposures of interest were the P30D use of e-cigarettes and mental health conditions at baseline. Respondents who reported using any e-cigarette products in the past 30 days at baseline were categorized as P30D users of e-cigarettes. Mental health problems were coded based on 4 internalizing and 7 externalizing problems measured in the PATH Study survey (Appendix Table 1). This study followed an approach to sum up the scores for past-year IMH and EMH problems, where the severity was categorized into 3 levels: low (0–1), moderate (2–3), and high (4 for IMH problems or 4–7 for EMH problems).[25,26]

State recreational cannabis law (legalized or not legalized) at the survey year, retrieved from the NIH Alcohol Policy Information System, was analyzed as a covariate.[27] Other baseline covariates were included to control for potential confounding effects: age (12–14 or 15–17 years), sex (male or female), race/ethnicity (Hispanic, non-Hispanic White, non-Hispanic Black, or non-Hispanic Other), parental education (less than high school, high school graduate, some college or associate degree, and bachelor's degree or higher), dichotomous P30D use of combustible tobacco (cigarettes, traditional cigars, cigarillos, or filtered cigars), and dichotomous P30D use of alcohol. The question on sexual orientation was only available for participants aged ≥14 years, so dichotomized sexual orientation (straight versus other) was only used to estimate the bivariate association with outcomes but was not included in the regression models.

Statistical Analysis

Data management and analyses were conducted using Stata, version 15 in 2020. The youth cohort all-wave weights were applied to account for complex sample design and produce representative estimates. The balanced repeated replication approach with Fay's adjustment of 0.3 was used to compute statistical precision.[20,28] The weighted prevalence of P30D cannabis use at follow-up waves was estimated overall and stratified by exposure and covariates. Generalized estimating equations with unstructured covariance were fitted to evaluate the associations between the outcome (P30D cannabis use at follow-up) and exposure variables (P30D e-cigarette use, IMH and EMH problems), controlling for individual characteristics and state recreational cannabis laws. Wave was also controlled to adjust the fluctuation across waves. Additional generalized estimating equations models were fitted to examine the potential effect modifications of IMH and EMH problems on the association between e-cigarette use and subsequent cannabis use by adding corresponding interaction terms (P30D e-cigarette use X IMH/EMH problems). When a significant interaction was identified, subgroup analyses were conducted to present the associations between baseline e-cigarette use and subsequent cannabis use. Additionally, 2 sets of sensitivity analyses were conducted by replacing the outcome with ever cannabis use during the follow-up period and replacing 3-category IMH/EMH problems with continuous measures. All statistical tests were 2-sided with the significance level set to 0.05.

RESULTS

At Wave 1, a total 49.0% of respondents were female, 54.3% were non-Hispanic White, 14.1% were non-Hispanic Black, 9.3% were non-Hispanic Other, and 22.3% were Hispanic. The sex and race/ethnicity proportions were consistent across the 3 baseline waves. Detailed descriptive statistics of other covariates are available in Table 1.

As shown in Table 2, among baseline never cannabis users, the prevalence of P30D cannabis use was 2.3% (95% CI=1.8%, 2.9%) at Wave 2, 2.4% (95% CI=2.0%, 2.9%) at Wave 3, and 3.2% (95% CI=2.9%, 3.6%) at Wave 4. Among adolescents who reported P30D e-cigarette use at baseline waves, the prevalence of P30D cannabis use was 13.8% (95% CI=4.3%, 36.1%) at Wave 2, 9.7% (95% CI=4.3%, 20.2%) at Wave 3, and 26.3% (95% CI=18.0%, 36.7%) at Wave By contrast, among adolescents who reported that they had not used e-cigarettes in the past 30 days, the prevalence of P30D cannabis use was 2.2% (95% CI=1.8%, 2.8%) at Wave 2, 2.4% (95% CI=2.0%, 2.8%) at Wave 3, and 2.9% (95% CI=2.6%, 3.2%) at Wave 4. In addition, at each baseline wave, the weighted prevalence of self-reported P30D cannabis use was higher among participants who endorsed high severity of IMH or EMH problems (Table 2 and Appendix Figure 2).

Table 3 presents the adjusted associations between baseline P30D e-cigarette use and P30D cannabis use at follow-up waves, controlling for individual characteristics and state recreational cannabis laws. As shown in Model 1 (without interaction terms), P30D e-cigarette use at baseline was significantly associated with P30D cannabis use at follow-up (AOR=4.81, 95% CI=2.93, 7.90). In addition, high-severity IMH problems (AOR=1.45, 95% CI=1.06, 1.97) and EMH problems (AOR=1.64, 95% CI=1.25, 2.15) were significantly associated with P30D cannabis use in follow-up waves, controlling for other covariates. Additionally, older age, using combustible tobacco, and using alcohol were also significantly associated with elevated odds of P30D cannabis use in follow-up waves, whereas being non-Hispanic other and having parents with a bachelor's degree or higher were associated with reduced odds of P30D cannabis use in follow-up waves. Model 2 shows that the interaction between P30D e-cigarette use and IMH problems, noted as "P30D e-cigarette use X internalizing problems," was statistically significant for high versus low severity. In addition, Model 3 shows that the interaction term for EMH problems, noted as "P30D e-cigarette use X externalizing problems," was not significant.

