OPEN ACCESS

Patterns of poly tobacco use among adults in the Population Assessment of Tobacco and Health (PATH) study, 2013–2017: a multistate Markov transition analysis

Fatema Shafie Khorassani ,[1] Andrew F Brouwer ,[2] Jana L Hirschtick,[2] Jihyoun Jeon,[2] Evelyn Jimenez-Mendoza,[2] Rafael Meza ,[2] Nancy L Fleischer [2]

► Additional supplemental material is published online only. To view, please visit the journal online (http://dx.doi.org/10.1136/tc-2022-057822).

[1]Biostatistics, University of Michigan School of Public Health, Ann Arbor, Michigan, USA
[2]Epidemiology, University of Michigan School of Public Health, Ann Arbor, Michigan, USA

Correspondence to
Fatema Shafie Khorassani, University of Michigan School of Public Health, Ann Arbor, Michigan, USA; fshafie@umich.edu

Received 2 November 2022
Accepted 4 April 2023

ABSTRACT

Background A better understanding of sociodemographic transition patterns between single, dual and poly tobacco product use may help improve tobacco control policy interventions.

Methods HRs of transition between never, non-current (no past 30-day use), cigarette, e-cigarette, other combustible, smokeless tobacco (SLT), dual and poly tobacco use states in adults were estimated for age, sex, race/ethnicity, education and income using a multistate model for waves 1–4 of the Population Assessment of Tobacco and Health study (2013–2017), a US-based cohort study, accounting for complex survey design.

Results Sole cigarette and SLT use were persistent, with 77% and 78% of adults continuing use after one wave. Other use states were more transient, with 29%–48% of adults reporting the same pattern after one wave. If single-product users transitioned, it was most likely to non-current use while dual or poly cigarette users were most likely to transition to exclusive cigarette use. Males were more likely than females to initiate combustible product use after a history of no use, and after a period of tobacco use cessation. Hispanic and non-Hispanic black participants initiated cigarette use at higher rates than non-Hispanic white participants, and had higher rates of experimentation with tobacco products between study waves. Lower socioeconomic status was associated with higher rates of transition into combustible tobacco use.

Conclusions Dual and poly tobacco use is largely transient, while single-use patterns are more stable over time. Transitions differ by age, sex, race/ethnicity, education and income, which may influence the impact of current and future tobacco control efforts.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Existing research on transition rates between product use categories that have not considered longitudinal trends or differences by sociodemographic factors.

WHAT THIS STUDY ADDS

⇒ Rates of transition between 11 use categories in a longitudinal cohort study.
⇒ Differences by sociodemographic factors.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Explaining mechanisms of transition between tobacco use categories.
⇒ Directing policies to populations most significantly impacted.

INTRODUCTION

Although cigarette smoking prevalence has nearly halved in the past 50 years, tobacco use remains the leading preventable cause of disease and premature death in the USA and globally.[1 2] In recent years, the landscape of tobacco use has drastically changed with changes in the availability, marketing and diversity of tobacco products.[3] Over 35% of the US adult population that uses tobacco products, representing 10% of the US adult population, report regularly using more than one tobacco or nicotine product, including cigarettes, e-cigarettes, hookah, cigars and other products.[3 4] Researchers are working to understand how the use of multiple tobacco products impacts smoking cessation,[5–8] nicotine addiction[9] and future tobacco product use.[10–13] Some studies examined transition rates of dual and poly tobacco use (three or more tobacco products) over time[14–21] and the factors associated with single, dual and poly tobacco use.[22–24]

People who use multiple tobacco products tended to have higher nicotine dependence and lower quit intentions than people who use single tobacco products.[23 25] Additionally, as different tobacco products are associated with varying health risks,[26] there may be differences in health outcomes associated with dual and poly use compared with single product use. There is evidence that people who use cigarettes plus additional tobacco products have a higher estimated mortality risk than people who only smoke cigarettes.[27]

Additionally, identifying sociodemographic disparities in the transition rates in and out of dual and poly tobacco use is important for public health intervention. Previous research has shown disparities in the use of certain tobacco products and their related health outcomes based on age, sex, race/ethnicityand socioeconomic status (SES).[28–31] Studying transition rates between tobacco use states by sociodemographic factors can help identify disparities in patterns of use, which may be contributing to the underlying causal mechanisms behind the observed disparities in health outcomes.

Prior work with nationally representative cross-sectional surveys has analysed the prevalence of

Check for updates

To cite: Shafie Khorassani F, Brouwer AF, Hirschtick JL, *et al*. *Tob Control* Epub ahead of print: [*please include* Day Month Year]. doi:10.1136/tc-2022-057822

dual and poly tobacco product use over time.[16 18 32 33] However, the cross-sectional nature of these studies does not permit the study of individual-level tobacco use patterns over time, which requires longitudinal data. The Population Assessment of Tobacco and Health (PATH) study, a longitudinal study on tobacco use, was launched by the National Institutes of Health (NIH) and Food and Drug Administration (FDA) to inform FDA policies.[34] Prior work has provided empirical estimates of transition probabilities between poly tobacco use states with the PATH data.[35–38] But these studies have not taken full advantage of the longitudinal nature of the data by using Markov multistate transition modelling to develop an understanding of the underlying transition rates and differences in transition rates by sociodemographic characteristics. In recent years, the Markov multistate framework has been used in the tobacco control field to analyse transition rates between tobacco use categories.[17 39–41] However, this approach has not yet been used to examine poly tobacco use transitions.

The goal of this study is to apply the Markov multistate transition modelling framework to the PATH data to estimate transition rates between single, dual and poly tobacco use categories in a representative US adult population, and to consider whether those rates differ by age, sex, race/ethnicity, education and income.

