

The Impact of Current Tobacco Product Use Definitions on Estimates of Transitions Between Cigarette and ENDS Use

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Abstract

Introduction: Definitions of current tobacco and nicotine delivery product use vary and depend on frequency of use, established-use criteria, and the product type. Previous research has not considered how transition rates between current use of different products depend on the current use definition.

Aims and Methods: We applied a multistate transition model to data on U.S. adults from waves 1–4 (2013–2017) of the Population Assessment of Tobacco and Health (PATH) study. We estimated transition rates between never, non-current, cigarette, electronic nicotine delivery systems (ENDS), and dual use states with and without established-use criteria (has smoked 100+ cigarettes in their lifetime; ever fairly regularly used ENDS) and different frequency thresholds (1+, 10+, 20+, and 30 days of the past 30 days). We considered use below a frequency threshold as either non-current use or a distinct, infrequent use category.

Results: When treating use below a frequency threshold as non-current use, transition probability estimates were largely robust to the choice of use frequency threshold, although sole ENDS users were more likely to transition to non-current use or dual use as the current use threshold increased. Removing the established-use criterion for ENDS reduced the estimates of sole ENDS and dual users staying in their use state. When treating infrequent use as a separate category, transition probability estimates were dependent on the use frequency threshold, particularly transitions among the dual use states.

Conclusions: Product use definitions have important implications for assessing product use transitions and thus the public health implications of cigarette and ENDS control strategies.

Implications: How we define “current use” of tobacco and nicotine delivery products changes our estimates of how individuals transition to, between, and from different patterns of use. We show that the robustness of transition estimates to whether or not non-established users are included as current users and to different frequency-of-use threshold depends in part on whether low-frequency users are categorized as non-current users or as a distinct category. Our results emphasize the importance of intentional definitions of product use that reflect the larger goals of public health and tobacco control.

Introduction

Individual use of tobacco and nicotine delivery products, including cigarettes and electronic nicotine delivery systems (ENDS), comes in a spectrum of frequency and intensity that may vary over time. Different patterns of use are likely associated with different magnitudes of health risk, but, as health effects manifest after many years of cumulative exposure, it is not immediately clear what cutoffs for current use behavior are the most risk relevant. Accordingly, it is important that we understand how sensitive our analyses are to definitions of use. Understanding how patterns of use—and how people transition between them—depend on our definitions and categorizations will be essential for ultimately estimating the public health impacts of tobacco and nicotine product policies with confidence. Although ENDS are considered a tobacco product in the United States, they are not in many other countries,¹ so we refer to them as nicotine products here.

Two considerations for measuring tobacco and ENDS use are whether one wants to include established-use criteria and what frequency threshold is used to denote current use. Many, though not all, surveys of cigarette use include a question about whether a participant has used at least 100 cigarettes in their lifetime, and this question is often used as an established-use criterion.² Because a fraction of users are experimenting and may never become regular users, many analyses choose to exclude not-yet-established users. In considering a frequency threshold for current use, we understand that the risks of infrequent tobacco use are different from frequent tobacco. However, these risks exist on a continuum. There is no standard frequency threshold for the number of days used in the past 30 days to distinguish current regular use from infrequent or non-regular use. Many studies use “any past 30-day” use or “everyday or someday” use to define current use,³ but other thresholds, eg, “at least 10 out of the past 30 days,”

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“daily” use, are also sometimes used. Although there may be no one “right” definition, it can be challenging to compare estimates across studies, and the choice of threshold could result in over- or underestimation of meaningful product use.

The appropriate choice of criteria for established and regular use is likely to depend on the type of tobacco or nicotine delivery product. In particular, ENDS use patterns differ from those of cigarettes. A substantial proportion of ENDS use is non-daily, with many reporting very infrequent, experimental, or social use.⁴⁻⁷ Frequency of ENDS use depends on whether users are also cigarette users, with current cigarette users using ENDS moderately and former cigarette users more likely to be using ENDS frequently or daily.⁵⁻⁷ Accordingly, it is not clear that the established-use criteria and current-use thresholds can or should be the same for cigarettes and ENDS. Previous analyses have taken a wide variety of approaches to defining ENDS use, many focusing on different frequencies of use⁵⁻¹⁰ (eg, infrequent (1–5 days out of past 30) ENDS user, intermediate (6–29 days) ENDS user, daily (30 days) ENDS user), some on established versus experimental use or including only established users^{11,12} (eg, experimental ENDS user, established ENDS user without cigarette use history, established ENDS user with cigarette use history), some examining both aspects¹³ (eg, experimental ENDS user, established some days ENDS user, established everyday user), and some including all current users regardless of frequency thresholds or established use criteria¹⁴⁻¹⁶.