Table 4 presents the subgroup analysis results stratified by IMH problems, controlling for other individual characteristics and state recreational cannabis law. Among adolescents with high severity of IMH problems, the AOR between baseline P30D e-cigarette use and P30D cannabis use at 12-month follow-up waves was 2.51 (95% CI=0.92, 6.83); among adolescents with low severity of IMH problems, the corresponding AOR was 8.84 (95% CI=4.19, 18.65).

Results of sensitivity analyses are presented in Appendix Tables 2–5. Consistent with Table 2, results in Appendix Table 2 show that, at each follow-up wave, ever cannabis use was higher among adolescents who reported baseline P30D e-cigarette use, compared with those who did not. In addition, Appendix Table 3 shows similar results regarding the

adjusted associations and interactions. Specifically, the AOR between ever cannabis use at follow-up waves and baseline P30D e-cigarette use was 5.84 (95% CI=3.09, 11.03) and 1.49 (95% CI=0.73, 3.08) for adolescents with low and high severity of IMH problems, respectively (Appendix Table 4). Appendix Table 5 presents the sensitivity analysis results using continuous measures of IMH and EMH problems, which showed that the associations and effect modifications were consistent with the results using categorical exposures.

DISCUSSION

Although the longitudinal association between e-cigarette use and subsequent cannabis initiation has been documented in several previous studies,[2–6] the putative effect modification by mental health conditions has not been reported previously. This study revealed that the strength of the association between baseline e-cigarette use and cannabis use at follow-up differed based on the severity of baseline IMH problems. Sensitivity analyses showed that this effect modification was robust to different exposure and outcome measures.

Consistent with previous literature,[29,30] this study found that adolescents who reported more severe EMH problems were significantly more likely to use cannabis, after controlling for e-cigarette use and other covariates. Current evidence on the association between IMH problems and cannabis use is mostly based on convenience samples and the results are mixed.[9–13] Findings from this study, which are based on a nationally representative longitudinal survey, showed that adolescents endorsing more severe IMH problems were significantly more likely to use cannabis. These findings suggest that both IMH and EMH problems are risk factors of subsequent cannabis use, implying that evidence-based mental health interventions[31–33] that improve youth mental health may help reduce the onset of cannabis use among adolescents.

This study's unique contribution was the revelation of the interaction between IMH problems and e-cigarette use in predicting subsequent cannabis use. It was initially hypothesized that among adolescents who used e-cigarettes, those who endorsed more severe IMH/EMH problems would be more likely to transition to cannabis use. Contradictory to this hypothesis, the results showed that P30D e-cigarette users who reported high severity of IMH symptoms were less likely to initiate cannabis use, compared with those who reported low severity of IMH problems. Several potential reasons may explain the modifying effect of IMH problems on the association between e-cigarette use and cannabis use. First, compared with adolescents with low severity of IMH problems, adolescents with high severity of IMH problems were more likely to suffer from depressive symptoms,[7] which could lead to social withdrawal that limited their interactions with their peers who engage in substance use.[9,13] The reduction in the likelihood of interacting with delinquent peers likely reduced their access to cannabis products, consequently weakening the association between e-cigarette use and subsequent cannabis use. Second, given the ubiquitous marketing and availability of e-cigarettes,[34–36] many of which are discreet and stealthy in their designs, and difficult to be detected by parents and teachers, these products may be the easiest and most accessible substance for adolescents, particularly for those with severe IMH problems,[1,37] who would use e-cigarettes to deal with stress and depression

(Appendix Table 6).[38] Supposing adolescents endorsing more severe IMH problems found that e-cigarettes (which themselves carry significant health risks[39]) were able to help them with emotion management, once they started using e-cigarettes, they may be less likely to resort to other substances at a later time, including cannabis, thus attenuating but not eliminating the association between IMH problems and cannabis use.

