



Dual and poly-nicotine and tobacco use among adolescents in the United States from 2011 to 2022

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ABSTRACT

Background: Adolescent nicotine and tobacco product use remains common despite declining smoking rates in the United States, likely due to the emergence of novel products. Concurrent use of multiple products may increase the risk of nicotine dependency and subsequent substance use.

Aim: To identify patterns and trends of dual and poly nicotine and tobacco use among adolescents in the US and explore associations of dual and poly nicotine and tobacco use with sociodemographic factors.

Methods: 12 years of annual National Youth Tobacco Survey data (2011–2022) from 242,637 respondents were used to examine prevalence trends of different combinations of nicotine or tobacco product use among adolescents in the US using weighted point estimates for each year. Poisson regression models examined socio-demographic factors associated with different patterns of dual and poly-product use from 2011 to 2022.

Results: Overall, the prevalence of dual (i.e. at least two products) and poly (i.e. at least three products) use decreased between 2011 and 2021 (from 9.5 % to 2.8 % and from 5.1 % to 1.1 %, respectively), but showed signs of increase between 2021 and 2022 (3.7 % for dual and 1.7 % for poly use). The most common combinations included a combustible product with either a novel or noncombustible product. The risk for dual and poly-product use was higher among non-Hispanic Whites, males, and high school students.

Conclusions: Previously declining trends in the prevalence of tobacco/nicotine dual and poly use may have been reversed. Close monitoring and targeted tobacco control policies are essential to tackle multiple product use among adolescents.

1. Introduction

The use of tobacco and nicotine products is responsible for nearly half a million deaths and substantial avoidable morbidity in the United States (US) annually (Prevention, 2023). An estimated 9 out of 10 adult daily smokers first tried smoking before age 18 (CDC, 2023). Despite a decrease in smoking prevalence over the past decade, with lower prevalence among younger adolescents, the US still has one of the largest smoking populations globally (GBD, 2019 Tobacco Collaborators, 2021).

In 2022, 16.5 % of high school students and 4.5 % of middle school students, totaling approximately 3.08 million adolescents, reported current use of nicotine and tobacco products. The most popular products reported were e-cigarettes (14.1 %), combustible tobacco products (5.2 %), smokeless tobacco (1.6 %), and heated tobacco products (HTPs) (1.1 %) (Park-Lee et al., 2022), which highlights both the wide range of

tobacco products accessible to young people and the increasing popularity of novel products among them. Among current users in middle and high school, 31 % have used multiple nicotine and tobacco products in the past 30 days (Park-Lee et al., 2022). The high proportion of early smoking initiation and the diversification in tobacco product use among adolescents are critical areas for focused public health interventions.

Nicotine and tobacco use pose significant health risks to adolescents. Nicotine, a key driver for tobacco addiction, adversely affects adolescent lung development, the immune system, cognitive and mental health, and the brain (McGrath-Morrow et al., 2020). Adolescents exposed to tobacco are also at increased risk of becoming long-term users, therefore facing a lifetime of higher risk of non-communicable diseases such as cardiovascular disease, cancers, and chronic respiratory conditions (CDC/US Department of Health and Human Services [HHS], 2014). Additionally, tobacco use exacerbates health inequalities, disproportionately affecting Black, Native, and LGBTQ+ (lesbian, gay, bisexual,

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transgender queer or questioning, or another diverse gender identity) populations, who not only tend to have higher prevalence of use, but already face higher disease and mortality rates relative to other groups (Amroussia et al., 2020; Dawkins et al., 2019; CDC, 2022a). Exposure to multiple nicotine and tobacco products increases the risk of tobacco-related diseases and nicotine dependence, exacerbating health inequities, particularly among vulnerable youth (Arrazola et al., 2014; Azagba et al., 2019; Leavens et al., 2019).

Adolescents are often drawn to nicotine and tobacco products due to peer pressure, curiosity, and targeted marketing by the tobacco industry (CDC, 2012). The tobacco industry markets its products aggressively towards adolescents and young adults (CDC, 2021). This is particularly true for novel products such as e-cigarettes and nicotine pouches, designed in appealing flavors and colors to attract younger demographics (CDC, 2021). Influenced by these factors, adolescents may be prone to experimentation, which could lead to the initiation of smoking or/and concurrent use of multiple products (Chen et al., 2021).

Previous studies using the National Youth Tobacco Survey (NYTS) have investigated patterns and trends of dual and poly use among adolescents in the US (Cook et al., 2023; Jebai et al., 2023; Tashakkori et al., 2023), highlighting e-cigarettes' fluctuating popularity with relation to dual and poly use over the past decade. However, these studies have not taken into account novel nicotine and tobacco products such as HTPs and nicotine pouches, which have gained increasing popularity among young people in recent years (McKelvey et al., 2018; World Health Organization [WHO], 2023). Additionally, prior studies, limited to data until 2020, did not capture recent changes, particularly the potential impact of the COVID-19 pandemic on adolescents. Furthermore, inconsistencies in subpopulation selection, study periods and definitions of dual and poly use hindered a comprehensive understanding of multiple nicotine and tobacco products use among US adolescents. No study has investigated trends and patterns of multiple nicotine and tobacco product use in US adolescents starting from before the advent of e-cigarettes until the period of the pandemic covering the full spectrum of novel products surveyed in NYTS (Cook et al., 2023; Jebai et al., 2023; Tashakkori et al., 2023). This study aims to address these limitations and gaps by assessing the prevalence and associated risk factors for concurrent use of multiple nicotine and tobacco products on the market in the US among adolescents from 2011 to 2022.