METHODS

Study population

The PATH study is a nationally representative longitudinal cohort study of tobacco use among the civilian, non-institutionalised US population aged 12 years and older.[34] The first four waves of data were collected from 2013 to 2017 using a complex survey sample design. Young adults (aged 18–24 years), non-Hispanic (NH) black people and people who use tobacco were oversampled, and so survey weights adjust for oversampling and nonresponse.[34] Each wave follows the population forward through time to assess changes in their tobacco use behaviours. Additional details on PATH methodology are available elsewhere.[34]

For this paper, we studied adults (aged 18 years and over) who participated in all of the first four waves of PATH since only those participants have an all-wave longitudinal weight available (26 072 out of a total of 44 107 observations), using the public use files of PATH. In each wave, participants were asked detailed questions about their tobacco product use using Audio Computer-Assisted Self-Interviewing. We assigned each participant to single, dual or poly tobacco use states in each wave based on their current use of cigarettes, e-cigarettes (inclusive of electronic nicotine delivery systems), other combustible products (OC, ie, traditional cigars, filtered cigars, cigarillos, pipes, hookah) and smokeless tobacco (SLT). We considered 11 tobacco use categories: (1) never use; (2) non-current tobacco use; single product use of (3) cigarettes, (4) e-cigarettes, (5) OC or (6) SLT; dual product use of (7) cigarettes and e-cigarettes, (8) cigarettes and OC or (9) cigarettes and SLT; and poly tobacco use including (10) use of cigarettes and at least two other product groups or (11) dual/poly product use without cigarettes. Never use was defined as never having an established cigarette use pattern (used >100 cigarettes in their lifetime) and never having used any other tobacco products. Non-current use was defined as ever having an established cigarette use pattern or ever having used any other tobacco product every day or some days but reporting no current use of any tobacco products. Current use was defined as ever having an established cigarette use pattern and currently using cigarettes every day or some days for cigarettes, or use of any other tobacco product every day or some days for other products. The established use definition was applied only for cigarettes to allow us to capture patterns of experimentation with other products.

We also used information on age (18–24, 25–34, 35–54, 55–90 years), sex (male, female), race and ethnicity (NH white, NH black, Hispanic, NH other race; determined from PATH-defined variables of race (white only, black only or other (including multiracial, American Indian or Alaska Native, Asian, Native Hawaiian or other Pacific Islander)) and ethnicity (Hispanic origin indicator)), educational attainment (less than high school (HS), high school or equivalent such as the General Education Development tests (HS/GED), some college or associate's degree (some college), bachelor's degree or higher; educational attainment was defined only for ages ≥25 years as younger individuals would likely still be in the education attainment process, and individuals aged <25 years were excluded when fitting models that included education) and total household income (<US$25 000, US$25 000–US$50 000, >US$50 000; consistent with prior work[39] and approximate tertiles of the study population). We used PATH imputations of missing sex, race and ethnicity values when available. After removing missing data and participants who had only one tobacco state observation throughout the study, we analysed 24 336 participants with 92 500 total observations and 17 351 total transitions. Participant weights were multiplied by the ratio of the number of the final sample size divided by the total of their representative survey weights, which normalises the existing PATH weights to the smaller study sample size to account for excluding participants with only one tobacco state observation.

Statistical analysis

Transition modelling

As a descriptive analysis, we calculated empirical transition rates by weighting the observed number of transitions using the all-waves longitudinal weights. We then used a Markov multistate transition model to estimate the transition hazard rates between the 11 states. A Markov multistate transition model is a continuous-time, finite-state stochastic process that assumes the probability of transition depends only on the current use state and not the past trajectory of use.[39] In the continuous-time model, participants are allowed to transition at any point in time, but we only observe each participant's state at discrete times, that is, at every wave of data collection. The times of these individual transitions are not directly estimated; instead, we estimate which values of the instantaneous rate of transitioning from one state to another are most consistent with the actual, observed states. Additional details about the continuous-time multistate models are available elsewhere.[39]

To estimate transition rates between the tobacco use categories, we used the weighted multistate model (wmsm) package in R,[39] which was adapted from Markov multistate transition modelling R package, msm[42] and is available at https://tcors.umich.edu/Resources.php. The weighted multistate model incorporates sample weights and replicate weights, accounting for the complex survey design of the PATH study, to provide unbiased point estimates and variances.

Transition rates may differ by sociodemographic groups. To evaluate these potential differences, we determined the transition HRs by age group, sex, race/ethnicity, education and income level for each transition of interest by fitting univariable multistate transition models and estimating the HRs of each transition for each covariate subgroup. For each univariable multistate

transition model, we excluded subjects that were missing that variable.

Model reduction

Some unlikely transitions, chosen through discussions with the research team, were disallowed from our model a priori. We disallowed direct, instantaneous two-step transitions (eg, transitions from (1) never or former use to dual or poly tobacco use, (2) single product use to poly product use or (3) one single product to a different single product, without first transitioning through a dual use state). We allowed transitions from any category to former use, since any type of cessation, even directly from two or more products to none, was of particular interest to us. Model reduction improved the computational efficiency and stability of our estimates by eliminating the need to estimate negligible transitions, thereby reducing the number of required parameters in the model while still allowing transitions between any two states through unobserved intermediary states. The model still allows participants to make any transition within one wave but only by first transitioning through at least one other unobserved state; for example, transitioning from never use (observed) to single product use (unobserved) then dual product use (observed) over the course of one wave. We compared our reduced model with a full model allowing all transitions using a Schwarz Information Criterion[39] and confirmed that we did not lose important information by reducing the model. The reduced model is provided in the online supplemental figure 1.

RESULTS

Sociodemographic characteristics of the study participants, along with the population-level percentage estimates, are provided in table 1.

