Emergence of Electronic Cigarette Use in US Adolescents and the Link to Traditional Cigarette Use

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Abstract

Background—Electronic cigarettes (e-cigarettes) are increasingly used by US adolescents and may be a gateway to traditional cigarette use. We examine rates of both products by age and examine differences in age-varying rates by sex and race/ethnicity.

Methods—Data are from the 2014 National Youth Tobacco Survey, a national sample of US middle and high school students (*n*=22,007); students ages 11–19 were included. Past 30-day e-cigarette and traditional cigarette use were examined as a function of age; sex and race/ethnicity were included as moderators. The age-varying association between e-cigarette and traditional cigarette use was also examined.

Results—Rates of e-cigarette use increase faster than traditional cigarette use from ages 13–16. Compared to females, males had higher rates of e-cigarette use from ages 14–17.5 and traditional cigarette use from ages 15–18. Between ages 12–14, more Hispanic adolescents used e-cigarettes compared to White or Black adolescents; after age 14 Hispanics and Whites reported similar rates, peaking at twice the rate for Blacks. Hispanic adolescents report greater traditional cigarette use versus Whites between ages 12–13, but lower rates between ages 15–18. E-cigarette use was strongly associated with traditional cigarette use, particularly during early adolescence [OR>40 before age 12].

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Conclusions—Young Hispanic adolescents are at elevated risk for use of e-cigarettes and traditional cigarettes during early adolescence. During early adolescence, youth using e-cigarettes are more likely to smoke traditional cigarettes compared to youth not using e-cigarettes. The study of age-varying effects holds promise for advancing understanding of disparities in health risk behaviors.

Keywords

Electronic cigarettes, or e-cigarettes, were developed as a "reduced harm product,"[1] and have been touted by some as a "safe alternative" to traditional cigarette smoking. Although recent work suggests that e-cigarettes may be less harmful than traditional cigarettes,[2–4] concerns remain regarding their potential long-term health effects, as well as the potential for influencing use of additional tobacco products.[5] There is additional concern regarding the rise in adolescent e-cigarette use, which surpassed adult use in 2012.[6] Research suggests that adolescent e-cigarette use increased by approximately 69% from 2011 to 2013,[7] and nearly tripled from 2013–2014.[8] These increases have pushed the prevalence of e-cigarette use above that of traditional cigarette use among US adolescents, with data from the 2014 National Youth Tobacco Survey (NYTS) showing that 13.4% of high-school adolescents reported using e-cigarettes in the past 30 days, compared to 9.2% who reported past 30-day use of traditional cigarettes.[8] Given that e-cigarettes may be easily accessible to adolescents and the introduction of flavoring may make them particularly appealing at this age, it is critical to understand the context of e-cigarette use among adolescents.

Emerging evidence suggests a strong likelihood of individuals using both e-cigarettes and traditional cigarettes.[9–11] However, little is known about how the most recent prevalence estimates of e-cigarette use vary as a function of adolescent age, and even less is known about how the *association* between e-cigarette use and traditional cigarette smoking varies throughout adolescence. This is important to understand, given consistent evidence that the age of experimentation with tobacco products is associated with future nicotine dependence. Particularly, tobacco use in early adolescence (i.e., prior to age 15) strongly predicts addiction later in life.[12–14]

Although some adolescent e-cigarette users have never smoked traditional cigarettes,[9,15] emerging evidence shows that adolescents who exclusively use e-cigarettes have greater *intent to use* traditional cigarettes in the future.[7,16] These findings raise concern that adolescent e-cigarette use could promote future cigarette smoking due to the development of nicotine addiction, and/or increased accessibility to multiple tobacco products via commercial and social sources.[17,18] Individual predispositions (e.g., risk-taking and sensation seeking behavior) and social determinants (e.g., socioeconomic status) may also promote the use of both products independently, regardless of which is used first.[18]

Disparities across sex and race/ethnicity subgroups in these behaviors are important to consider, given evidence for sex and racial/ethnic differences in smoking during adolescence and into adulthood. Male adolescents display higher rates of traditional and e-cigarette smoking compared to females, and White adolescents display higher rates of traditional

cigarette smoking compared to Hispanic and Black adolescents.[8,19,20] However, Hispanic and White adolescents have demonstrated similar rates of e-cigarettes use, both groups using at a higher rate than Black adolescents.[8]