Previous studies, however, indicated that adolescents characterized by high levels of internalizing symptoms may experience elevated risk of cannabis use onset in late youth or early adulthood, when their social context became more supportive of cannabis use.[13,40] Given the positive prospective association between IMH and subsequent cannabis use, once initiated, cannabis could escalate to a regular way to manage stress for those endorsing more severe IMH problems. Future studies are needed to investigate how the associations would vary across different developmental stages, particularly among those with more severe IMH problems. Additionally, early interventions may be warranted to help younger adolescents effectively manage their distress without turning to substance use.[31–33]

This study found that the association between e-cigarette use and subsequent cannabis use did not differ by severity of EMH problems. Developmental models showed that adolescents with EMH problems are more likely to adopt rule-breaking behaviors and interact with deviant peers, thus increasing the likelihood of substance use.[13,14] Compared with adolescents with IMH problems, who are more likely to use substance to improve their mood (i.e., self-medication),[17,41] e-cigarette use is more likely to be a behavioral expression, but not a potential coping strategy, for adolescents with EMH symptoms. The present study results also suggest that EMH problems are a confounder rather than an effect modifier between e-cigarette use and cannabis use. Unfortunately, there are no sufficient details in the PATH Study to examine the mechanisms of transition from e-cigarette to cannabis use among adolescents with IMH/EMH problems. More data (both quantitative and qualitative) are needed to investigate the motivations of adolescents with mental health problems to use e-cigarettes or cannabis.

This study also found that older age, combustible tobacco use, and alcohol use were significantly associated with elevated odds of P30D cannabis use in follow-up waves, consistent with the findings from previous studies.[2–5] In addition to controlling for individual characteristics, this study also distinguished the effect of state recreational cannabis laws, a factor that has not been adequately considered in previous studies. Results showed that the association between state recreational cannabis laws and adolescent cannabis use was positive, but not statistically significant at α=0.05 (AOR=1.32, 95% CI=0.96, 1.83). With more U.S. states legalizing recreational cannabis for adults,[42] future studies using more recent data are still needed to monitor the effect of recreational cannabis laws on cannabis use among adolescents.

Limitations

This study is subject to several limitations. First, self-reported use of cannabis and tobacco products may introduce recall bias and social desirability bias.[43] Previous studies found that the prevalence of e-cigarette use in the PATH survey was significantly lower than other national representative surveys,[44] which was also reflected by the wide CIs in this

study. Second, although this study established a temporal association between e-cigarette use and cannabis use, it did not necessarily imply a causal relationship. Third, owing to the restrictions imposed by sample weights, which only applied to the younger adolescent (aged 12–17 years) cohort, this study was not able to analyze older adolescents and young adults. Fourth, the items measuring mental health problems in PATH is a short screening measure, not a diagnostic measure, asking symptoms over the past year, which may subject to measurement error. Finally, owing to data availability, this study could not assess frequency of cannabis use in this study. Therefore, the association between e-cigarette use and subsequent experimental versus sustained cannabis use could not be examined.

CONCLUSIONS

Results from this study suggest that efforts to prevent adolescent cannabis initiation need to incorporate measures addressing the youth vaping epidemic. Tailored interventions may also be needed for vulnerable population groups characterized by severe IMH and EMH conditions. In addition, efforts to prevent substance use might need to target different motivations for substance use among youth experiencing different types and severity of mental health symptomatology.More research is needed to clarify mechanistic pathways connecting e-cigarette use to later cannabis use.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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REFERENCES

1. Wang TW, Neff LJ, Park-Lee E, Ren C, Cullen KA, King BA. E-cigarette use among middle and high school students—United States, 2020. MMWR Morb Mortal Wkly Rep. 2020;69(37):1310–1312. 10.15585/mmwr.mm6937e1. [PubMed: 32941408]
2. Audrain-McGovern J, Stone MD, Barrington-Trimis J, Unger JB, Leventhal AM. Adolescent e-cigarette, hookah, and conventional cigarette use and subsequent marijuana use. Pediatrics. 2018;142(3):e20173616. 10.1542/peds.2017-3616.
3. Park E, Livingston JA, Wang W, Kwon M, Eiden RD, Chang Y-P. Adolescent e-cigarette use trajectories and subsequent alcohol and marijuana use. Addict Behav. 2020;103:106213. 10.1016/j.addbeh.2019.106213.
4. Dai H, Catley D, Richter KP, Goggin K, Ellerbeck EF. Electronic cigarettes and future marijuana use: a longitudinal study. Pediatrics. 2018;141(5):e20173787. 10.1542/peds.2017-3787.
5. Evans-Polce RJ, Veliz PT, Boyd CJ, McCabe SE. E-cigarette and cigarette use among US adolescents: longitudinal associations with marijuana use and perceptions. Am J Prev Med. 2020;58(6):854–857. 10.1016/j.amepre.2020.01.013. [PubMed: 32201183]
6. Chadi N, Schroeder R, Jensen JW, Levy S. Association between electronic cigarette use and marijuana use among adolescents and young adults: a systematic review and meta-analysis. JAMA Pediatr. 2019;173(10):e192574. 10.1001/jamapediatrics.2019.2574.