Table 1 Descriptive characteristics of study population

		N	%
Total		24 336	
Sex	Female	11 087	50
	Male	10 196	46
	Missing	3053	3
Age group (years)	18–24	5740	13
	25–34	4161	17
	35–54	6698	34
	55+	4682	33
	Missing	3055	3
Race ethnicity	Hispanic	3708	15
	NH black	3139	11
	NH other	1530	7
	NH white	12 570	62
	Missing	3389	5
Education*	College or more	4126	11
	HS degree/GED	4158	28
	Less than HS	2038	28
	Some college	5152	29
	Missing	3122	4
Income (US$)	<25 000	8328	29
	25 000–50 000	4447	20
	50 000+	6703	38
	Missing	4858	13

Sample size (N) is unweighted, but the percentage (%) is weighted using the PATH wave 4 all-waves longitudinal weights.
*Educational attainment is only defined for participants aged 25 years or over.
HS, high school; NH, non-Hispanic; PATH, Population Assessment of Tobacco and Health.

Transition probabilities

We compared the one-wave transition probabilities between empirical observed estimates with the estimates from our weighted multistate transition model (figure 1). The modelled transition probabilities matched the observed probabilities well, with all modelled probabilities within 3 percentage points of the observed probabilities. When examining the modelled transition probabilities, exclusive cigarette and exclusive SLT use were persistent, with 76.8% (95% CI 75.9 to 77.7) and 77.2% (95% CI 74.5 to 79.9), respectively, of adults with these use patterns maintaining the same pattern after one wave. Other single-product use states were more transient, with <50% of adults maintaining the same use pattern after one wave (in descending order: 46.6% (95% CI 44.5 to 48.7) exclusive OC, 45.7% (95% CI 42.6 to 48.9) exclusive e-cigarette, 39.3% (95% CI 34.5 to 44.0) dual cigarette and SLT, 35.5% (95% CI 33.4 to 37.6) dual cigarette and OC, 32.3% (95% CI 30.1 to 34.5) poly use with cigarette, 29.7% (95% CI 27.7 to 31.8) dual cigarette and e-cigarette and 29.1% (95% CI 26.0 to 32.1) dual or poly use without cigarettes). If adults who used a single product transitioned, it was most likely to non-current use, with 8.2% (95% CI 7.6 to 8.8) from exclusive cigarette use, 26.8% (95% CI 24.0 to 29.6) from exclusive e-cigarette use, 37.9% (95% CI 36.0 to 39.9) from exclusive OC use and 12.9% (95% CI 10.7 to 15.1) from exclusive SLT use after one wave. If adults who used at least one product in addition to cigarettes transitioned after one wave, it was most likely to sole cigarette use, with 46.2% (95% CI 43.9 to 48.5) of dual cigarette and e-cigarette use, 37.7% (95% CI 35.4 to 39.9) of dual cigarette and OC use, 25.9% (95% CI 22.3 to 29.4) of dual cigarette and SLT use and 21.0% (95% CI 19.3 to 22.7) of poly use with cigarettes transitioning. One-wave transitions from dual or poly use without cigarettes likely occurred to a sole non-cigarette product (10.0% to e-cigarettes, 16.4% to OC, 8.6% to SLT) or non-current use (19.2% (95% CI 16.7 to 21.6)). The 95% CI of all of the modelled transition probabilities are available in online supplemental table 1.

Covariate HRs

Figure 2 shows the modelled cumulative probability of transitioning within one wave by sociodemographic factors. To compare the groups, we estimated univariable HRs for each transition, which are provided with their 95% CIs in online supplemental figure 2 and online supplemental table 2. Older age was associated with less transient tobacco use behaviour in general, with lower hazards of transitioning from exclusive cigarette, e-cigarette or SLT use to dual, poly or non-current use than the youngest age group (18–24 years). Compared with participants aged 18–24 years, participants in older age groups had lower hazards of transitioning from exclusive cigarette use to dual cigarettes and e-cigarette use (HR age 55+ years: 0.45, 95% CI 0.33 to 0.62), and from exclusive e-cigarette use to dual or poly use without cigarettes (HR age 25–34 years: 0.28, 95% CI 0.13 to 0.59; HR age 35–54 years: 0.10, 95% CI 0.04 to 0.27; HR age 55+ years : 0.06, 95% CI 0.02 to 0.26). Age was also associated with the hazard of adding cigarette use to exclusive e-cigarette use, with adults aged 55 years and over having a lower hazard of transitioning from exclusive e-cigarette use to dual cigarette and e-cigarette use (HR age 55+ years: 0.53, 95% CI 0.31 to 0.91) when compared with the 18–24 years age group. All age groups had lower hazards of transitioning from

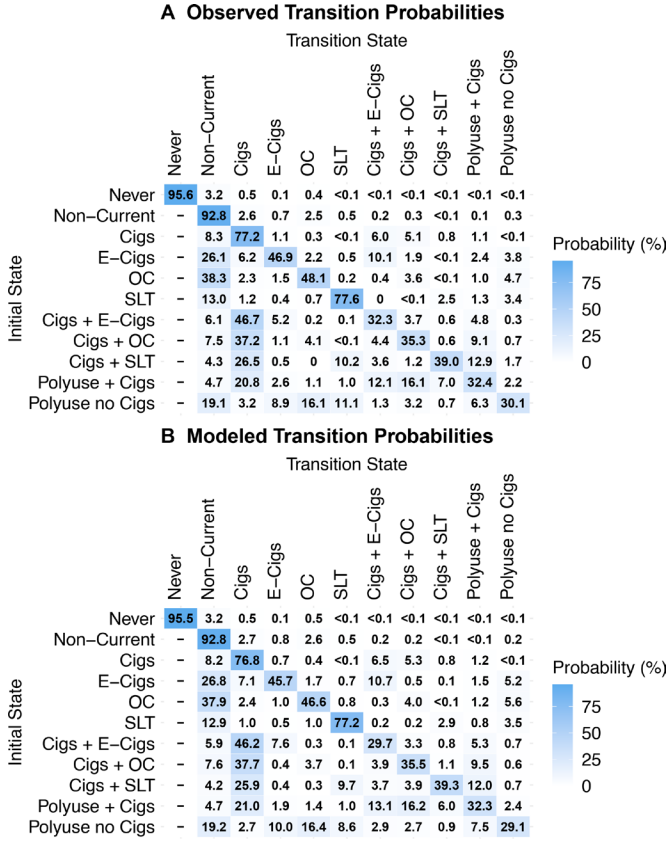

Figure 1 One wave transition probability between tobacco use states. (A) Observed transition probabilities adjusted for longitudinal survey weights, and (B) estimated transition probabilities from the multistate transition model. Polyuse+Cigs is any product combination of three or more products that includes cigarettes, Polyuse no Cigs is any product combination of two or more products that does not include cigarettes. Cigs, cigarettes; E-Cigs, e-cigarettes; OC, other combustibles; SLT, smokeless tobacco.