The current study is exploratory in nature, focusing on contemporary age trends in emergent e-cigarette use, recent traditional cigarette use, and the link between the two behaviors among US adolescents aged 11–19. Time-varying effect modeling (TVEM[21]) is used to document detailed age trends in the prevalence of (1) recent use of traditional cigarettes, (2) recent use of e-cigarettes, and (3) recent use of both products, as well as how these complex age trends vary across sex and racial/ethnic population subgroups. This innovative approach enables the investigation of changing associations across age using cross-sectional data, thus providing important age-relevant nuances that are likely obscured when using more traditional approaches. Prior applications of TVEM in nicotine research include estimation of the time-varying association between mood and craving,[22] craving and cessation fatigue,[23] and mood and smoking lapse,[24] across time since quitting in a smoking cessation trial, and the nuanced association between age of onset of regular cigarette use and subsequent use in adulthood.[14]

METHODS

Sample

Data were drawn from the most recent wave of data (2014) from the National Youth Tobacco Survey (NYTS). NYTS is a nationally representative, public use dataset which includes information on N=22,007 middle and high school students' "tobacco-related knowledge, attitudes, and behaviors". [25] Cross-sectional data were collected using a stratified, three-stage cluster sample design; Hispanic and non-Hispanic Black students were oversampled to enable more precise prevalence estimates for minority populations. Students from 207 schools completed the survey, for an overall participation rate of 73.3% (participation rates were 91.4% and 80.2% for students and schools respectively). The analytic sample contained 21,798 adolescents between ages 11–19 (49% female; 48% non-Hispanic White, 17% non-Hispanic Black, 29% Hispanic); 157 respondents were excluded because their age was reported as younger than 11, and 52 had a missing value for age. The institutional review board at The Pennsylvania State University approved this study by exemption.

Measures

Age was reported to the nearest year, and ranged from 9 years old to 19 years old (or older), with a mean age of approximately 14.5 years. Due to the small proportion of participants younger than 11 (0.7%), only participants aged 11 and older were included in the analysis sample. *Sex* was measured by self-report; for this analytic sample, 50.7% reported being male and 48.4% female. *Race/ethnicity* was assessed by a series of self-report questionnaire items, and individuals were assigned to a single category including Non-Hispanic White (45.0%), Non-Hispanic Black (15.6%), or of Hispanic origin (27.6%). Individuals in other race/ethnicity categories (6.3%) were not included in moderation analyses using this variable due to limited statistical power. *Recent traditional cigarette use* and *recent e-cigarette use*

were assessed via the questions "During the past 30 days, on how many days did you [smoke cigarettes/use e-cigarettes]?" Recent use was coded 0 if no use was reported in the past 30 days and 1 if use was reported.

Analytic Approach

Time-varying effect modeling (TVEM) was used to estimate the prevalence rate of traditional cigarette use and e-cigarette use as flexible functions of age, and the age-varying association between e-cigarette and traditional cigarette use. Models were run using logistic TVEM, a semi-parametric model that estimates regression coefficients (e.g., rates and associations between predictors and an outcome) as non-parametric functions of continuous age.[24] First, intercept-only models estimating the rate of each behavior as a function of age were run for the full analysis sample. Second, models including sex and race/ethnicity as covariates were run to test for subgroup differences in the complex age trends; centering was used to obtain group-specific intercept functions. Next, recent e-cigarette use was included as a predictor of recent traditional cigarette use to estimate the age-varying association between the behaviors. We then added sex and race/ethnicity interactions with recent e-cigarette use to examine possible subgroup differences in this age-varying association. All models were run in SAS 9.4 using the TVEM macro.[21,26]

RESULTS

Among US adolescents ages 11–19, past-30 day traditional cigarette use was reported by 6.4% and past-30 day e-cigarette use was reported by 9.2%. Overall, males were significantly more likely to engage in both behaviors when compared with females (7.5% of males and 5.3% of females reported traditional cigarette use; 10.5% of males and 7.8% of females reported e-cigarette use). The prevalence of both behaviors also varied significantly by race/ethnicity. Traditional cigarette use was most common among White adolescents (7.7%), followed by Hispanic (6.1%) and Black (4.1%) adolescents. E-cigarette use, however, was most common among Hispanic adolescents (10.8%), followed by White (10.4%) and Black (5.0%) adolescents. Overall, just 3.3% of participants reported using both types of cigarettes during the past 30 days.