Previous work has shown that tobacco and ENDS use prevalence estimates are sensitive to these criteria.^{4,17} While estimates of initiation, cessation, and product switching are also likely to depend on these criteria, it is not known how and to what extent that is the case. Multistate transition models are increasingly being used in the tobacco control literature to estimate transition rates between different patterns of tobacco use from longitudinal data.^{12,14,16,18,19} The advantage of this approach is that all modeled transition rates can be simultaneously estimated, accounting for other possible transitions. In this analysis, we use multistate transition models to estimate transition rates among exclusive cigarette, exclusive ENDS, dual, and non-current use in U.S. adults and how these estimates change as a function of established-use criteria and current-use frequency thresholds. We also investigate how the extent of these changes differs depending on whether infrequent users (ie, those using at a frequency below the current-use threshold) are classified as non-current, or whether their use is considered to be a separate category of infrequent use.

This analysis focuses on the magnitude and direction of the impact of product use definitions on point estimates of transition probabilities. Although there are confidence intervals associated with each point estimate, focusing on whether changing the results of the definition in a statistically significant difference would suggest that we are testing the hypothesis that the definitions impact the results as if the definitions were a variable. That is not the case, and, we argue, not the right approach. Instead, we concentrate on the more fundamental, specification question of the direction, and extent to which the choice of definition impacts one’s conclusions.

Methods

Data and Tobacco Use State Definitions

We used data on adults in waves 1–4 of the Population Assessment of Tobacco and Health (PATH) study with a

wave 4 all-waves longitudinal weight, as appropriate for a nationally (United States) representative longitudinal analysis on these data.²⁰ We focused on waves 1–4 because the underlying transition rates were approximately constant over this period,¹² and transition rates changed with the increase in JUUL and other ENDS use in 2018 (wave 5). With those changes, it would have been more difficult to isolate the impact of product use definitions. Because we focused on understanding the impact of definitions of use broadly rather than specifically estimating and reporting results for specific groups, we did not distinguish individuals by age, sex, race and ethnicity, or other sociodemographic characteristics. The time between waves was approximately 1 year. We restrict the sample to participants who had complete information on cigarette and ENDS use in more than 1 wave, since single observations are uninformative for estimating transitions.

We assigned each PATH participant to a tobacco use state in each wave for different combinations of established- and current-use criteria for cigarettes and ENDS. We did not consider other product use in our tobacco use state definitions, eg, a never user is defined by never use of cigarette and ENDS, regardless of cigar, smokeless, etc., use. (Use of other products among never or non-current users of cigarettes or ENDS was minimal: 1.4% used cigars in the past 30 days, 0.8% used cigarillos, and 2.1% used smokeless.) Our established-use criteria were “smoked at least 100 cigarettes in your lifetime” for cigarettes and “every used ENDS fairly regularly” for ENDS. For current use for each product, we used four different use frequency thresholds: 1+, 10+, 20+, and 30 days of use out of the past 30 days. We also estimated transition rates in models that considered infrequent use (ie, use under the frequency threshold) as (1) non-current use and (2) a distinct category of infrequent use. The definitions and categories of use are summarized in [Supplementary Figures S1 and S2](#). There are five categories of use when infrequent users are considered non-current users and 10 categories when infrequent use is considered distinct from both non-current and frequent use.