exclusive e-cigarette use to non-current use than the 18–24 years age group (HR age 25–34 years: 0.64, 95% CI 0.44 to 0.92; HR age 35–54 years: 0.46, 95% CI 0.33 to 0.65; HR age 55+ years: 0.34, 95% CI 0.21 to 0.54). All age groups also had lower hazards of transitioning from dual cigarette and e-cigarette use to exclusive e-cigarette use than the 18–24 years age group (HR age 25–34 years: 0.73, 95% CI 0.46 to 1.16; HR age 35–54 years: 0.38, 95% CI 0.25 to 0.57; HR age 55+ years: 0.50, 95% CI 0.34 to 0.75), although the difference between the 25–34 years age group and the 18–24 years age group was not statistically significant.

Compared with females, male participants had higher hazards of initiating exclusive cigarette or exclusive OC use from never use and initiating exclusive e-cigarette, OC or SLT use after a period of tobacco product cessation. However, they had lower hazards of initiating exclusive cigarette use after being in a non-current use state when compared with females (HR 0.64, 95% CI 0.53 to 0.77). Males had higher hazards of transitioning from exclusive cigarette use to dual cigarette and OC use (HR 1.69, 95% CI 1.43 to 2.01) or dual cigarette and SLT use (HR 6.47, 95% CI 2.80 to 14.96), but lower hazard of transitioning to dual cigarette and e-cigarette use (HR 0.82, 95% CI 0.70 to 0.96) than females. Males also had higher hazards of transitioning from dual cigarette and e-cigarette use to exclusive e-cigarette use (HR 1.69, 95% CI 1.30 to 2.18) or poly use with cigarettes (HR 1.93, 95% CI 1.30 to 2.86) than females.

Compared with NH white participants, Hispanic and NH black participants had a higher hazard of initiating exclusive cigarette use after never using tobacco products (HR Hispanic: 3.08, 95% CI 1.46 to 6.46; HR NH black: 3.72, 95% CI 1.96 to 7.04). Hispanic and NH black participants also had a higher hazard of transitioning from never use to non-current use than NH white participants, indicating higher rates of experimentation with tobacco products in between waves of the study (HR Hispanic: 1.72, 95% CI 1.26 to 2.35; HR NH black: 1.92, 95% CI 1.35 to 2.73). Hispanic and NH black participants generally had a higher hazard of transitioning from non-current use to exclusive cigarette, e-cigarette and OC use, and a lower hazard of transitioning from exclusive cigarette use to dual cigarette and e-cigarette use than NH white participants. Hispanic participants or NH other race had higher hazards of transitioning from exclusive cigarette use to non-current use than NH white participants (HR Hispanic: 1.73, 95% CI 1.39 to 2.16; HR NH other: 1.67, 95% CI 1.05 to 2.64), while there was no statistical difference between NH black and NH white participants for this transition. There were no associations between race/ethnicity and transitions from exclusive e-cigarette use to dual cigarette and e-cigarette use, but both Hispanic and NH black participants had higher rates of transition from exclusive e-cigarette use to non-current use than NH white participants (HR Hispanic: 2.79, 95% CI 1.86 to 4.18; HR NH black: 2.33, 95% CI 1.49 to 3.64). Compared with NH white participants, all other racial/ethnic groups had higher hazards of transitioning from exclusive OC use to dual or poly use without cigarettes, but there were no statistical differences in transitions from exclusive SLT use to dual or poly use without cigarettes. Hispanic participants had higher hazards of transitioning out of dual cigarette and e-cigarette use to either exclusive cigarette use (HR Hispanic: 1.36, 95% CI 1.08 to 1.70), exclusive e-cigarette use (HR Hispanic: 1.57, 95% CI 1.00 to 2.44) or poly use with cigarettes (HR Hispanic: 2.35, 95% CI 1.09 to 5.08) than NH white participants. NH black participants had higher hazards of transitioning from dual cigarette and e-cigarette use to poly use with cigarettes than NH white participants (HR NH black: 2.07, 95% CI 1.08 to 3.97).

When compared with participants who had obtained a Bachelor's degree or higher, having no HS diploma, a HS diploma or GED or some college was associated with higher hazards of exclusive cigarette initiation from never use (HR<HS: 8.94, 95% CI 2.20 to 36.30; HR HS/GED: 15.10, 95% CI 4.38 to 52.07) and non-current use (HR<HS: 2.33, 95% CI 1.52 to 3.56; HR HS/GED: 4.17, 95% CI 2.69 to 6.44; HR some college: 1.58, 95% CI 1.08 to 2.32), as well as lower hazards of exclusive cigarette cessation (HR<HS: 0.36, 95% CI 0.28 to 0.47; HR HS/GED: 0.38, 95% CI 0.27 to 0.53; HR some college: 0.46, 95% CI 0.35 to 0.62). Not having a Bachelor's degree or higher was also associated with higher hazards of exclusive e-cigarette initiation after a period of non-current use (HR<HS: 2.84, 95% CI 1.39 to 5.80; HR HS/GED: 4.20, 95% CI 1.75 to 10.07; HR some college: 4.45, 95% CI 2.41 to 8.23).