The prevalence of both traditional cigarette use and e-cigarette use varied strongly by age, as shown in Figure 1. Each curve shows the intercept coefficient function (i.e., the age-varying intercept), transformed from the logit to the probability scale, reflecting the overall rate of each behavior as a continuous function of age from 11 to 19. Age-specific 95% confidence intervals are shown to convey the level of uncertainty for the estimate at that particular age. Factors that may be associated with width of the intervals include sparseness of data (which often occurs at the minimum and maximum ages in TVEM) and the prevalence of an outcome at certain ages. Rates of use for both products were lowest at age 11. The prevalence of e-cigarette use increased rapidly between ages 12 and 16, when it peaked at approximately 0.15; between ages 16 and 19 the rate of e-cigarette use remained constant (Panel A, top). The prevalence of traditional cigarette use increased more slowly and steadily from ages 11 to 19, peaking at about 0.19 at age 19 (Panel B, bottom). Thus, e-

cigarette use was more common than traditional cigarette use from age 12 through mid-adolescence, but rates were similar in later adolescence.

Figure 2 presents sex differences in the age trends of both behaviors. Panel A (top) shows the prevalence of e-cigarette use as a function of age for males and females. Sex differences emerged at around age 14, with males using e-cigarettes at a higher rate than females; this difference was only present between ages 14 and 17.5. Among older adolescents, the rate of e-cigarette use was not significantly different for males and females. Panel B (bottom) shows the age-varying prevalence of traditional cigarette use for males and females. Sex differences emerged after age 15, again with males using at a higher rate than females, however this difference was no longer present for adolescents age 18 and older. In sum, males engaged in more traditional cigarette use and e-cigarette use compared to females during the high school years only.

Similarly, Figure 3 presents race/ethnicity differences in the age trends of both behaviors. Panel A (top) shows the prevalence of e-cigarette use as a function of age separately for White, Black, and Hispanic adolescents. No group differences were present at age 11; however, between ages 12 and 14 Hispanic adolescents emerged as the heaviest e-cigarette users, using at a significantly higher rate than both White and Black adolescents.

From ages 14 to 19, Hispanic and White adolescents were characterized by similar rates of e-cigarette use, with the prevalence peaking at age 19 at about 0.20. The prevalence among Black adolescents was highest at approximately age 16, with a prevalence of less than half the peak rate in other subgroups. Panel B (bottom) shows the prevalence of traditional cigarette use as a function of age for the three subgroups. The age trend for White and Black adolescents was similar from ages 11 to 14; after age 14 the rate among White adolescents increased rapidly with age to nearly 0.20 at age 19. The rate among Black adolescents rose slowly and steadily with age to a little more than half the rate of White adolescents. The age trend for Hispanic adolescents was quite different. Between ages 12 and 13, Hispanic adolescents had a higher prevalence of traditional cigarette use compared to adolescents in other race/ethnicity groups. They continued to report a higher rate of use than Black adolescents until age 18, when the confidence intervals widened. However, there was a crossover effect between Hispanic and White adolescents such that Hispanic adolescents smoked at a significantly higher rate in early adolescence, but at a significantly lower rate during the high school years (i.e., ages 15 to 18).

E-cigarette use was significantly related to traditional cigarette smoking across all ages; the strength of this association was considerably stronger in early adolescence compared to mid-to-late adolescence (see Figure 4). For example, adolescents using e-cigarettes at age 12 had 40 times higher odds of also smoking traditional cigarettes compared to their peers who were not using e-cigarettes. Among adolescents age 16, using e-cigarettes conferred a relatively weaker, but still strong, risk for traditional cigarette use (OR=12). Sex and race/ethnicity did not significantly moderate this association at any age.