Transition Modeling

We used a Markov multistate transition model to analyze the underlying transition hazard rates.¹² A Markov multistate transition model is a continuous-time, finite-state stochastic process that assumes that transition rates depend only on the current state and not on the length of time in the current state, past states, or the overall transition history.²¹ In short, a Markov multistate transition model estimates transition hazard rates, that is, the instantaneous risk of transitioning from one state to another. These transition hazard rates collectively define the probabilities of being in each state at future times, thereby connecting the model to longitudinal data of the actual observed states. Specifically, given a matrix of transition rates Q , the probabilities of an individual being in each state at time t is given by the matrix $P(t) = \exp(Qt)$. In this analysis, we give the estimated cumulative 1-wave transition probabilities, $P(1)$, displayed as heatmaps. Along a given row, which corresponds to a starting tobacco use state, the heatmap gives the probability of transitioning to each other state or remaining in the current state after 1 wave.

Because estimating rates of rare transitions can result in highly uncertain results and problems with optimization algorithm convergence, not all direct transitions are allowed.¹² The adjacency matrices for the two types of models (that differ in how infrequent users are classified) are shown in

[Supplementary Figures S3 and S4](#). In short, we generally allow only initiation, discontinuation, or a change in frequency in one product at a time.

Our models were implemented in R (v4.0), adapted from the “msm” R package²² to incorporate a complex survey design.¹²

Analyses

We compared the impacts of the established-use criteria and current-use frequency thresholds in four specific analyses summarized in [Table 1](#). In short, we compare transition probabilities when including or excluding non-established users from the current-use categories for a fixed current-use threshold and when comparing current-use thresholds for fixed established-use criteria. We do this both for models that treat infrequent use as (1) non-current use and (2) a category of use distinct from non-current and frequent use. In each analysis, we use the estimated transition rates to calculate the corresponding 1-year transition probabilities. Note that in analyses 1 and 3, we do not consider the situation where non-established cigarette users are excluded from current use but non-established ENDS users are included; we do not think that this combination is relevant.

Results

A distribution of the number of days of cigarette and ENDS use reported (among users of each product) is given in [Supplementary Figure S5](#). Most users of either product report using that product 30 out of the past 30 days. Participants who used less than 30 days often rounded to the nearest 5 or 10 days used. A larger fraction of ENDS users than cigarette users reported using fewer than 30 out of the past 30 days.

Analysis 1: Transition Probabilities Depend on Established-Use Criteria in Models That Treat Infrequent Use as Non-current

In [Figure 1](#), we present the heatmaps for 1-year transition probabilities as we changed whether non-established users

are included in the non-current or current use categories. The current-use frequency threshold was set to “1+ days out of the past 30 days”, akin to an “everyday or someday” use definition. 95% CI bounds ([Supplementary Figures S6 and S7](#)) and a comparison of the underlying transition rates ([Supplementary Figure S8](#)) are given in the [Supplementary material](#). Removing the established-use criterion for cigarette users had only a minor impact on transition estimates. Compared to excluding non-established cigarette users from the current-use category ([Figure 1, A and B](#)), including them as current users ([Figure 1C](#)) resulted in a minor decrease in the point estimate of the persistence (ie, probability of remaining in state) of exclusive cigarette use (from 85.4% (95%CI 84.7%–86.0%) and 82.2% (81.4%–83.1%) persistent in [Figure 1, A and B](#) to 80.6% (79.9%–81.4%) persistent in [Figure 1C](#)). In contrast, removing the established-use criterion for ENDS had a much larger impact on transition estimates. Compared to excluding non-established ENDS users from the current-use category ([Figure 1A](#)), including them as current users ([Figure 1B and C](#)) resulted in a larger decrease in the estimated persistence of exclusive ENDS use (from 56.9% (53.8%–60.0%) persistent in [Figure 1A](#) to 47.4% (44.7%–50.2%) and 49.2% (46.2%–52.3%) persistent in [Figure 1B and C](#)) and dual use (from 41.1% (38.7%–43.4%) persistent in [Figure 1A](#) to 34.1% (32.4%–35.7%) and 33.6% (32.0%–35.3%) persistent in [Figure 1B and C](#)). For exclusive ENDS users, this reduced persistence was paired with an increase in transition to noncurrent use (from 21.9% (21.7%–22.0%) in [Figure 1A](#) to 32.3% (32.1%–32.5%) and 29.0% (28.9%–29.1) in [Figure 1B and C](#), respectively), and, for dual users, it was paired with an increase in transition to exclusive cigarette use (from 44.9% (44.6%–45.3%) in [Figure 1A](#) to 54.1% (53.6%–54.5%) and 53.7% (53.3%–54.1%) in [Figure 1B and C](#), respectively). Removing the established-use criterion for ENDS also increased the estimated probability that exclusive cigarette users would transition to dual use.