Having an income <US$50 000 was associated with higher hazards of both exclusive cigarette initiation from never use (HR <US$25 000: 4.87, 95% CI 1.90 to 12.49; HR US$25 000–US$50 000: 2.83, 95% CI 1.09 to 7.39) and exclusive cigarette initiation from non-current use (HR <US$25 000: 3.13, 95% CI 2.51 to 3.91; HR US$25 000–US$50 000: 1.77, 95% CI 1.31 to 2.38) when compared with any lower income. Incomes lower than <US$50 000 were not associated with exclusive e-cigarette

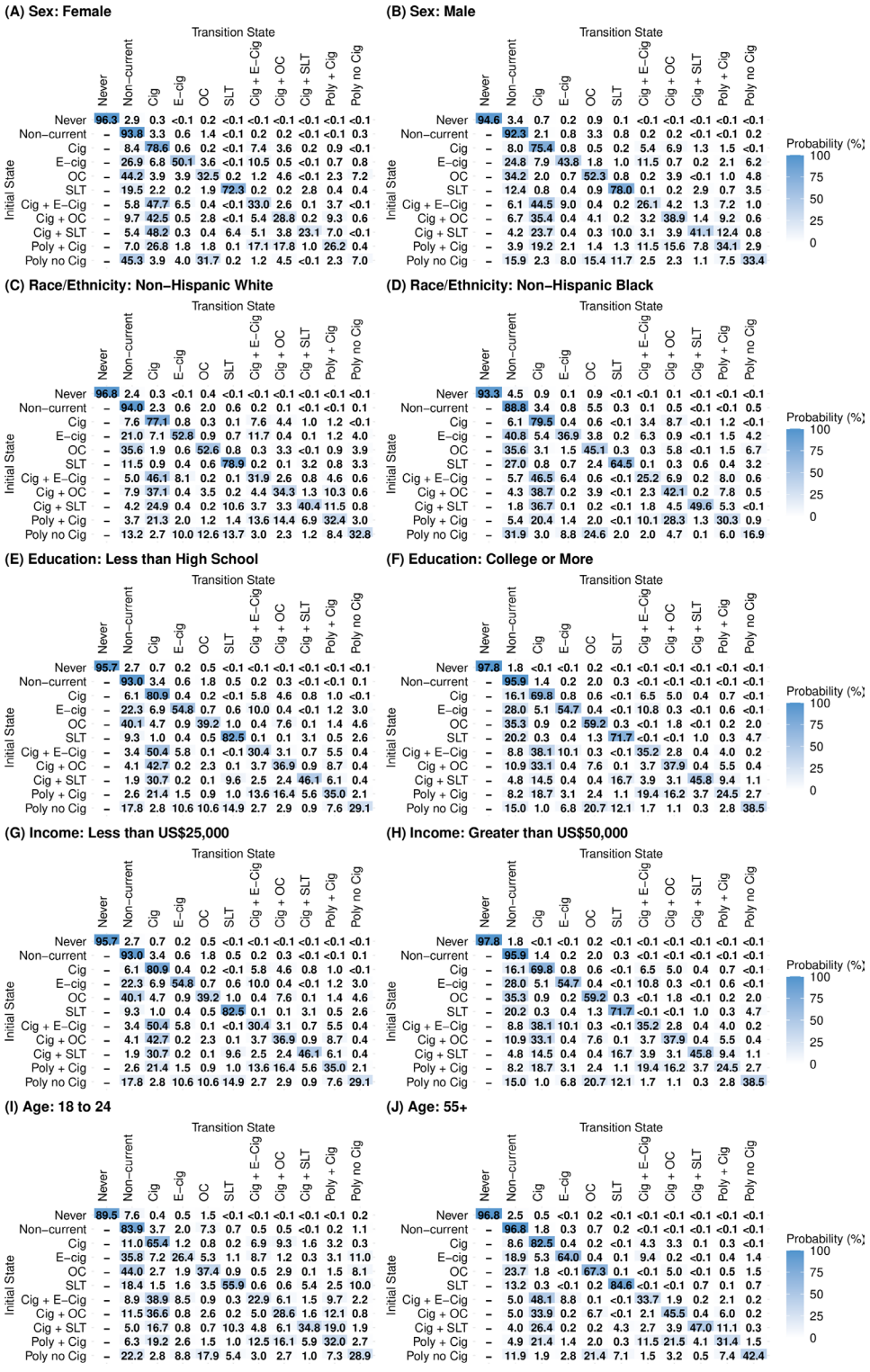

Figure 2 One wave transition probability between tobacco use states by sociodemographic factors. Polyuse+Cigs is any product combination of three or more products that includes cigarettes, Polyuse no Cigs is any product combination of two or more products that does not include cigarettes. Cigs, cigarettes; E-Cigs, e-cigarettes; OC, other combustibles; SLT, smokeless tobacco.

initiation from never use but were associated with initiation of exclusive e-cigarette use after a period of non-current use (HR <US$25 000: 2.17, 95% CI 1.35 to 3.48; HR US$25 000–US$50 000: 1.87, 95% CI 1.08 to 3.24) when compared with incomes >US$50 000. Participants with incomes <US$50 000 had a decreased hazard of cigarette cessation from exclusive cigarette use (HR <US$25 000: 0.62, 95% CI 0.50 to 0.77; HR US$25 000–US$50 000: 0.74, 95% CI 0.58 to 0.95) and were more likely to add additional tobacco products once they already used OC exclusively, with higher hazards of transitioning to either dual cigarette and OC use (HR <US$25 000: 3.59, 95% CI 2.51 to 5.12; HR US$25 000–US$50 000: 2.54, 95% CI 1.64 to 3.94) or dual or poly use without cigarettes (HR <US$25 000: 3.80, 95% CI 2.70 to 5.34; HR US$25 000–US$50 000:

1.90, 95% CI 1.22 to 2.95). The lowest income group had the lowest rates of transitioning from dual cigarette and e-cigarette use to sole e-cigarette use (HR <US$25 000: 0.62, 95% CI 0.45 to 0.88).