DISCUSSION

A key finding of this study is that there is no age during adolescence at which Hispanic adolescents use e-cigarettes at lower rates than White adolescents. Although past research has shown heightened rates of e-cigarette use among Hispanic versus White adolescents,[8] our results suggest that this disparity is particularly large during early adolescence (ages 12–14), when the risk of future nicotine addiction is especially high[14]. Thus, our findings suggest that Hispanic adolescents in the US may be at particularly high risk for future nicotine dependence and subsequent health consequences through their early use of e-cigarettes.

The age-varying prevalences indicated a crossover effect in traditional cigarette use across age between Hispanic and White adolescents, with Hispanic adolescents using at higher rates in early adolescence and White adolescents using at higher rates in mid- to late-adolescence. This result is consistent with prior research showing a crossover effect,[8,27] but extends our understanding of age trends by including even younger individuals, thus allowing the emergence of disparities to be documented, and by revealing the specific age periods during which significant disparities exist. One possible explanation of this observed crossover is the higher school dropout rate among Hispanic youth compared to Whites.[28] Another possibility is that younger Hispanic adolescents experience high rates of perceived discrimination, which–according to general strain theory[29]–may lead to unhealthy behaviors such as smoking as a coping strategy.[30] Although no other crossover effect was detected for White and Black adolescents, several significant group differences were identified during key age periods. Compared to Whites, significantly fewer Black adolescents reported using either product between ages 14–18. Males reported significantly higher rates of using e-cigarettes beginning at age 14 and traditional cigarettes beginning at age 15; however, by around age 18 there were no significant sex differences. Recent data from Monitoring the Future suggest a possible crossover between males and females, with a slightly higher rate of cigarette use among females in 8th grade and among males in 10th and 12th grade.[27] The current findings cover age more continuously, showing no specific age at which females use either product at a higher rate. Taken together, these findings may enable a deepening understanding of age-relevant correlates of traditional and e-cigarette use throughout adolescence, including e-cigarette advertisement exposure.[31] This study also highlights the potential benefit of reanalyzing national data using flexible methods such as TVEM that can shed new light on developmental processes.

Our findings, specifically the results shown in Figure 4, strongly suggest that e-cigarette use and traditional cigarette smoking go hand-in-hand among adolescents, and that e-cigarette use may be most strongly linked with traditional cigarette smoking during early adolescence. This very strong link across products in early adolescence may indicate growing health disparities in the future, and merits further study.

One possible explanation for this age trend in use of both products is that early nicotine users are adolescents showing a heightened general propensity for risk-taking behavior (i.e., the common liability hypothesis).[18] Adolescents who engage in early substance use are often distinguished by high novelty- and sensation-seeking, behavioral disinhibition, and

early engagement in problem behavior.[32] Early experimenting adolescents, by virtue of their higher risk-taking propensities, may therefore be more likely to experiment with multiple types of substances or product use than those who first experiment in later adolescence. Second, the association could reflect a greater developmental tendency for addiction in early versus later adolescence (i.e., the addiction hypothesis).[18] Given the heightened neurodevelopmental plasticity and reward sensitivity that occurs during early adolescence,[33] the use of one form of nicotine during this time may be more likely to lead to dependence symptoms in young versus older adolescents, and might result in the use of multiple forms of nicotine to satisfy accompanying urges. Indeed, evidence from seventh-grade adolescents has shown that symptoms of dependence can occur rapidly following nicotine use onset, sometimes detectable even after the first puff of a cigarette.[34] Third, these age-related differences could also reflect increased awareness and familiarity of e-cigarette products among the younger adolescents, which may lead early adolescent smokers to more readily include e-cigarette use as part of their smoking repertoire. These explanations are unlikely to be mutually exclusive, and future research exploring each of these avenues jointly may be needed to understand the mechanisms driving the heightened risk for multiple nicotine product use in early adolescence.