Table 1. Summary of Analyses in Terms of How Infrequent Use is Categorized, Whether Established Use Criteria are Used for Cigarettes and ENDS, and What Current Use Frequency Threshold is Used to Distinguish Between Infrequent and Frequent Use

Analysis	Category of infrequent use	Established use [†]	Current use threshold
1	Non-current use	a) Non-established cigarette users excluded, Non-established ENDS users excluded b) Non-established cigarette users excluded, Non-established ENDS users included c) Non-established cigarette users included, Non-established ENDS users included	1+ days out of past 30 days
2	Non-current use	Non-established cigarette users excluded, and Non-established ENDS users excluded	a) 1+ days out of past 30 days b) 10+ days out of past 30 days c) 20+ days out of past 30 days d) 30 days out of past 30 days
3	Infrequent use	a) Non-established cigarette users excluded, Non-established ENDS users excluded b) Non-established cigarette users excluded, Non-established ENDS users included c) Non-established cigarette users included, Non-established ENDS users included	30 days out of past 30 days
4	Infrequent use	Non-established cigarette users excluded, and Non-established ENDS users excluded	a) 10+ days out of past 30 days b) 20+ days out of past 30 days c) 30 days out of past 30 days

[†]Inclusion and exclusion refer to whether non-established users are considered current users or not. An established cigarette user has smoked at least 100 cigarettes in their lifetime, and an established ENDS user has ever used ENDS fairly regularly.