DISCUSSION

In this analysis, we estimated underlying transition rates between single, dual and poly tobacco use with cigarettes, e-cigarettes, OC and SLT. We found that exclusive cigarette and exclusive SLT use were the most persistent patterns, while the other single-product use and dual and poly use patterns were much more transient. If adults who used tobacco products did transition between product use categories, single product use patterns were most likely to transition to non-current use, while adults with dual or poly use patterns who smoked cigarettes were most likely to quit the other products and exclusively use cigarettes. In addition, we compared transition rates by sociodemographic factors and found important differences by age, sex, race/ethnicity, education and income.

To contextualise our findings, it is important to keep the tobacco product risk continuum in mind,[26] with non-combustible products (e-cigarettes, SLT) considered less harmful than combustible products (cigarettes, OC). For example, we found that tobacco product use was more transient among younger adults and more stable among older adults. If e-cigarettes are used as a harm reduction tool by adults who smoke cigarettes,[43 44] older adults who smoke cigarettes may maintain a higher risk of cigarette-related diseases than younger adults since they are less likely to either pick up e-cigarettes or to transition to exclusive e-cigarette use from dual use of both cigarettes and e-cigarettes when compared with younger adults.

We found that men had higher rates of transition overall than women, specifically to initiating additional combustible product use from either never use or exclusive cigarette use. Men were less likely to transition from exclusive cigarette use to dual cigarette and e-cigarette use implying that men may be less likely than women to use e-cigarettes as a smoking cessation tool. Although men who used both cigarettes and e-cigarettes were more likely than women to transition to exclusive e-cigarette use, men were also more likely to move from cigarette and e-cigarette dual use into a poly use state. These transition patterns into dual or poly use with cigarettes may put men at increased risk of disease, as adults who use cigarettes with other products may smoke as many cigarettes per day as adults who smoke cigarettes exclusively.[27 45–47] These results are in line with existing literature showing that men have higher rates of poly tobacco use than women in the USA and globally.[18 24 48]

We found that Hispanic and NH black adults were more likely than NH white adults to transition into more risky tobacco use states, potentially increasing their burden of disease. For example, Hispanic and NH black adults were more likely than NH white adults to initiate exclusive cigarette, e-cigarette or OC use from never or former use states. Consistent with prior literature,[29 37] NH black and Hispanic adults who smoked cigarettes were less likely to quit or initiate e-cigarette use, implying that e-cigarettes have not been a useful smoking cessation tool in this population. Furthermore, NH black adults were more likely than NH white adults to transition into a poly use state from dual use with cigarettes and e-cigarettes which may increase their disease burden, since people who use multiple products do not decrease the amount of cigarettes they smoke per day.[27 45–47]

Adults without a bachelor's degree or higher and income levels <US$50 000 were more likely than adults with higher SES to initiate tobacco use and transition into more harmful product use states. Adults with these education and income levels were more likely to start smoking cigarettes (exclusively) and less likely to stop than adults with bachelor's degrees or higher, or with incomes >US$50 000. Adults with an income <US$50 000 were more likely to move to potentially harmful dual and poly use states and less likely to move to use states that may have lower risk, which emphasises the need for public health interventions to acknowledge the use of multiple risky tobacco products among low-income populations, who are often specifically targeted by tobacco companies. These results correspond with literature showing this trend on a global scale.[24]

This study has several limitations. The data we used came from 2013 to 2017 and therefore do not capture more recent changes in tobacco product use behaviours. However, the PATH data present detailed information on a nationally representative sample and using a four-wave sample allows us to analyse transition rates over a longer period of time than is available in other sources. We grouped all dual and poly use categories that did not include cigarette products due to sample size, which means we were unable to capture the transitions between dual and poly use within those groups. Our analysis used baseline covariate information and therefore did not consider how participant's covariate information may have changed over time, including unmeasured social-contextual factors. Another potential limitation is that we do not consider the long-term trajectory of product use for individuals, since the Markov model assumes the probability of transitioning from one state to another depends only on the current state. This limitation may be addressed in future work, or using data with longer trajectory information. Our paper focused on the US population. Patterns of tobacco use vary widely globally,[24] and our results may not be generalisable to other countries. However, some of our results (namely the associations between gender, income and poly tobacco use) were consistent with results of analyses conducted on a global scale.[24] Finally, although we used the all-waves survey weights provided by PATH as recommended when analysing longitudinal trends, using these weights resulted in dropping a sizeable proportion (40.9%) of people who did not complete all waves, which may have resulted in biased estimates if the population that was lost to follow-up in the study had different transitions between tobacco product use; however, the longitudinal weights provided by PATH incorporate weighting for attrition which should account for part of this potential bias, making them the most appropriate choice for the analysis.[34 49]

Considering many categories of tobacco use had the potential to reduce our power to detect differences, since there may have been very small numbers of transitions between specific categories. We attempted to address this by collapsing low-prevalence categories, for example, collapsing the dual and poly use categories without cigarettes into one category. We also used model reduction techniques based on usual tobacco use patterns to disallow instantaneous two-step transitions, meaning that if someone transitioned between sole cigarette use and sole e-cigarette use, we expected that they first went through an unobserved transition into dual cigarette and e-cigarette use. In future work, we will consider multivariable models and interactions between variables.

In this paper, we estimated the probability of transitioning between tobacco use categories including single, dual and poly tobacco use states and considered whether transition rates differed by age, sex, race/ethnicity, education and income. Our study is the first to use a multistate modelling framework to assess the rates underlying transitions between single, dual

and poly tobacco use in nationally representative longitudinal data and one of the first to look at these transition probabilities by sociodemographic group. Understanding the rates of transition between different tobacco products and how they differ by sociodemographic factors can help inform future public health interventions for tobacco product cessation and harm reduction in the USA.

Contributors FSK: methodology, formal analysis, writing—original draft, writing—review and editing, visualisation, guarantor. AFB: methodology, formal analysis, writing—review and editing, visualisation, supervision. JLH: writing—original draft, writing—review and editing, supervision. JJ: data curation, writing—review and editing. EJ-M: data curation, writing—review and editing. RM: conceptualisation, resources, writing—review and editing, funding acquisition. NLF: conceptualisation, resources, writing—review and editing, supervision, funding acquisition.