7. Achenbach TM, Ivanova MY, Rescorla LA, Turner LV, Althoff RR. Internalizing/externalizing problems: review and recommendations for clinical and research applications. J Am Acad Child Adolesc Psychiatry. 2016;55(8):647–656. 10.1016/j.jaac.2016.05.012. [PubMed: 27453078]
8. Brown BB, Prinstein MJ. Encyclopedia of adolescence. Cambridge: Academic Press; 2011.
9. Scalco MD, Colder CR, Hawk LW Jr, Read JP, Wieczorek WF, Lengua LJ. Internalizing and externalizing problem behavior and early adolescent substance use: a test of a latent variable interaction and conditional indirect effects. Psychol Addict Behav. 2014;28(3):828–840. 10.1037/a0035805. [PubMed: 25134030]
10. Colder CR, Frndak S, Lengua LJ, Read JP, Hawk LW, Wieczorek WF. Internalizing and externalizing problem behavior: a test of a latent variable interaction predicting a two-part growth model of adolescent substance use. J Abnorm Child Psychol. 2018;46(2):319–330. 10.1007/s10802-017-0277-6. [PubMed: 28229368]
11. Miettunen J, Murray G, Jones P, et al. Longitudinal associations between childhood and adulthood externalizing and internalizing psychopathology and adolescent substance use. Psychol Med. 2014;44(8):1727–1738. 10.1017/s0033291713002328. [PubMed: 24028974]
12. Pedersen MU, Thomsen KR, Heradstveit O, Skogen JC, Hesse M, Jones S. Externalizing behavior problems are related to substance use in adolescents across six samples from Nordic countries. Eur Child Adolesc Psychiatry. 2018;27(12):1551–1561. 10.1007/s00787-018-1148-6. [PubMed: 29619558]
13. Colder CR, Scalco M, Trucco EM, et al. Prospective associations of internalizing and externalizing problems and their co-occurrence with early adolescent substance use. J Abnorm Child Psychol. 2013;41(4):667–677. 10.1007/s10802-012-9701-0. [PubMed: 23242624]
14. Dodge KA, Malone PS, Lansford JE, Miller S, Pettit GS, Bates JE. A dynamic cascade model of the development of substance-use onset. Monogr Soc Res Child Dev. 2009;74(3):vii–119. 10.1111/j.1540-5834.2009.00528.x.
15. Kassel JD. Substance abuse and emotion. American Psychological Association; 2010.
16. Audrain-McGovern J, Rodriguez D, Testa S, Alexander E, Pianin S. Adolescent e-cigarette onset and escalation: associations with internalizing and externalizing symptoms. J Adolesc Health. 2021;68(4):801–807. 10.1016/j.jadohealth.2020.09.033. [PubMed: 33158686]
17. Riehm KE, Young AS, Feder KA, et al. Mental health problems and initiation of e-cigarette and combustible cigarette use. Pediatrics. 2019;144(1):e20182935. 10.1542/peds.2018-2935.
18. Ladegard K, Thurstone C, Rylander M. Marijuana legalization and youth. Pediatrics. 2020;145(suppl 2):S165–S174. 10.1542/peds.2019-2056d. [PubMed: 32358207]
19. Wang GS, Davies SD, Halmo LS, Sass A, Mistry RD. Impact of marijuana legalization in Colorado on adolescent emergency and urgent care visits. J Adolesc Health. 2018;63(2):239–241. 10.1016/j.jadohealth.2017.12.010. [PubMed: 29609916]
20. Hyland A, Ambrose BK, Conway KP, et al. Design and methods of the Population Assessment of Tobacco and Health (PATH) Study. Tob Control. 2017;26(4):371–378. 10.1136/tobaccocontrol-2016-052934. [PubMed: 27507901]
21. United States National Institute on Drug Abuse, United States Food and Drug Administration Center for Tobacco Products. Population Assessment of Tobacco and Health (PATH) Study [United States] Restricted-Use Files. Inter-university Consortium for Political and Social Research; 2020.
22. Kasza KA, Edwards KC, Tang Z, et al. Correlates of tobacco product initiation among youth and adults in the USA: findings from the PATH Study Waves 1–3 (2013–2016). Tob Control. 2020;29(suppl 3):s191–s202. 10.1136/tobaccocontrol-2020-055671. [PubMed: 32321853]
23. Edwards KC, Kasza KA, Tang Z, et al. Correlates of tobacco product reuptake and relapse among youth and adults in the USA: findings from the PATH Study Waves 1–3 (2013–2016). Tob Control. 2020;29(suppl 3):s216–s226. 10.1136/tobaccocontrol-2020-055660. [PubMed: 32321855]
24. Wooldridge JM. Econometric analysis of cross section and panel data. Cambridge: MIT press; 2010.
25. Conway KP, Green VR, Kasza KA, et al. Co-occurrence of tobacco product use, substance use, and mental health problems among youth: findings from wave 1 (2013–2014) of the

population assessment of tobacco and health (PATH) study. Addict Behav. 2018;76:208–217. 10.1016/j.addbeh.2017.08.009. [PubMed: 28846942]