2. Methods

2.1. Data source and study population

This study utilized data from the National Youth Tobacco Survey (NYTS) (CDC, 2022b), a cross-sectional survey of middle and high school students in the US that collects information on socioeconomic and behavioral factors related to nicotine and tobacco use. The NYTS uses a stratified, three-stage cluster sampling design to generate a nationally representative sample of students. Recruitment began with the random selection of counties as primary sampling units, followed by the selection of schools within those counties as secondary sampling units. Students were then selected from the chosen schools. The NYTS was initially conducted as a self-administered, paper-and-pencil questionnaire, and transitioned to an electronic format after 2019 due to COVID-19 (HHS, n.d.). Since 2021, the survey has been conducted both in schools and at home, adapting to the changing circumstances of the pandemic (CDC, 2022b). See Supplementary Table 1 for survey administration, school participation rates, and student participation rates for select years.

The sample for this study included annual data from 2011 to 2022 ($N = 242,637$). The study population consisted of all students who completed the survey during this time period. Respondents were between the ages of 9 and 19.

2.2. Outcome variables

We examined patterns and trends in U.S. adolescents' use of 12 nicotine or tobacco products: e-cigarettes, cigarettes, cigars, waterpipe, chewing tobacco, roll-your-own cigarettes, pipes, snus, dissolvable tobacco products, bidis, HTPs, and nicotine pouches. Product use was determined through one of two questions in all years of the survey; "During the past 30 days, on how many days did you use [tobacco/nicotine product]?" or "In the past 30 days, which of the following products have you used on at least one day?". Questions concerning HTPs and nicotine pouches were only asked in the 2021 and 2022 surveys (Supplementary Table 2).

Being a current product user was defined as reporting having used the product in the past 30 days. Any use was defined as the current use of at least one nicotine or tobacco product. Dual use was defined as the current use of ≥ 2 nicotine or tobacco products (Chen et al., 2021). Poly use was defined as the current use of ≥ 3 nicotine or tobacco products (Chen et al., 2021). Hence, the difference in prevalence between dual and poly use can be interpreted as prevalence of exclusively dual use, i.e. two products only.

The 12 different tobacco or nicotine products were divided into three mutually exclusive categories based on shared characteristics of the products; (1) Combustible tobacco products: cigarettes, cigars, waterpipe, roll-your-own cigarettes, pipe, bidis; (2) Smokeless tobacco products: chewing tobacco products, snus, dissolvable tobacco products; (3) Novel products: e-cigarettes, HTPs, nicotine pouches. Lastly, we created a subcategory of noncombustible products by combining smokeless products with novel products.

We additionally examined four categories of dual use: (1) dual use of at least one combustible product and at least one smokeless product, (2) dual use of at least one combustible product and at least one novel product, (3) dual use of at least one smokeless product and at least one novel product, and (4) dual use of at least one combustible product and at least one noncombustible product.

2.3. Covariates

Based on the variables and categorization used by the CDC (Gentzke et al., 2022), as well as the methodology used in previous studies (Jebai et al., 2023), the sociodemographic variables used in this study included sex (male or female), school level (middle [6th-8th grade] or high school [9th-12th grade]), and race and ethnicity. Race and ethnicity were ascertained through two NYTS questions: "What race or races do you consider yourself to be?" and "Are you Hispanic, Latino, Latina, or of Spanish origin?". These two questions were recoded into four groups (non-Hispanic White, non-Hispanic Black, Hispanic, and non-Hispanic or other race). "Other race" included American Indian or Alaska Native, Asian, and Native Hawaiian or Other Pacific Islander. Hispanic included Mexican, Mexican American, Chicano, or Chicana, Puerto Rican, Cuban, and Another Hispanic, Latino, Latina, or Spanish origin. Missing data on race/ethnicity were included as a separate category in our regression analyses.

2.4. Statistical analysis

NYTS datasets from 2011 to 2022 were pooled to explore trends and patterns of nicotine and tobacco product use overtime. The prevalence of different types and combinations of nicotine and tobacco products use during the study period are presented as weighted point estimates with 95 % confidence intervals (CIs). All analyses were performed with Stata (version 17.0). Sampling weights, survey strata, and primary sampling units were considered for all analyses in this study to account for the complex survey design.

Adjusted prevalence ratios of different patterns of dual and poly use were estimated using Poisson regression analysis, which accounted for the complex sampling design and sampling weights. The year 2016 was

Table 1

Selected Sample Characteristics of United States adolescents in NYTS in 2011, 2016, and 2022.