Funding This project was funded through the National Cancer Institute (NCI) of the National Institutes of Health (NIH) and Food and Drug Administration (FDA) Center for Tobacco Products (CTP) under Award Number U54CA229974 and through NCI under Award Number T32CA083654.

Disclaimer The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health or the Food and Drug Administration.

Competing interests None declared.

Patient consent for publication Not applicable.

Ethics approval This study did not undergo IRB/ethics approval because it was a secondary analysis of publicly available data collected for research purposes and fully de-identified. Participants gave informed consent to participate in the study before taking part.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available in a public, open access repository. Data are publicly available from the public use files provided by PATH.

ORCID iDs
Fatema Shafie Khorassani http://orcid.org/0000-0001-7445-322X
Andrew F Brouwer http://orcid.org/0000-0002-3779-5287
Rafael Meza http://orcid.org/0000-0002-1076-5037
Nancy L Fleischer http://orcid.org/0000-0002-4371-9133

REFERENCES

1 National Center for Chronic Disease Prevention and Health Promotion (US) Office on Smoking and Health. *The health consequences of smoking—50 years of progress: a report of the surgeon general*. Centers for Disease Control and Prevention (US), 2014.
2 World Health Organization (WHO). *WHO report on the global tobacco epidemic*. World Health Organization, 2021.
3 Pacek LR, Wiley JL, McClernon FJ. A conceptual framework for understanding multiple tobacco product use and the impact of regulatory action. *Nicotine Tob Res* 2019;21:268–77.
4 Sánchez-Romero LM, Cadham CJ, Hirschtick JL, *et al*. A comparison of tobacco product prevalence by different frequency of use thresholds across three US surveys. *BMC Public Health* 2021;21:1203.
5 Loukas A, Chow S, Pasch KE, *et al*. College students' polytobacco use, cigarette cessation, and dependence. *Am J Hlth Behav* 2016;40:514–22.
6 Schauer GL, Malarcher AM, Babb SD. Prevalence and correlates of switching to another tobacco product to quit smoking cigarettes. *Nicotine & Tobacco Research* 2015;17:622–7.
7 East K, Brose LS, McNeill A, *et al*. Harm perceptions of electronic cigarettes and nicotine: a nationally representative cross-sectional survey of young people in Great Britain. *Drug Alcohol Depend* 2018;192:257–63.
8 Odani S, Tsuno K, Agaku IT, *et al*. Heated tobacco products do not help smokers quit or prevent relapse: a longitudinal study in japan. *Tob Control* 2023. 10.1136/tc-2022-057613 [Epub ahead of print 27 Feb 2023].
9 Zhang X, Sun Y, Cheung YTD, *et al*. Cigarettes, heated tobacco products and dual use: exhaled carbon monoxide, saliva cotinine and total tobacco consumed by hong kong tobacco users. *Tob Control* 2023. 10.1136/tc-2022-057598 [Epub ahead of print 24 Jan 2023].
10 O'Hegarty MM, Pederson LL, Asman KJ, *et al*. Are adolescent cigarette smokers who use smokeless tobacco more likely to continue smoking in the future than cigarette-only smokers: results from waves I and II of the adolescent health survey. *ISRN Public Health* 2012;2012:1–7.
11 Soneji S, Sargent JD, Tanski SE, *et al*. Associations between initial water pipe tobacco smoking and snus use and subsequent cigarette smoking: results from a longitudinal study of US adolescents and young adults. *JAMA Pediatr* 2015;169:129–36.
12 Dutra LM, Glantz SA, Lisha NE, *et al*. Beyond experimentation: five trajectories of cigarette smoking in a longitudinal sample of youth. *PLoS ONE* 2017;12:e0171808.
13 Miech R, Patrick ME, O'Malley PM, *et al*. E-Cigarette use as a predictor of cigarette smoking: results from a 1-year follow-up of a national sample of 12th grade students. *Tob Control* 2017;26:e106–11.
14 Macy JT, Li J, Xun P, *et al*. Dual trajectories of cigarette smoking and smokeless tobacco use from adolescence to midlife among males in a midwestern US community sample. *NICTOB* 2016;18:186–95.
15 Tam J, Day HR, Rostron BL, *et al*. A systematic review of transitions between cigarette and smokeless tobacco product use in the United States. *BMC Public Health* 2015;15:258.
16 Anic GM, Holder-Hayes E, Ambrose BK, *et al*. E-cigarette and smokeless tobacco use and switching among smokers: findings from the national adult tobacco survey. *Am J Prev Med* 2018;54:539–51.
17 Hair EC, Romberg AR, Niaura R, *et al*. Longitudinal tobacco use transitions among adolescents and young adults: 2014–2016. *Nicotine & Tobacco Research* 2019;21:458–68.
18 Fix BV, O'Connor RJ, Vogl L, *et al*. Patterns and correlates of polytobacco use in the united states over a decade: NSDUH 2002-2011. *Addict Behav* 2014;39:768–81.
19 Kurti AN, Bunn JY, Villanti AC, *et al*. Patterns of single and multiple tobacco product use among US women of reproductive age. *Nicotine Tob Res* 2018;20:S71–80.
20 Rath JM, Villanti AC, Abrams DB, *et al*. Patterns of tobacco use and dual use in us young adults: the missing link between youth prevention and adult cessation. *J Environ Public Health* 2012;2012:679134.
21 Huh J, Leventhal AM. Progression of poly-tobacco product use patterns in adolescents. *Am J Prev Med* 2016;51:513–7.
22 Robertson L, Hoek J, Blank M-L, *et al*. Dual use of electronic nicotine delivery systems (ENDS) and smoked tobacco: a qualitative analysis. *Tob Control* 2019;28:13–9.
23 Ali M, Gray TR, Martinez DJ, *et al*. Risk profiles of youth single, dual, and poly tobacco users. *Nicotine Tob Res* 2016;18:1614–21.
24 Agaku IT, Filippidis FT, Vardavas CI, *et al*. Poly-tobacco use among adults in 44 countries during 2008-2012: evidence for an integrative and comprehensive approach in tobacco control. *Drug Alcohol Depend* 2014;139:60–70.
25 Strong DR, Pearson J, Ehlke S, *et al*. Indicators of dependence for different types of tobacco product users: descriptive findings from wave 1 (2013-2014) of the population assessment of tobacco and health (PATH) study. *Drug Alcohol Depend* 2017;178:257–66.
26 Zeller M, Hatsukami D, Strategic Dialogue on Tobacco Harm Reduction Group. The strategic dialogue on tobacco harm reduction: a vision and blueprint for action in the US. *Tob Control* 2009;18:324–32.
27 Choi K, Inoue-Choi M, McNeel TS, *et al*. Mortality risks associated with dual– and poly–tobacco-product use in the United States. *Am J Epidemiol* 2022;191:397–401.
28 Fagan P, Moolchan ET, Lawrence D, *et al*. Identifying health disparities across the tobacco continuum. *Addiction* 2007;102 Suppl 2:5–29.
29 Harlow AF, Stokes A, Brooks DR. Socioeconomic and racial/ethnic differences in e-cigarette uptake among cigarette smokers: longitudinal analysis of the population assessment of tobacco and health (PATH) study. *Nicotine & Tobacco Research* 2019;21:1385–93.
30 Barrington-Trimis JL, Bello MS, Liu F, *et al*. Ethnic differences in patterns of cigarette and e-cigarette use over time among adolescents. *J Adolesc Health* 2019;65:359–65.
31 Friedman AS, Horn SJL. Socioeconomic disparities in electronic cigarette use and transitions from smoking. *Nicotine & Tobacco Research* 2019;21:1363–70.
32 Berg CJ, Haardoerfer R, Escoffery C, *et al*. Cigarette users' interest in using or switching to electronic nicotine delivery systems for smokeless tobacco for harm reduction, cessation, or novelty: a cross-sectional survey of US adults. *Nicotine & Tobacco Research* 2015;17:245–55.
33 Mattingly DT, Zavala-Arciniega L, Hirschtick JL, *et al*. Trends in exclusive, dual and polytobacco use among U.S. adults, 2014-2019: results from two nationally representative surveys. *Int J Environ Res Public Health* 2021;18:13092.
34 Hyland A, Ambrose BK, Conway KP, *et al*. Design and methods of the population assessment of tobacco and health (PATH) study. *Tob Control* 2017;26:371–8.