26. Duan Z, Wang Y, Huang J. Sex difference in the association between electronic cigarette use and subsequent cigarette smoking among US adolescents: findings from the PATH Study Waves 1–4. Int J Environ Res Public Health. 2021;18(4):1695. 10.3390/ijerph18041695.
27. NIH Alcohol Policy Information System. CANNABIS POLICY TOPICS - Recreational Use of Cannabis: Volume 1. https://alcoholpolicy.niaaa.nih.gov/cannabis-policy-topics/recreational-use-of-cannabis-volume-1/104. Accessed June 17, 2020.
28. Judkins DR. Fay's method for variance estimation. J Off Stat. 1990;6(3):223–239.
29. Esmaeelzadeh S, Moraros J, Thorpe L, Bird Y. Examining the association and directionality between mental health disorders and substance use among adolescents and young adults in the US and Canada—a systematic review and meta-analysis. J Clin Med. 2018;7(12):543. 10.3390/jcm7120543.
30. Becker TD, Arnold MK, Ro V, Martin L, Rice TR. Systematic review of electronic cigarette use (vaping) and mental health comorbidity among adolescents and young adults. Nicotine Tob Res. 2021;23(3):415–425. 10.1093/ntr/ntaa171. [PubMed: 32905589]
31. Bender K, Tripodi SJ, Sarteschi C, Vaughn MG. A meta-analysis of interventions to reduce adolescent cannabis use. Res Soc Work Pract. 2011;21(2):153–164. 10.1177/1049731510380226.
32. Bonsack C, Manetti SG, Favrod J, et al. Motivational intervention to reduce cannabis use in young people with psychosis: a randomized controlled trial. Psychother Psychosom. 2011;80(5):287–297. 10.1159/000323466. [PubMed: 21646823]
33. Miovský M, Voňková H, Gabrhelík R, Šťastná L. Universality properties of school-based preventive intervention targeted at cannabis use. Prev Sci. 2015;16(2):189–199. 10.1007/s11121-013-0453-z. [PubMed: 24420651]
34. Huang J, Duan Z, Kwok J, et al. Vaping versus JUULing: how the extraordinary growth and marketing of JUUL transformed the US retail e-cigarette market. Tob Control. 2019;28(2):146–151. 10.1136/tobaccocontrol-2018-054382. [PubMed: 29853561]
35. Marynak K, Gentzke A, Wang TW, Neff L, King BA. Exposure to electronic cigarette advertising among middle and high school students—United States, 2014–2016. MMWR Morb Mortal Wkly Rep. 2018;67(10):294–299. 10.15585/mmwr.mm6710a3. [PubMed: 29543786]
36. Duan Z, Wang Y, Emery SL, Chaloupka FJ, Kim Y, Huang J. Exposure to e-cigarette TV advertisements among US youth and adults, 2013–2019. PLoS One. 2021;16(5):e0251203. 10.1371/journal.pone.0251203.
37. Miech R, Johnston L, O'Malley P, Bachman J, Schulenberg J, Patrick M. Monitoring the Future national survey results on drug use, 1975–2018: volume I, secondary school students. Institute for Social Research; 2019. 10.3998/2027.42/150622.
38. Green VR, Conway KP, Silveira ML, et al. Mental health problems and onset of tobacco use among 12-to 24-year-olds in the PATH study. J Am Acad Child Adolesc Psychiatry. 2018;57(12):944–954. 10.1016/j.jaac.2018.06.029. [PubMed: 30522740]
39. National Academies of Sciences, Engineering, Medicine. Public health consequences of e-cigarettes. Washington, DC: The National Academies Press; 2018. 10.17226/24952.
40. Sung M, Erkanli A, Angold A, Costello EJ. Effects of age at first substance use and psychiatric comorbidity on the development of substance use disorders. Drug Alcohol Depend. 2004;75(3):287–299. 10.1016/j.drugalcdep.2004.03.013. [PubMed: 15283950]
41. Audrain-McGovern J, Rodriguez D, Kassel JD. Adolescent smoking and depression: evidence for self-medication and peer smoking mediation. Addiction. 2009;104(10):1743–1756. 10.1111/j.1360-0443.2009.02617.x. [PubMed: 19549056]
42. National Conference of State Legislatures. State Medical Marijuana Laws. https://www.ncsl.org/research/health/state-medical-marijuana-laws.aspx. Published 2021. Accessed February 2, 2021.
43. Coughlin SS. Recall bias in epidemiologic studies. J Clin Epidemiol. 1990;43(1):87–91. 10.1016/0895-4356(90)90060-3. [PubMed: 2319285]
44. Boyd CJ, Veliz P, Evans-Polce RJ, Eisman AB, McCabe SE. Why are national estimates so different? a comparison of youth e-cigarette use and cigarette smoking in the MTF and

PATH surveys. J Stud Alcohol Drugs. 2020;81(4):497–504. 10.15288/jsad.2020.81.497. [PubMed: 32800087]

Table 1.