	2011	2016	2022
Sample size	18,866	20,675	28,291
	N (Weighted %)		
Sex (N,%)			
Male	9,284(51.0)	10,438(50.6)	14,375 (51.1)
Female	9,315(49.0)	10,082(49.4)	13,692 (49.0)
School level (N,%)			
Middle school	8,880(43.3)	9,658(44.2)	12,041 (43.8)
High school	9,720(56.7)	10,897(55.8)	16,118 (56.2)
Race and ethnicity (N,%)			
Non-Hispanic White	7,394(55.9)	8,818(52.9)	12,871 (51.3)
Non-Hispanic Black	3,727(15.7)	3,539(13.7)	3,984 (14.4)
Hispanic [§]	4,908(15.7)	3,933(16.6)	5,123 (18.0)
Non-Hispanic and other race	1,943(9.0)	2,842(10.0)	5,139 (12.1)
Missing	894(3.7)	1,543(6.9)	1,174 (4.1)

Note:

[§] Hispanic persons could be of any race. Race includes White, Black, American Indian, or Alaska Native, Asian, and Native Hawaiian or Other Pacific Islander.

used as the reference year, but an additional analysis was performed using 2022 as the reference year to directly compare 2021 with 2022. The final specification of the regression models was guided by previous literature on the topic (Dai & Leventhal, 2023), likelihood ratio tests (LRT) and consideration of the Akaike information criterion (AIC). We modeled time as a categorical variable (in calendar years) to account for the temporal trends. Models were additionally adjusted for race and ethnicity, sex, and school level.

2.5. Ethical approval

As NYTS datasets are publicly available with de-identified information, this study did not require approval from an ethics committee.

3. Results

The study sample consisted of 242,637 respondents, of whom 48.9 % were female, 43.9 % middle-school students, 53.1 % non-Hispanic Whites, 14.9 % non-Hispanic Blacks, 16.1 % Hispanics, and 10.7 % non-Hispanic and other race (Table 1, Supplementary Table 3).

From 2011 to 2022, the prevalence of use of the assessed products varied both over time and by product (Supplementary Tables 4 and 5, Supplementary Figs. 1 and 2). The prevalence for both dual and poly use had a slightly variable but overall decreasing trend between 2011 and 2021, with use of at least two products declining from 9.5 % (95 % CI:8.3–10.8) in 2011 to 2.8 % (95 % CI:2.3–3.3) in 2021, and poly use of at least three products declining from 5.1 % (95 % CI:4.4–6.0) in 2011 to 1.1 % (95 % CI:0.8–1.4) in 2021 (Fig. 1, Supplementary Table 6). For both dual and poly use, an increase in prevalence was observed between 2021 and 2022, with dual use prevalence at 3.7 % (95 % CI:3.0–4.5) and poly use prevalence at 1.7 % (95 % CI:1.4–2.1) in 2022.

The combinations of dual use we examined presented variable prevalence trends over time (Fig. 1, Supplementary Table 7). The prevalence of dual use of at least one combustible and at least one smokeless product showed a consistent decline from 4.0 % (95 % CI:3.3–4.7) in 2011 to 0.7 % (95 % CI:0.6–0.9) in 2022. In contrast, dual use of smoking and novel products increased from 0.9 % (95 % CI:0.6–1.1) in 2011 to 6.8 % (95 % CI:6.0–7.7) in 2015, reached another