35 Kasza KA, Coleman B, Sharma E, *et al*. Transitions in Tobacco Product Use by U.S. adults between 2013–2014 and 2014–2015: findings from the PATH study wave 1 and Wave 2. *Int J Environ Res Public Health* 2018;15:2515.
36 Kasza KA, Coleman B, Sharma E, *et al*. Correlates of transitions in tobacco product use by U.S. adult tobacco users between 2013–2014 and 2014–2015: findings from the PATH study wave 1 and Wave 2. *Int J Environ Res Public Health* 2018;15:2556.
37 Simon P, Buta E, Gueorguieva R, *et al*. Transitions across tobacco use profiles among adolescents: results from the population assessment of tobacco and health (PATH) study waves 1 and 2. *Addiction* 2020;115:740–7.
38 Coleman B, Rostron B, Johnson SE, *et al*. Transitions in electronic cigarette use among adults in the population assessment of tobacco and health (PATH) study, waves 1 and 2 (2013-2015). *Tob Control* 2019;28:50–9.
39 Brouwer AF, Jeon J, Hirschtick JL, *et al*. Transitions between cigarette, ends and dual use in adults in the path study (waves 1-4): multistate transition modelling accounting for complex survey design. *Tob Control* 2020. 10.1136/tobaccocontrol-2020-055967 [Epub ahead of print 16 Nov 2022].
40 Niaura R, Rich I, Johnson AL, *et al*. Young adult tobacco and E-cigarette use transitions: examining stability using multistate modeling. *Nicotine Tob Res* 2020;22:647–54.
41 Kaufman AR, Land S, Parascandola M, *et al*. Tobacco use transitions in the United States: the National longitudinal study of adolescent health. *Preventive Medicine* 2015;81:251–7.
42 Jackson CH. Multi-state models for panel data: the **msm** package for *r*. *J Stat Soft* 2011;38:1–28.
43 Fairchild AL, Lee JS, Bayer R, *et al*. E-Cigarettes and the harm-reduction continuum. *N Engl J Med* 2018;378:216–9.
44 Abrams DB, Glasser AM, Pearson JL, *et al*. Harm minimization and tobacco control: reframing societal views of nicotine use to rapidly save lives. *Annu Rev Public Health* 2018;39:193–213.
45 Rostron BL, Schroeder MJ, Ambrose BK. Dependence symptoms and cessation intentions among US adult daily cigarette, cigar, and e-cigarette users, 2012-2013. *BMC Public Health* 2016;16:814.
46 Tomar SL, Alpert HR, Connolly GN. Patterns of dual use of cigarettes and smokeless tobacco among US males: findings from national surveys. *Tob Control* 2010;19:104–9.
47 Petersen A, Myers MG, Tully L, *et al*. Polytobacco use among young adult smokers: prospective association with cigarette consumption. *Tob Control* 2020;29:43–8.
48 Osibogun O, Taleb ZB, Bahelah R, *et al*. Correlates of poly-tobacco use among youth and young adults: findings from the population assessment of tobacco and health study, 2013-2014. *Drug Alcohol Depend* 2018;187:160–4.
49 Piesse A, Opsomer J, Dohrmann S, *et al*. Longitudinal uses of the population assessment of tobacco and health study. *Tob Regul Sci* 2021;7:3–16.