Descriptive Statistics of Covariates at Baseline Waves Among Adolescents Who Reported Never Used Cannabis

Covariates at baseline waves	Wave 1 n=5,049 % (95% CI)	Wave 2 n=6,522 % (95% CI)	Wave 3 n=7,888 % (95% CI)
P30D e-cigarette use			
Yes	0.6 (0.4, 0.9)	0.9 (0.6, 1.2)	1.4 (1.1, 1.7)
No	99.4 (99.1, 99.6)	99.1 (98.8, 99.4)	98.6 (98.3, 98.9)
Internalizing mental health problems			
Low	52.3 (50.6, 53.9)	53.1 (51.7, 54.5)	51.3 (49.9, 52.7)
Moderate	29.3 (28.0, 30.7)	27.8 (26.7, 29.0)	28.2 (27.1, 29.3)
High	18.4 (17.2, 19.7)	19.1 (18.1, 20.1)	20.5 (19.4, 21.6)
Externalizing mental health problems			
Low	39.6 (37.9, 41.3)	44.0 (42.7, 45.3)	43.9 (42.7, 45.2)
Moderate	30.7 (29.2, 32.2)	27.9 (26.8, 29.1)	27.6 (26.6, 28.7)
High	29.7 (28.4, 31.1)	28.1 (26.9, 29.4)	28.4 (27.3, 29.6)
Age group, years			
12−14	96.7 (96.0, 97.3)	77.8 (77.1, 78.5)	65.0 (64.3, 65.6)
15−17	3.3 (2.7, 4.0)	22.2 (21.5, 22.9)	35.0 (34.4, 35.7)
Sex			
Male	51.0 (50.5, 51.5)	51.0 (50.4, 51.5)	51.0 (50.4, 51.5)
Female	49.0 (48.5, 49.5)	49.0 (48.5, 49.6)	49.0 (48.5, 49.6)
Race/ethnicity			
Non-Hispanic White	54.3 (53.8, 54.9)	53.7 (53.0, 54.3)	52.8 (52.1, 53.5)
Non-Hispanic Black	14.1 (13.6, 14.5)	13.3 (12.8, 13.8)	12.9 (12.5, 13.3)
Non-Hispanic other	9.3 (8.9, 9.6)	9.8 (9.4, 10.3)	10.3 (9.9, 10.8)
Hispanic	22.3 (21.9, 22.7)	23.2 (22.7, 23.7)	24.0 (23.4, 24.5)
Sexual orientation (ages ≥14 years)			
Straight/heterosexual	95.0 (93.7, 96.1)	92.5 (91.4, 93.4)	91.3 (90.4, 92.0)
Gay, lesbian, bisexual, or other	5.0 (3.9, 6.3)	7.5 (6.6, 8.6)	8.7 (8.0, 9.6)
P30D combustible tobacco use[a]			
Yes	0.6 (0.4, 0.9)	0.6 (0.4, 0.9)	0.7 (0.5, 1.0)
No	99.4 (99.1, 99.6)	99.4 (99.1, 99.6)	99.3 (99.0, 99.5)
P30D alcohol use			
Yes	1.5 (1.2, 1.9)	3.9 (3.3, 4.6)	4.3 (3.7, 4.9)
No	98.5 (98.1, 98.8)	96.1 (95.4, 96.7)	95.7 (95.1, 96.3)
Parental education			
Less than high school	17.4 (16.0, 18.9)	16.5 (15.2, 17.9)	15.7 (14.5, 16.9)
High school graduate	17.5 (16.2, 19.0)	16.8 (15.8, 18.0)	16.3 (15.2, 17.4)
Some college or associate degree	20.1 (18.8, 21.5)	30.3 (28.7, 32.0)	31.3 (29.7, 32.9)
Bachelor’s degree or higher	45.0 (42.6, 47.3)	36.3 (34.0, 38.8)	36.8 (34.7, 38.9)

Covariates at baseline waves	Wave 1 n=5,049 % (95% CI)	Wave 2 n=6,522 % (95% CI)	Wave 3 n=7,888 % (95% CI)
State recreational cannabis law			
Legalized	6.2 (3.5, 10.8)	6.2 (3.5, 10.6)	18.8 (15.0, 23.3)
Not legalized	93.8 (89.2, 96.5)	93.8 (89.4, 96.5)	81.2 (76.7, 85.0)

[a]Combustible tobacco included cigarette, cigar, cigarillo, and filtered cigar.