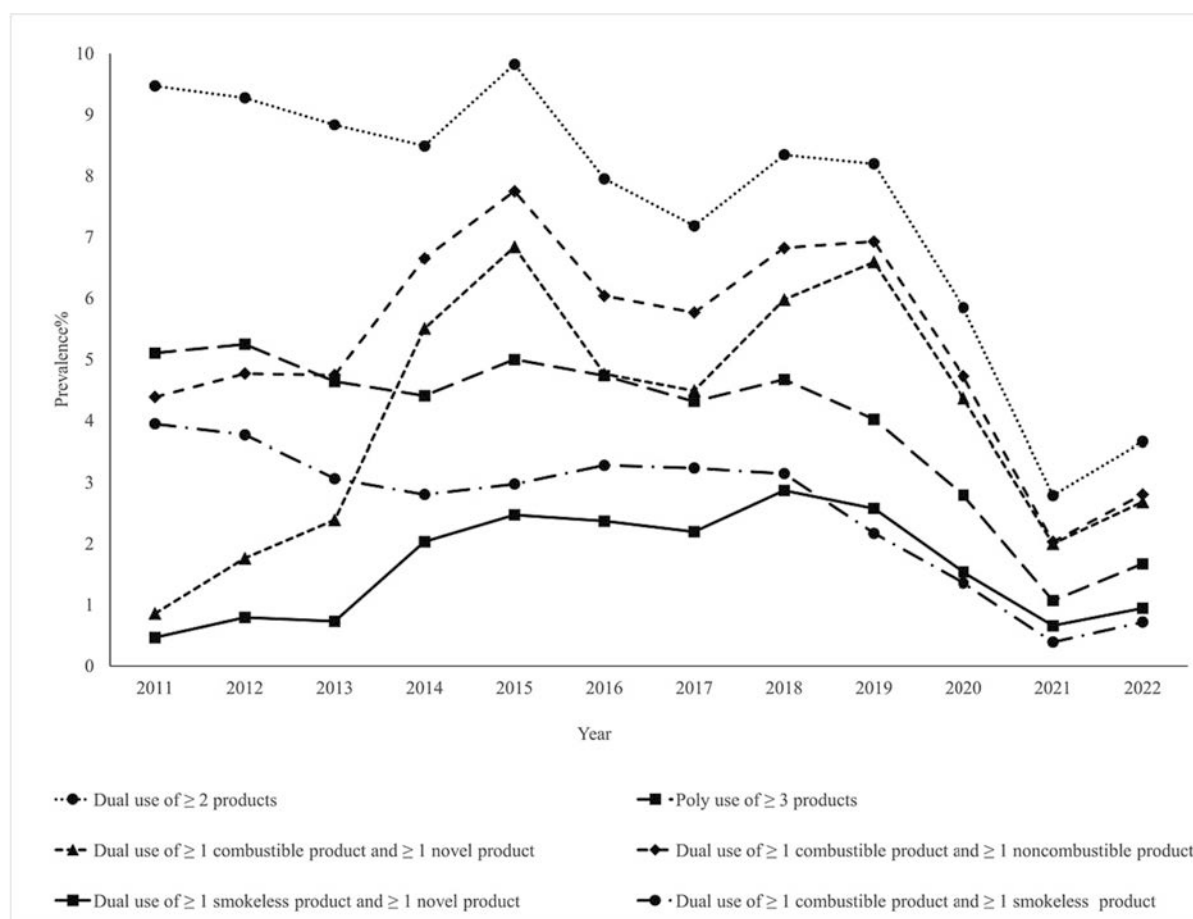


Fig. 1. Trends in the prevalence of dual and poly nicotine or tobacco product use among adolescents in the United States from 2011 to 2022 in the NYTS (N = 242,637).

peak in 2019 at 6.6 % (95 % CI:5.8–7.6) and dropped to a low of 2.0 % in 2021 (95 % CI:1.7–2.4). These temporal trends are also reflected in the prevalence of dual use of combustible and noncombustible products, which was at 4.4 % (95 % CI:3.7–5.2) in 2011, 7.8 % (95 % CI:6.9–8.8) in 2015 and 2.8 % (95 % CI:2.3–3.5) in 2022. Dual use of at least one smokeless and at least one novel product remained quite low from 2011 (0.5 %, 95 % CI:0.3–0.7) to 2022 (1.0 %, 95 % CI:0.7–1.2), although it reached a high of 2.9 % (95 % CI:2.4–3.4) in 2018.

Fig. 2 presents the prevalence of dual and poly use stratified by race/ethnicity. In 2011, Hispanic respondents had the highest prevalence of dual product use (11.2 %, 95 % CI:10.0–12.5), followed by non-Hispanic White (9.8 %, 95 % CI:8.0–11.8), non-Hispanic and other races (9.5 %, 95 % CI:7.7–11.7), and non-Hispanic Black (7.2 %, 95 % CI:5.7–9.0). Dual use patterns remained similar in 2016 for all racial and ethnic groups, decreasing marginally from 2011. By 2022, dual use had decreased substantially for all groups and racial differences between the different categories narrowed. The group with the highest prevalence of dual use in 2022 was non-Hispanic Black (4.5 %, 95 % CI:3.4–6.0), followed by non-Hispanic White (3.9 %, 95 % CI:3.0–4.9). The picture was similar for poly use, with Hispanic respondents (6.6 %, 95 % CI:5.9–7.5) having had the highest prevalence in 2011, followed by non-Hispanic White (5.3 %, 95 % CI:4.2–6.5), non-Hispanic and other race (5.1 %, 95 % CI:3.8–6.9) and non-Hispanic Black (3.2 %, 95 %

CI:2.4–4.3). By 2022, the prevalence of poly use remained highest among Hispanic adolescents (2.0 %, 95 % CI: 1.4–2.9), followed by non-Hispanic White (1.7 %, 95 % CI: 1.3–2.3), non-Hispanic Black (1.6 %, 95 % CI: 1.1–2.3), and non-Hispanic and other race (1.1 %, 95 % CI: 0.6–1.8).