Limitations of the Present Study

Despite important strengths of using the NYTS to study traditional and e-cigarette use behaviors across adolescence, three limitations are important to consider. First, because the NYTS is cross-sectional, age and historical year are confounded. Future analyses relying on prior waves of NYTS, as well as future waves of NYTS as they become available, may help shed light on the issue of confounding in this rapidly evolving phenomenon of adolescent e-cigarette use. The NYTS design also does not permit a careful test of competing hypotheses discussed above; a deeper examination relying on longitudinal data is important for future work. Second, this study was exploratory in nature due to the paucity of research on trajectories of traditional and e-cigarette use among contemporary youth. Third, TVEM does not yet have the capability of applying sample weights. Because Hispanic and non-Hispanic Black students were oversampled, the overall rates of use presented in Figure 1 may not be an accurate reflection of use in the entire US adolescent population. However, this design was ideal for describing patterns of use in these important population subgroups; indeed the finding that Hispanic youth use at rates significantly higher even than White youth in early adolescence likely could not have been detected without such a design. Finally, coding the recent use items into dichotomous variables does not allow us to differentiate among regular, occasional, and experimental use. Assessing differences in use frequency may provide a more nuanced understanding of the emergence of nicotine dependence, in addition to potential risk exposure.[2]

CONCLUSION

As called for by Coyle and DiClemente,[35] this study demonstrates how TVEM can be applied to existing data to elucidate potential developmental trends in, and age-specific disparities in, health behaviors. Such results may shed new light on promising targets and timing for future interventions. This study used national data from a large epidemiologic

study of tobacco use behaviors among US adolescents. Important age trends were identified, particularly with respect to behavior among Hispanic adolescents. Findings suggest that prevention programs may need to target both e-cigarette and traditional cigarette smoking in order to prevent tobacco-related problems in adolescents, particularly for adolescents under age 15.

Acknowledgments

Abbreviations

NYTS   National Youth Tobacco Survey

TVEM   time-varying effect modeling

OR   odds ratio

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Highlights

- An innovative modeling technique is applied to examine age trends in adolescent e-cigarette use from a large, contemporary data set.

- Rates of e-cigarette use increase faster than traditional cigarette use from ages 13–16.

- Risk for e-cigarette use was higher for male and Hispanic adolescents at certain ages.