P30D, past-30-day.

Table 2.

Percentage of P30D Cannabis Use at Each Follow-Up Wave by Baseline Covariates

Covariates at corresponding baseline wave	Wave 1 % (95% CI)	Wave 2 % (95% CI)	Wave 3 % (95% CI)
Overall P30D cannabis use at follow-up waves	2.3 (1.8, 2.9)	2.4 (2.0, 2.9)	3.2 (2.9, 3.6)
P30D e-cigarette use			
Yes	13.8 (4.3, 36.1)	9.7 (4.3, 20.2)	26.3 (18.0, 36.7)
No	2.2 (1.8, 2.8)	2.4 (2.0, 2.8)	2.9 (2.6, 3.2)
Internalizing mental health problems			
Low	1.3 (0.9, 1.9)	1.9 (1.5, 2.5)	2.7 (2.2, 3.2)
Moderate	2.4 (1.7, 3.4)	2.3 (1.7, 3.1)	3.1 (2.4, 4.0)
High	5.1 (3.7, 7.1)	4.2 (3.1, 5.7)	4.9 (4.0, 6.0)
Externalizing mental health problems			
Low	1.1 (0.7, 1.8)	1.9 (1.4, 2.6)	2.3 (1.8, 2.8)
Moderate	2.1 (1.4, 3.0)	1.9 (1.3, 2.7)	3.3 (2.6, 4.2)
High	4.4 (3.3, 5.9)	3.7 (2.9, 4.7)	4.7 (3.9, 5.7)
Age group, years			
12−14	2.3 (1.8, 2.9)	2.0 (1.6, 2.5)	2.4 (2.0, 2.8)
15−17	2.4 (0.8, 6.8)	3.9 (3.0, 5.2)	4.8 (4.0, 5.6)
Sex			
Male	1.8 (1.3, 2.6)	2.4 (1.9, 3.0)	3.0 (2.5, 3.7)
Female	2.8 (2.1, 3.6)	2.5 (1.9, 3.2)	3.4 (2.8, 4.0)
Race/ethnicity			
Non-Hispanic White	2.4 (1.8, 3.2)	2.6 (2.0, 3.3)	3.7 (3.1, 4.3)
Non-Hispanic Black	3.5 (2.1, 5.8)	1.8 (1.1, 3.1)	3.2 (2.2, 4.8)
Non-Hispanic other	0.8 (0.3, 2.6)	2.3 (1.2, 4.1)	1.2 (0.6, 2.1)
Hispanic	1.9 (1.2, 2.8)	2.4 (1.8, 3.3)	3.2 (2.6, 4.1)
Sexual orientation (ages ≥14 years)			
Straight/heterosexual	3.4 (2.6, 4.5)	3.5 (2.8, 4.2)	4.3 (3.7, 5.0)
Gay, lesbian, bisexual, or other	7.9 (2.9, 19.9)	5.6 (2.6, 11.4)	6.1 (4.1, 8.9)
P30D combustible tobacco use[a]			
Yes	12.9 (4.5, 31.7)	14.8 (6.8, 29.4)	18.9 (10.8, 31.0)
No	2.3 (1.8, 2.9)	2.4 (2.0, 2.8)	3.1 (2.7, 3.4)
P30D alcohol use			
Yes	11.4 (5.5, 22.3)	10.9 (7.8, 15.1)	12.1 (8.5, 17.1)
No	2.2 (1.7, 2.7)	2.1 (1.7, 2.6)	2.8 (2.5, 3.2)
Parental education			
Less than high school	4.2 (3.2, 5.7)	2.1 (1.3, 3.2)	3.9 (3.0, 4.9)
High school graduate	2.1 (1.2, 3.5)	2.3 (1.4, 3.6)	3.2 (2.3, 4.5)
Some college or associate degree	2.0 (1.3, 3.0)	3.4 (2.5, 4.5)	3.5 (2.9, 4.3)
Bachelor’s degree or higher	1.8 (1.2, 2.7)	1.9 (1.3, 2.7)	2.6 (2.1, 3.3)
State recreational cannabis law			

Covariates at corresponding baseline wave	Wave 1 % (95% CI)	Wave 2 % (95% CI)	Wave 3 % (95% CI)
Legalized	3.4 (1.6, 7.3)	2.9 (1.3, 6.4)	3.4 (2.6, 4.4)
Not legalized	2.2 (1.8, 2.8)	2.4 (2.0, 2.9)	3.2 (2.6, 4.4)

[a]Combustible tobacco included cigarette, cigar, cigarillo, and filtered cigar.