Poisson regression analyses largely confirmed the findings from the descriptive analyses (Table 2). Compared to the reference year of 2016 (mid-point of our study period), the adjusted prevalence ratio (PR) for dual use was highest in 2015 (PR = 1.23, 95 % CI:1.04–1.44) and lowest in 2021 (PR = 0.35, 95 % CI:0.28–0.44). Regarding poly use, no year had a statistically significantly higher PR compared to 2016; the lowest PR was observed in 2021 (PR = 0.23, 95 % CI:0.17–0.31). Our analysis using 2022 as the reference year indicated a statistically significant increase from 2021 to 2022 in dual and poly product use, (PR = 0.77, 95 % CI:0.60–0.99; PR = 0.66, 95 % CI:0.47–0.91 respectively) (Supplementary Table 8). Compared to non-Hispanic White adolescents, non-Hispanic Black and non-Hispanic and other race adolescents were less likely to engage in dual and poly product use. Hispanic adolescents were more likely engage in poly-product use (PR = 1.11, 95 % CI:1.02, 1.20). Males, compared to females, and high-school students, compared to middle-school students had statistically significantly higher PR for both dual and poly use.

Males, non-Hispanic Whites and those in high school were more

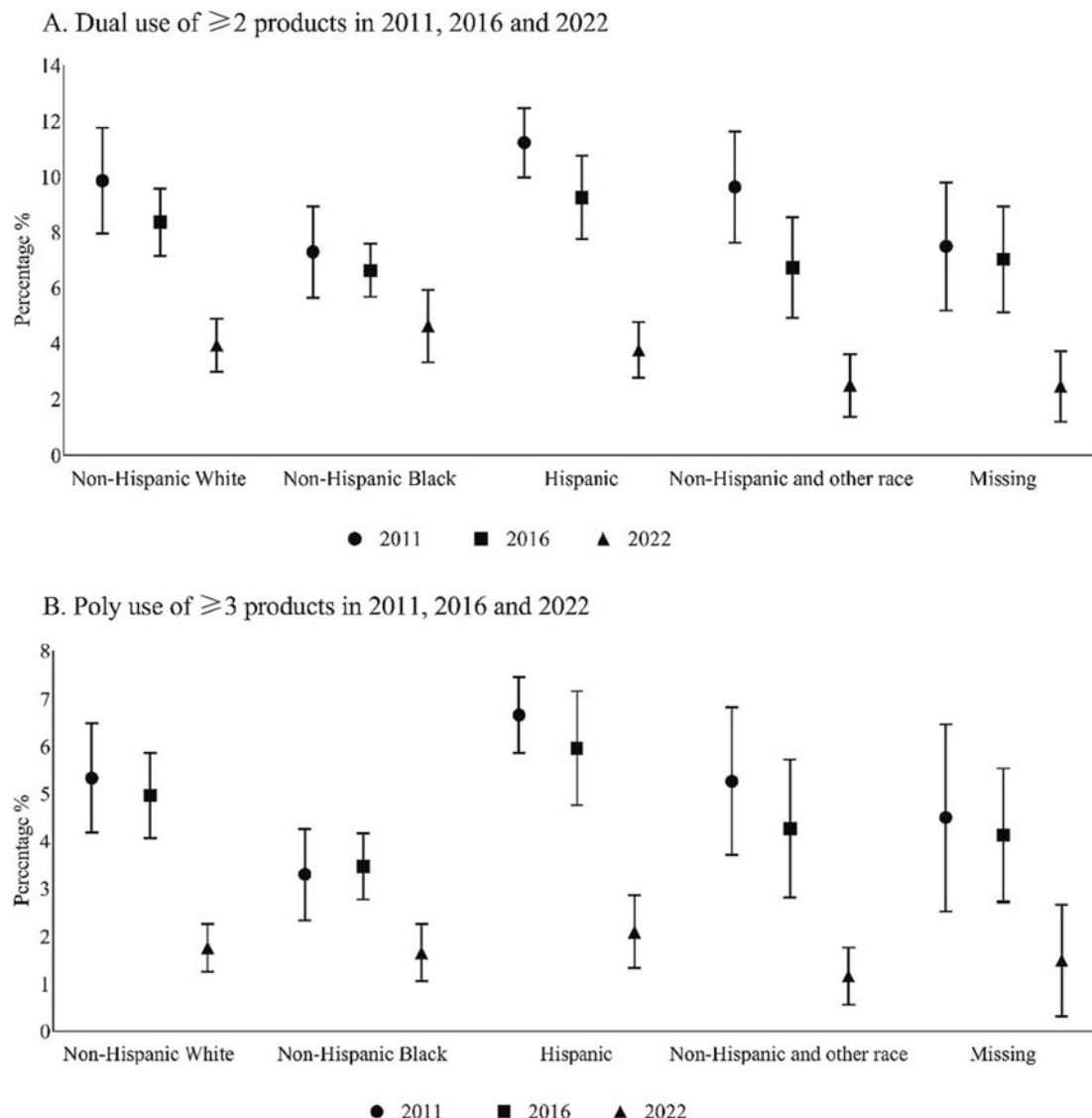


Fig. 2. Trends of dual (A) and poly (B) nicotine or tobacco product use stratified by race and ethnicity in 2011, 2016, and 2022 in the NYTS (N = 242,637).

Table 2

Association between sociodemographic factors and dual and poly use in the NYTS, 2011–2022.