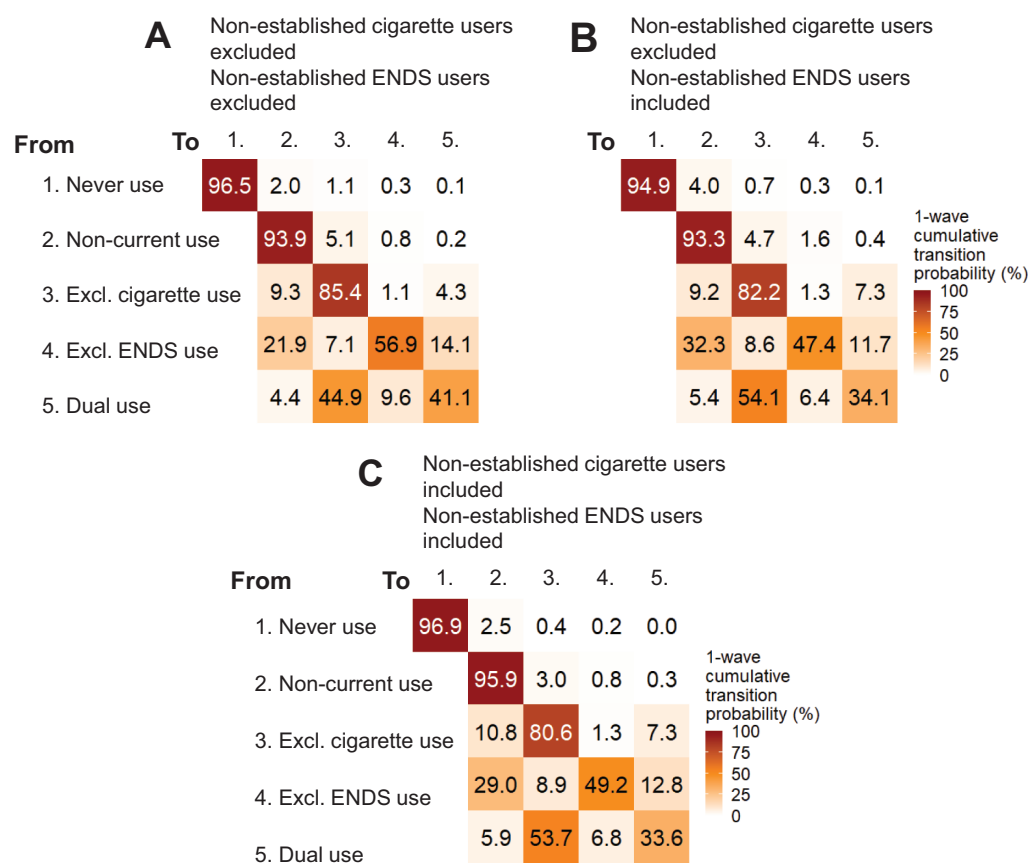


Figure 1. Heatmaps for 1-year transition probabilities between tobacco product use states as we changed whether non-established users are included in the non-current or current use categories and treating infrequent users as non-current. The current use frequency threshold was set to 1+ days out of the past 30 days.

Analysis 2: Transition Probabilities Depend on Current Use Frequency Thresholds in Models that Treat Infrequent Use as Non-current

In [Figure 2](#), we present heatmaps for 1-year transition probabilities as we changed the current use frequency threshold (1+, 10+, 20+, and 30 days out of the past 30) while treating infrequent use in the latter three simulations as non-current use. 95% CI bounds ([Supplementary Figures S9–10](#)) and a comparison of the underlying transition rates ([Supplementary Figure S11](#)) are given in the supplementary material. Estimated transition rates and probabilities were largely robust to changing the current use threshold when infrequent use was considered non-current use. The one possible exception was the transition from exclusive ENDS to cigarette users. As the current use threshold becomes stricter (moving from [Supplementary Figures 2A–D](#)), exclusive ENDS users are slightly more likely to transition to dual use (14.1% (12.6%–15.6%) in [Supplementary Figure 2A](#) to 17.4% (15.5%–19.4%) in [Supplementary Figure 2D](#)), indicating the more frequent exclusive ENDS users were more likely to start using cigarettes (note that these exclusive ENDS users may have been former cigarette users).

Analysis 3: Transition Probabilities Depend on Established-Use Criteria in Models That Treat Infrequent Use as a Distinct Category

In [Supplementary Figure S12](#), we present heatmaps for 1-year transition probabilities as we changed whether non-established users are included in the non-current or current use categories while treating infrequent use as a distinct

category of use. 95% CI bounds ([Supplementary Figures S13–14](#)) and a comparison of the underlying transition rates ([Supplementary Figure S15](#)) are given in [Supplementary material](#). For this analysis, the current-use frequency threshold was set at “30 days in the past 30 days,” akin to distinguishing someday or non-daily users from everyday or daily users. This choice of frequency threshold is provided as an illustration that is motivated by the distribution of reported days used ([Supplementary Figure S5](#)), in which most users indicate using 30 out of the past 30 days.

Treating infrequent use as a distinct pattern of use revealed different patterns for frequent and infrequent users. Infrequent exclusive cigarette users were almost equally likely to transition to non-current and frequent exclusive cigarette use, with only minimal changes with the exclusion criteria (state 3 in [Supplementary Figures S12A–C](#)). Frequent exclusive cigarette users largely persisted in their use, regardless of exclusion criteria (row 4). Similarly, infrequent exclusive ENDS users mostly transitioned to non-current use (state 5), with a smaller but substantial fraction transitioning to frequent exclusive ENDS use. Frequent exclusive ENDS use was more persistent than infrequent exclusive ENDS use but less persistent than frequent exclusive cigarette use (state 6). All of the dual use categories were comparatively transient (states 7–10), with transitions to other dual use categories or to frequent exclusive cigarettes common.