P30D, past-30-day.

Table 3.

AORs of P30D Cannabis Use at 12-Month Follow-Up Waves Among Baseline Cannabis-Naïve Adolescents

Baseline characteristics	Model 1 No interaction AOR (95% CI)	Model 2 IMH interaction AOR (95% CI)	Model 3 EMH interaction AOR (95% CI)
P30D e-cigarette use			
Yes	**4.81 (2.93, 7.90)**	**10.80 (5.41, 21.56)**	**10.26 (4.09, 25.70)**
No	ref	ref	ref
Internalizing mental health problems (IMH)			
Low	ref	ref	ref
Moderate	1.06 (0.79, 1.41)	1.10 (0.82, 1.49)	1.06 (0.79, 1.41)
High	**1.45 (1.06, 1.97)**	**1.59 (1.17, 2.16)**	**1.46 (1.07, 1.98)**
Externalizing mental health problems (EMH)			
Low	ref	ref	ref
Moderate	1.21 (0.92, 1.58)	1.20 (0.91, 1.59)	1.27 (0.96, 1.69)
High	**1.64 (1.25, 2.15)**	**1.63 (1.24, 2.14)**	**1.70 (1.27, 2.26)**
P30D e-cigarette use X IMH			
Yes X High		**0.20 (0.06, 0.64)**	
Yes X Moderate		0.43 (0.11, 1.64)	
No X Low		ref	
P30D e-cigarette use X EMH			
Yes X High			0.42 (0.13, 1.40)
Yes X Moderate			0.25 (0.04, 1.36)
No X Low			ref
Age group, years			
12–14	ref	ref	ref
15–17	**1.68 (1.33, 2.12)**	**1.67 (1.33, 2.09)**	**1.69 (1.34, 2.13)**
Sex			
Male	0.94 (0.75, 1.17)	0.93 (0.75, 1.17)	0.94 (0.75, 1.59)
Female	ref	ref	ref
Race/ethnicity			
Non-Hispanic White	ref	ref	ref
Non-Hispanic Black	1.09 (0.75, 1.58)	1.09 (0.75, 1.17)	1.09 (0.75, 1.59)
Non-Hispanic other	**0.52 (0.34, 0.81)**	**0.52 (0.34, 0.81)**	**0.52 (0.34, 0.80)**
Hispanic	0.86 (0.66, 1.12)	0.85 (0.65, 1.10)	0.86 (0.66, 1.12)
P30D combustible tobacco use[a]			
Yes	**2.23 (1.08, 4.64)**	**2.21 (1.09, 4.49)**	**2.16 (1.03, 4.53)**
No	ref	ref	ref
P30D alcohol use			
Yes	**3.38 (2.34, 4.88)**	**3.42 (2.37, 4.95)**	**3.45 (2.40, 4.94)**
No	ref	ref	ref

Baseline characteristics	Model 1 No interaction AOR (95% CI)	Model 2 IMH interaction AOR (95% CI)	Model 3 EMH interaction AOR (95% CI)
Parental education			
Less than high school	ref	ref	ref
High school graduate	0.73 (0.49, 1.07)	0.73 (0.50, 1.08)	0.72 (0.49, 1.07)
Some college or associate degree	0.81 (0.63, 1.04)	0.80 (0.62, 1.03)	0.81 (0.63, 1.04)
Bachelor's degree or higher	**0.59 (0.43, 0.82)**	**0.59 (0.43, 0.82)**	**0.59 (0.43, 0.82)**
State recreational cannabis law			
Legalized	1.32 (0.96, 1.83)	1.35 (0.98, 1.87)	1.33 (0.96, 1.69)
Not legalized	ref	ref	Ref

Note: Boldface indicates statistical significance ($p<0.05$).

[a]Combustible tobacco included cigarette, cigar, cigarillo, and filtered cigar.

P30D, past-30-day.

Table 4.

Subgroup Analysis for Adjusted Associations Among Adolescent Never Used Cannabis At Baseline

Baseline e-cigarette using status	**P30D cannabis use for low internalizing problems**	**P30D cannabis use for moderate internalizing problems**	**P30D cannabis use for high internalizing problems**
	AOR[a] (95% CI)	**AOR[a] (95% I)**	**AOR[a] (95% CI)**
P30D e-cigarette use			
Yes	**8.84 (4.19, 18.65)**	**4.51 (1.45, 13.99)**	2.51 (0.92, 6.83)
No	ref	ref	ref

Note: Boldface indicates statistical significance ($p<0.05$).

[a]Controlling for wave, sex, age, race/ethnicity, parental education, past-year externalizing mental health problems, P30D combustible tobacco use, P30D alcohol use, state-level recreational cannabis legalization status at baseline.

P30D, past-30-day.