	Dual use of ≥ 2 products. PR (95 % CI)	Poly use of ≥ 3 products. PR (95 % CI)
Year		
2011	1.18 (1.00–1.40)	1.07 (0.87–1.32)
2012	1.17 (0.99–1.37)	1.11 (0.91–1.35)
2013	1.11 (0.95–1.30)	0.98 (0.80–1.20)
2014	1.07 (0.91–1.26)	0.94 (0.77–1.15)
2015	1.23 (1.04–1.44) *	1.05 (0.85–1.29)
2016	1 (Ref.)	1 (Ref.)
2017	0.89 (0.73–1.08)	0.88 (0.69–1.13)
2018	1.04 (0.88–1.23)	0.98 (0.79–1.21)
2019	1.03 (0.85–1.23)	0.84 (0.66–1.08)
2020	0.73 (0.59–0.91) *	0.59 (0.45–0.77) *
2021	0.35 (0.28–0.44) *	0.23 (0.17–0.31) *
2022	0.45 (0.36–0.56) *	0.34 (0.27–0.44) *
Race and ethnicity		
Non-Hispanic White	1 (Ref.)	1 (Ref.)
Non-Hispanic Black	0.77 (0.72–0.83) *	0.65 (0.59–0.72) *
Hispanic [§]	1.04 (0.98–1.11)	1.11 (1.02–1.20) *
Non-Hispanic and other race	0.84 (0.78–0.91) *	0.87 (0.78–0.96) *
Missing	0.85 (0.78–0.93) *	0.88 (0.78–0.99) *
Sex		
Male	1 (Ref.)	1 (Ref.)
Female	0.66 (0.63–0.68) *	0.55 (0.52–0.58) *
School level		
Middle school	1 (Ref.)	1 (Ref.)
High school	3.43 (3.21–3.66) *	3.26 (2.99–3.54) *

Note: Poisson regression models adjusted for year, race and ethnicity, sex, and school level. PR: Prevalence Ratio. CI: confidence interval. Ref: reference category.

* $p < 0.05$.

§ Hispanic persons could be of any race.

likely than their peers to report each of the combinations of dual use we assessed, controlling for all other factors (Table 3). In these adjusted models, we found that, compared to the reference year of 2016, the PRs for all combinations were the lowest in 2021. The PR for dual use was highest for combustible and novel products in 2018 (PR = 1.19, 95 %

CI:0.93–1.52), for combustible and smokeless products in 2015 (PR = 1.43, 95 % CI:1.22–1.67), and for combustible and noncombustible products in 2015 (PR = 1.27, 95 % CI:1.08–1.50).

Table 3

Adjusted prevalence ratios (PR) (estimated using Poisson regression) and respective 95 % confidence intervals (95 % CI) in the analysis of the sociodemographic factors associated with dual product use in the NYTS, 2011–2022.

	≥ 1 smokeless product and ≥ 1 novel product. PR (95 % CI)	≥ 1 combustible product and ≥ 1 novel product. PR (95 % CI)	≥ 1 combustible product and ≥ 1 smokeless product. PR (95 % CI)	≥ 1 combustible product and ≥ 1 noncombustible product. PR (95 % CI)
Year				
2011	1.20 (0.94–1.53)	0.20 (0.14–0.29) *	0.18 (0.14–0.25) *	0.72 (0.59–0.89) *
2012	1.15 (0.91–1.44)	0.33 (0.25–0.43) *	0.37 (0.30–0.46) *	0.79 (0.65–0.95) *
2013	0.92 (0.71–1.21)	0.30 (0.23–0.41) *	0.50 (0.41–0.61) *	0.78 (0.64–0.95) *
2014	0.87 (0.68–1.12)	0.87 (0.67–1.14)	1.16 (0.97–1.39)	1.11 (0.93–1.31)
2015	0.89 (0.68–1.16)	1.03 (0.81–1.31) *	1.43 (1.22–1.67) *	1.27 (1.08–1.50) *
2016	1 (Ref.)	1 (Ref.)	1 (Ref.)	1 (Ref.)
2017	0.94 (0.71–1.26)	0.88 (0.66–1.17)	0.92 (0.74–1.13)	0.93 (0.75–1.15)
2018	0.94 (0.73–1.20)	1.19 (0.93–1.52) *	1.25 (1.05–1.47) *	1.12 (0.94–1.33)
2019	0.65 (0.48–0.88) *	1.06 (0.79–1.43)	1.38 (1.15–1.65) *	1.14 (0.95–1.37)
2020	0.41 (0.30–0.56) *	0.64 (0.47–0.88) *	0.91 (0.72–1.14) *	0.78 (0.62–0.97) *
2021	0.12 (0.08–0.18) *	0.27 (0.19–0.40) *	0.41 (0.33–0.52) *	0.33 (0.26–0.42) *
2022	0.21 (0.15–0.27) *	0.39 (0.29–0.51) *	0.55 (0.44–0.69) *	0.45 (0.36–0.57) *
Race and ethnicity				
Non-Hispanic White	1 (Ref.)	1 (Ref.)	1 (Ref.)	1 (Ref.)
Non-Hispanic Black	0.49 (0.43–0.56) *	0.47 (0.40–0.56) *	0.71 (0.64–0.78) *	0.64 (0.58–0.70) *
Hispanic [§]	0.97 (0.88–1.07)	0.86 (0.75–0.98) *	1.04 (0.96–1.14)	1.00 (0.93–1.08)
Non-Hispanic and other race	0.83 (0.74–0.94) *	0.77 (0.67–0.88) *	0.81 (0.74–0.90) *	0.82 (0.75–0.90) *
Missing	0.81 (0.69–0.95) *	0.68 (0.55–0.82) *	0.78 (0.68–0.89) *	0.81 (0.72–0.91) *
Sex				
Male	1 (Ref.)	1 (Ref.)	1 (Ref.)	1 (Ref.)
Female	0.37 (0.34–0.40) *	0.33 (0.30–0.37) *	0.73 (0.69–0.78) *	0.63 (0.6–0.66) *
School level				
Middle school	1 (Ref.)	1 (Ref.)	1 (Ref.)	1 (Ref.)
High school	3.31 (2.99–3.66) *	3.51 (3.11–3.96) *	3.45 (3.15–3.77) *	3.37 (3.12–3.64) *