Unlike in analysis 1 where all frequencies of use were combined, here, where we distinguish between 1–29-day users vs 30-day users, the transition probabilities were

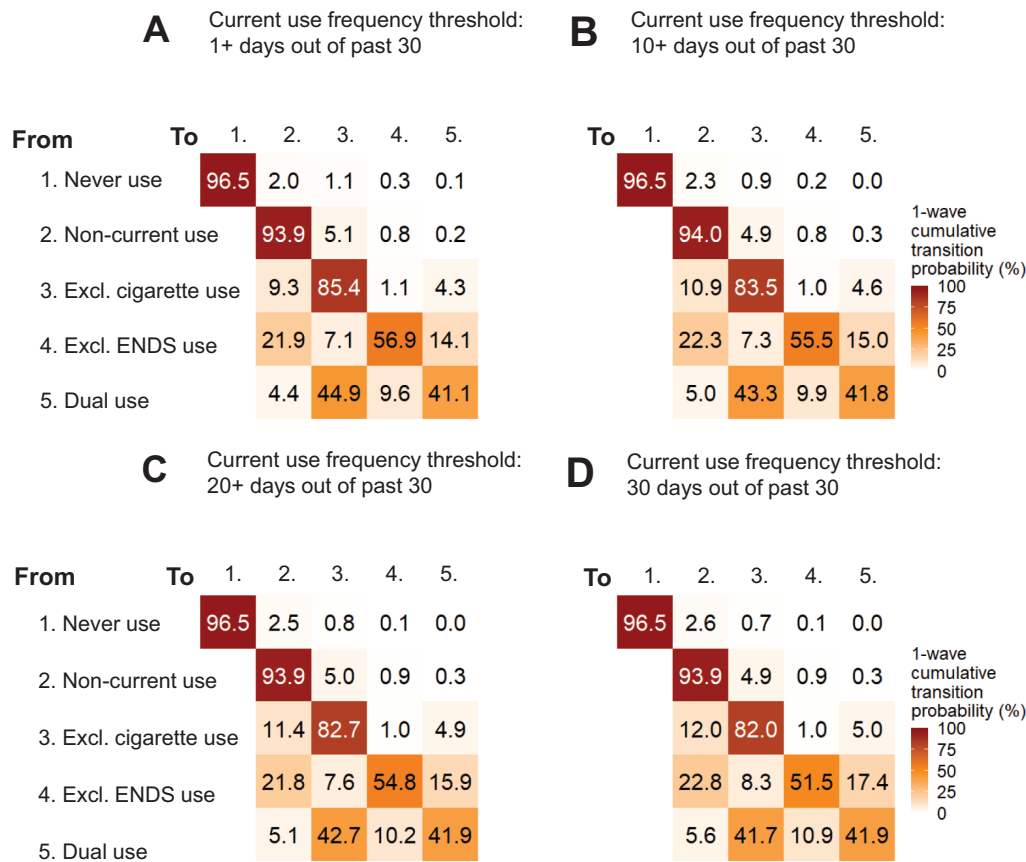


Figure 2. Heatmaps for 1-year transition probabilities between tobacco product use states as we changed the current use frequency threshold and treating infrequent users as non-current. Non-established cigarette and ENDS users are considered never users of that product.

largely robust to changes in the established-use criteria. Previously, removing the established-use criterion for ENDS resulted to decreased estimates of persistence. Here, removing it made little difference to the persistence estimates of frequent exclusive ENDS use (61.1% (57.5%–64.6%) in [Supplementary Figure S12A](#) to 59.0% (55.5%–62.6%) and 60.3% (59.0%–63.9%) in [Supplementary Figure S12B and C](#)). Similarly, we see only minor changes in the persistence estimates of infrequent exclusive ENDS use (21.1% (16.4%–25.8%) in [Supplementary Figure S12A](#) to 18.7% (16.1%–21.4%) and 17.3% (14.1%–20.6%) in [Supplementary Figure S12B and C](#)), although we did see a larger decrease in transitions to frequent exclusive ENDS use and an increase in transitions to non-current use (from 43.4% (43.3%–43.5%) to 53.2% (53.0%–53.4%) and 51.7% (51.7%–51.8%)). Consistent with the previous model, this latter result indicates that never regular, infrequent users are more likely to discontinue use.