- E-cigarette and traditional cigarette use were strongly associated throughout adolescence, and the association was substantially stronger before age 15.
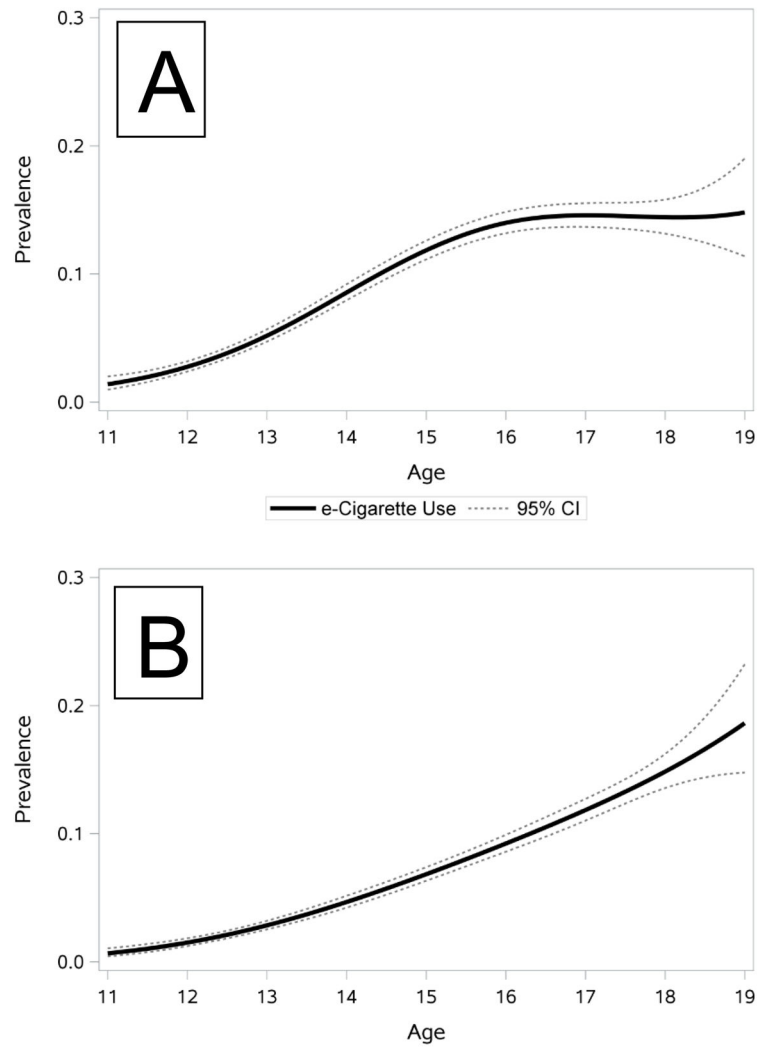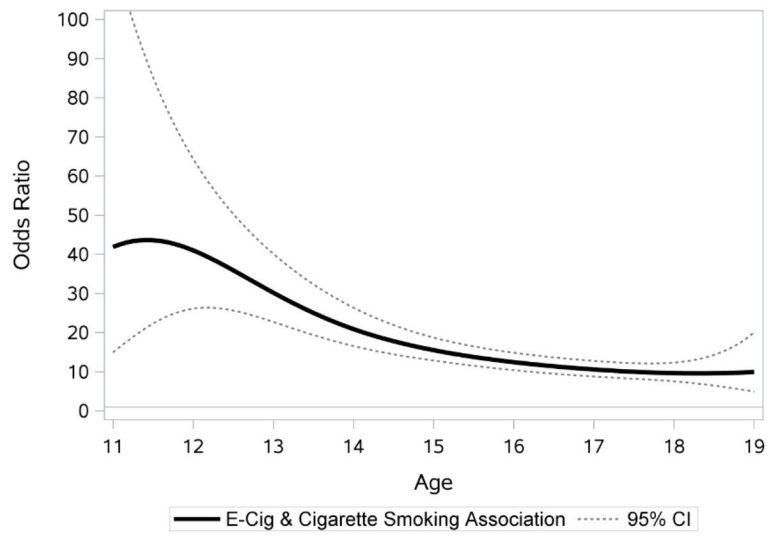
Figure 1.
Overall prevalence of electronic cigarette use (Panel A) and traditional cigarette use (Panel B) as a continuous function of age from 11 to 19.
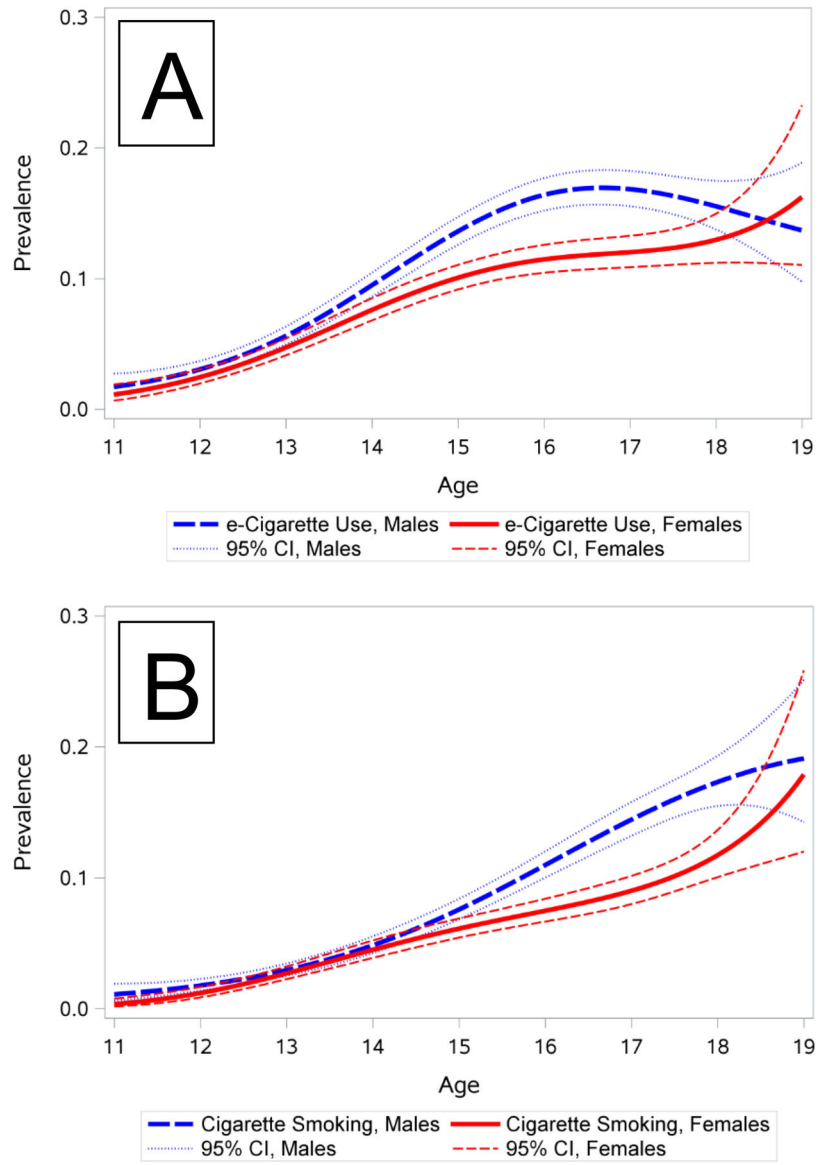
Figure 2.