Note: Poisson regression models adjusted for year, race and ethnicity, sex, and school level. PR: Prevalence Ratio. CI: confidence interval. Ref: reference category.

* $p < 0.05$.

§ Hispanic persons could be of any race.

4. Discussion

Our study found a decline in the prevalence of dual and poly-nicotine and tobacco product use from 2011 to 2021, followed by a slight increase in 2022. Of the four combinations of dual use examined, the most common was a combustible product paired with a novel product. Across all racial groups, there was a decreasing trend in dual and poly product use over the study period, which was more pronounced for dual use. Additionally, males, high school students, and non-Hispanic Whites were more likely to engage in dual and poly-nicotine or tobacco product use. Despite these overall trends, our analysis showed variation in both prevalence and trends over time for different combinations of products.

The observed decreasing prevalence of dual and poly product use aligns with findings from other US studies and can likely be attributed to effective tobacco control policies, such as increased taxes, advertising bans, and preventative education implemented over the past few decades (Barrington-Trimis et al., 2020; Cook et al., 2023; Jebai et al., 2023; WHO, 2023). This decline might also be partly due to the general denormalization of nicotine and tobacco products, making them less enticing to young people.

Nevertheless, there has been a noticeable, albeit small, uptick in dual and poly product use between 2021 and 2022. While this rise might represent a temporary fluctuation within a broader decreasing trend, especially considering the steep decline from 2019 to 2021, it may potentially indicate the beginning of an increase in dual and poly use. One factor that might contribute to this trend is the growing popularity of e-cigarettes and other novel products (Ali et al., 2023). Prior to 2021, the surveys were not capturing the use of HTPs and nicotine pouches. With the inclusion of specific questions about these products in the NYTS from 2021, a more accurate representation of their use could be a reason behind changing estimates of dual and poly use. However, it is important to note that no new questions were added in 2022, suggesting that the observed increase between 2021 and 2022 cannot be attributed to changes in the survey. It is additionally possible that the COVID-19 pandemic impacted the observed decrease from 2019 to 2021 due to fewer social gatherings, economic downturn, or fear of nicotine or tobacco products contributing to more severe COVID-19 infection (Macy et al., 2013; Almeda & Gómez-Gómez, 2022). Schools reopening and eased pandemic restrictions could therefore have contributed to the uptick in dual and poly use from 2021 to 2022. These observations underscore the need for closer monitoring of nicotine and tobacco product use trends and patterns among adolescents and young adults.

We found that combining traditional cigarettes with novel products was consistently the most common type of dual use, which is a consistent finding in past studies, regardless of variations in definitions and analytical approaches (Cook et al., 2023; Jebai et al., 2023; Tashakkori et al., 2023). In 2022, the higher prevalence of dual and poly use, compared to the previous year, was driven by increases in the prevalence of e-cigarettes, HTPs, and nicotine pouches, confirming their major role in the US market. However, the impact of these novel products may vary due to differing availability and popularity. For instance, a patent dispute has limited the market availability of HTP product IQOS, making them a less accessible option (Philip Morris Products S.A. v. International Trade Commission, 2023). Conversely, e-cigarettes, popular among adolescents, are likely the primary driver for the increase of dual and poly product use (Park-Lee et al., 2022).