Analysis 4: Transition Probabilities Depend on Current Use Frequency Thresholds in Models That Treat Infrequent Use as a Distinct Category

In [Supplementary Figure S16](#), we present heatmaps for 1-year transition probabilities as we changed the current use frequency threshold, while treating infrequent use as a distinct category. 95% CI bounds ([Supplementary Figures S17–S18](#)) and a comparison of the underlying transition rates ([Supplementary Figure S19](#)) are given in the supplementary material. Transitions patterns were not robust to

changes in the current use frequency thresholds, particularly for infrequent use categories. As we increased the current use threshold, thereby moving more users from the frequent to infrequent use states, the persistence of infrequent exclusive cigarette use increased (from 32.6% (29.1%–36.1%) with a 10+ day threshold ([Supplementary Figure S16A](#)) to 47.2% (45.2%–49.2%) with a 30-day threshold ([Supplementary Figure S16C](#))). Transitions to both non-current use and frequent exclusive cigarette use decreased in parallel with the increased threshold. This result indicates that persistence increases with the frequency of cigarette use. As we increased the current use threshold for ENDS use, the persistence of infrequent exclusive ENDS use also increased (from 14.7% (9.8%–19.5%) with a 10-day threshold ([Supplementary Figure S16A](#)) to 21.1% (16.4%–25.8%) with a 30-day threshold ([Supplementary Figure S16C](#))), though not as dramatically as for cigarette use. The dual use categories except for frequent use of both products were estimated to be more persistent with a higher use threshold; persistence of states 7–9 was 6.1% (0.0%–13.8%), 15.6% (7.6%–23.7%), and 15.9% (13.2%–18.6%) for the 10+ days threshold ([Supplementary Figure S16A](#)) and 9.5% (5.8%–13.2%), 25.0% (19.6%–30.4%), and 24.0% (21.2%–26.7%) for the 30-day threshold ([Supplementary Figure S16C](#)). Persistence of the frequent use of both products decreased with the increasing threshold (state 10, from 27.9% (24.6%–31.1%) in [Supplementary Figure S16A](#) to 11.5% (8.3%–14.7%) in [Supplementary Figure S16C](#)). These results indicate that use of both products frequently is not a persistent pattern of use.

However, changing the threshold of current use largely impacted only the transitions among the dual use categories and had comparatively less of an effect on transitions to single product use (states 3–6).

Discussion

This analysis demonstrated how estimates of transitions between different patterns of cigarette and ENDS use depend on (1) whether the definition of current use is restricted to established users and (2) the use frequency threshold used to define current use. We also found that the robustness of transition estimates to these definitions depended on whether we treated infrequent use (ie, using fewer days than the current use frequency threshold) as non-current use or as a distinct category of use. When we treated infrequent use as non-current, transition estimates are less robust to the established use criteria (when using a 1+ days frequency threshold) and more robust to the current threshold of use. When we treated infrequent use as a distinct category of current use, we found the opposite: estimates were more robust to the established use criteria (using a 30-day frequency threshold) and less robust to the current threshold of use.

Our findings indicate that non-established ENDS users are, not surprisingly, less likely to persist in their use than established ENDS users. However, we do not see as great of an effect for cigarette users. This result shows that while the 100+ lifetime cigarette criterion affects prevalence estimates,⁴ it does not substantially affect transition estimates. The differences in the impact of the established use criterion between the products may be related to the products themselves or to the definition of established use. While the 100+ lifetime cigarette threshold for established use has long been used by the field, ENDS were still relatively new in 2013–2017, and there is no clearly agreed on comparable measure for ENDS use. In the PATH data, information is available on whether participants “ever fairly regularly used ENDS.” It is not clear how analogous this criterion is to the 100+ lifetime cigarette criterion.

Previous analyses of tobacco product transitions have taken a variety of approaches to defining current ENDS use, from including all users but distinguishing multiple frequencies of use^{5,6,8,9} to distinguishing between experimental and established users but including all frequencies,^{11,12} to distinguishing between daily and non-daily experimental and established users¹³ to including all past 30-day users.^{14,16} Coleman et al.’s^{6,8} use of “infrequent” to indicate 0–2 days per month, “moderate” as someday use more than 2 days per month, and “frequent” users as daily users set a precedent that several other authors have followed. However, these categories have not been standardized; in the broader literature, daily or everyday versus non-daily or someday distinctions are common, but various studies have described lowest frequency of use categories as lesser than or equal to 4,²³ lesser than or equal to 5^{10,24} or lesser than or equal to 10²⁵ days per month and daily or frequent use categories defined as 15+,²⁶ 20+,^{10,24,25,27,28} or 25+ days^{4,29} when using a past 30-day definition. While variations in criteria can highlight subtleties in the data, they also limit comparability between studies. While we would ideally like our categorizations to reflect behavior and health impacts, there is likely no one correct answer because of the continuous nature of exposures. Practical concerns, including