Sex differences in prevalence of electronic cigarette use (Panel A) and traditional cigarette use (Panel B) as a continuous function of age from 11 to 19.
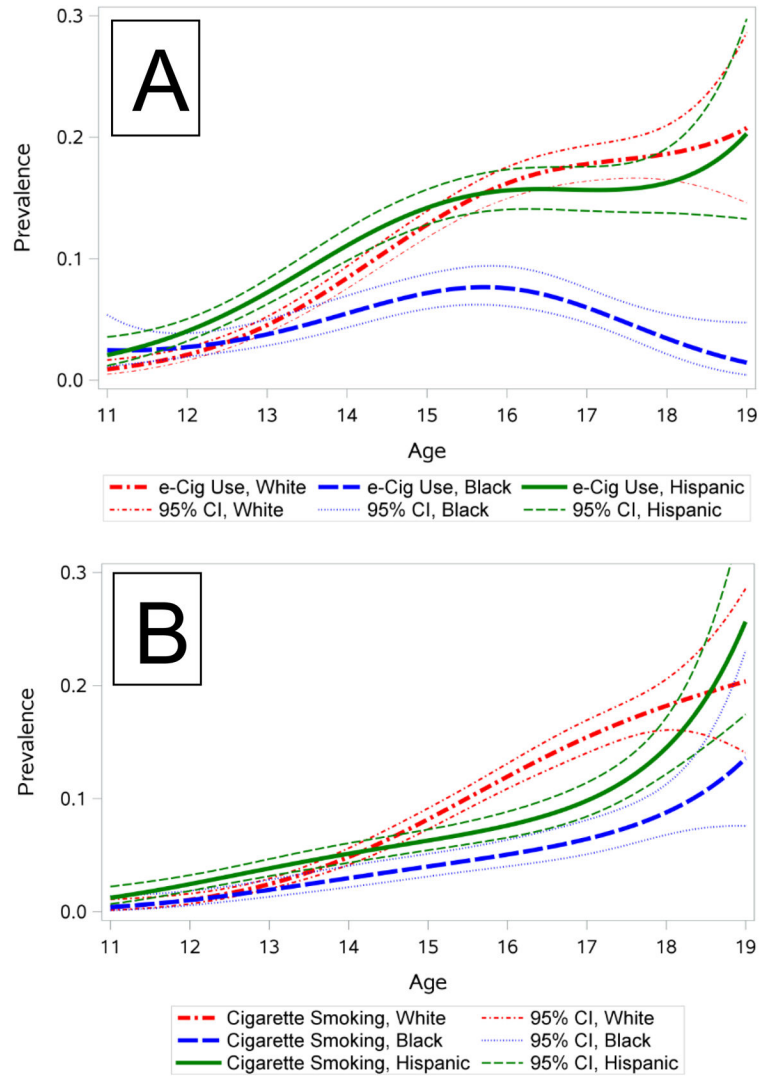
Figure 3.
Race/ethnic differences in prevalence of electronic cigarette use (Panel A) and traditional cigarette use (Panel B) as a continuous function of age from 11 to 19.

Figure 4.
Age-varying odds ratio showing increase in odds of traditional cigarette smoking corresponding to electronic cigarette use.