A systematic review from 2018 found that e-cigarette use increases the odds of smoking initiation and current smoking (Khouja et al., 2020), and similar concerns could be raised about other nicotine-containing novel products. While findings on this association are mixed and further research is needed, previous studies suggest a potential pathway of nicotine addiction where non-tobacco-using adolescents initiate tobacco use following exposure to nicotine through e-cigarette use (Jackson et al., 2021; Khouja et al., 2020; Soneji et al., 2017). This exposure may also lead them to experiment with other tobacco products, potentially becoming dual or poly users (Jackson et al.,

2021; Soneji et al., 2017). Despite the decline in cigarettes and other smoking tobacco use among US adolescents, the variety of different products on the market presents new challenges for addiction prevention and raises concerns about current regulations to effectively prevent their use by young people.

This point is clearly illustrated by the emergence of nicotine pouches in the US market, on top of a number of existing smokeless tobacco products (Kramer et al., 2023). These flavored tobacco-free alternatives were shown to be appealing and, hence, are highly popular among young people (Tosakoon et al., 2023). Their dual use allows smokers to use nicotine in places where smoking is not permitted (Dai & Leventhal, 2023; Timberlake et al., 2011), thus potentially undermining the effectiveness of tobacco control policies, such as smoke-free environments. Not surprisingly, concurrent use of smoking and smokeless products was commonly reported in our analysis.

However, prevalence and trends of use were not uniform across the sample. The proportion of non-Hispanic White and non-Hispanic Black adolescents reporting dual and poly product use decreased each year from 2011 to 2022. This finding is consistent with a study using Monitoring the Future survey data from 1991 to 2019 (Meza et al., 2020). Despite the decreasing trend of use among non-Hispanic Black adolescents, we found the highest rates of dual use alternated between Hispanic and non-Hispanic Black adolescents during the study period. This could be explained by the tobacco industry's targeted advertising towards low-income communities in the US, which are predominantly non-White (Poverty Rate by Race and Ethnicity U.S. 2022 | Statista, 2023; Rodriguez et al., 2012; Lee et al., 2017). However, our analysis of the association between sociodemographic factors and dual and poly product use indicated non-Hispanic White males were most susceptible to dual use. This finding was in line with research that has suggested White adolescents tend to use tobacco products more than other ethnic/racial groups, possibly due to greater accessibility and economic resources (HHS, 2017). Preventive measures and reinforcement of regulations are vital in tackling dual and poly-use among adolescents of vulnerable sociodemographic groups. More in-depth analysis of the various product combinations across race/ethnicity and of the ways these contribute to dual and poly use would provide further insights with important implications for tobacco control in the US.

5. Strengths and limitations

This study utilized a nationally representative dataset spanning from 2011 to 2022. This timeframe covers the introduction of e-cigarettes and later of HTPs and nicotine pouches to the US market, which also captures legislative shifts around novel products and the period of the COVID-19 pandemic. Our comprehensive analysis builds upon previous studies by extending the range of both the study period and the types of products included. The NYTS uses self-reporting, which may be subject to recall and reporting bias. However, survey questions were mostly consistent over time, allowing us to capture changes in prevalence, although there was some minor variation in the wording between years.

Our study did not measure the extent of product use. However, previous studies have found higher nicotine dependence among poly product users relative to dual and single product users, supporting the plausibility of heavier use among multiple product users (Ali et al., 2016; Apelberg et al., 2014). Similarly, defining product use as any use in the past 30 days may capture experimentation and not regular use, potentially overestimating the number of product users. Furthermore, the COVID-19 pandemic led to a reduced NYTS sample size in 2020 and a hybrid method of administration in schools and at home in 2021 and 2022. Thus, data post-2020 may not be directly comparable to previous years. Nevertheless, the consistency in data collection between 2021 and 2022 suggests that the observed increase in prevalence in 2022 could reflect actual behavioral changes. Lastly, the sample in this study was drawn from a school-based population and did not include adolescents who were home-schooled or who have dropped out, which may have

affected the generalizability of our findings beyond this population.

6. Conclusion

Our analysis investigated dual and poly-nicotine and tobacco product use among US adolescents across a decade, revealing a concerning increase from 2021 to 2022. The most common combination was the concurrent use of smoking and novel products. The higher risks of dual and poly product use were notably linked to non-Hispanic White and male students, underscoring the need for targeted tobacco control strategies, particularly to counteract the tobacco industry's aggressive marketing targeting youth demographics and to tackle multiple product use and nicotine addiction among adolescents.

CRedit authorship contribution statement

Baihui Y. Zhang: Formal analysis, Methodology, Writing – original draft preparation. **Olivia S. Bannon:** Writing – review & editing. **Daniel Tzu-Hsuan Chen:** Methodology, Supervision. **Filippos T. Filippidis:** Conceptualization, Methodology.

All authors reviewed the manuscript, provided comments, and approved the final version. All the authors were involved in the interpretation of data and revision for critical intellectual input.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. This project has received funding from the European Union's Horizon 2020 Research and Innovation program under the Marie Skłodowska-Curie Grant Agreement No 101008139 (EUREST-RISE).

Data availability

The dataset analyzed in this study is publicly available and can be downloaded at CDC website: https://www.cdc.gov/tobacco/data_statistics/surveys/nyts/data/index.html

Appendix A. Supplementary material

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.addbeh.2024.107970>.

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