distributions of frequency of use⁷ and established use may also be relevant to ensuring analyses are well powered. Moreover, ENDS users are known to self-titrate to achieve desired nicotine intake,³⁰ so that use patterns may depend on ENDS device characteristics, although self-titration may impact number of uses per day more than the number of days used per month. Ultimately, further research is needed to understand, define, and validate measures of established ENDS use.

We found that infrequent use was less persistent than frequent use, for both cigarettes and ENDS. Infrequent exclusive cigarette users were about equally likely to transition to non-current use or to frequent exclusive use, whereas infrequent exclusive ENDS users were most likely to transition to non-current use. Similar results have been shown for the PATH data using different methods.⁸ Distinguishing between infrequent and frequent use of both products as part of dual use did not reveal many clear, consistent patterns, and the transition estimates changed substantially with the current use threshold. These findings indicate that many dual users may fluctuate in the frequency of their use of both products. We did note that infrequent use of both products (particularly <10-day, [Supplementary Figure S16A](#)) and frequent use of both products (particularly 30-day, [Supplementary Figure S16C](#)) showed particularly transient patterns of use, which may offer insight into which users are most likely to change their patterns of use and thus how to target intervention efforts.

It is unclear whether our results for ENDS will hold for future waves of the PATH study. The data used in this study were collected from 2013 to 2017, largely before the widespread use of pod-based ENDS³¹ and prior to disposable systems.³² One limitation of our methods is that it does not directly consider participants’ full tobacco product use histories. Furthermore, our non-current use category captured short-term abstinence rather than longer-term cessation and did not distinguish between the types of products previously used. Because we were focusing on the impact of use criteria, we did not adjust for sociodemographic factors, although these should be incorporated when estimating transition rates for specific groups.¹²

Product-use definitions affect our assessment of tobacco and nicotine delivery product use transitions and thus will similarly influence our estimates of the public health impact of cigarette and ENDS control strategies. Here, we found that the robustness of our transition estimates to established and current-use criteria depended on whether infrequent use was treated as non-current use or as a separate category of use. Future analyses of transitions should be cognizant of the potential sensitivity of their results to the definitions of use and interpret them accordingly.

Supplementary Material

A Contributorship Form detailing each author’s specific involvement with this content, as well as any supplementary data, are available online at <https://academic.oup.com/ntr>.

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Declaration of Interests

None declared.

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Data Availability

Data are available at.²⁰ Example code is provided at <https://tcors.umich.edu/Resources.php>.

References

- Munafo M. Are e-cigarettes tobacco products? *Nicotine Tob Res.* 2019;21(3):267.
- Bondy SJ, Victor JC, Diemert LM. Origin and use of the 100 cigarette criterion in tobacco surveys. *Tob Control.* 2009;18(4):317–323.
- Centers for Disease Control and Prevention. Current Cigarette Smoking Among Adults in the United States; 2020. https://www.cdc.gov/tobacco/data_statistics/fact_sheets/adult_data/cig-smoking/index.htm. Updated 10 December 2020. Accessed November 1, 2021.
- Sanchez-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(1):1203.
- Parker MA, Villanti AC. Patterns and frequency of current e-cigarette use in United States adults. *Subst Use Misuse.* 2019;54(12):2075–2081.
- Coleman BN, Rostron B, Johnson SE, et al. Electronic cigarette use among US adults in the Population Assessment of Tobacco and Health (PATH) study, 2013–2014. *Tob Control.* 2017;26(e2):e1171–e126.
- Amato MS, Boyle RG, Levy D. How to define e-cigarette prevalence? finding clues in the use frequency distribution. *Tob Control.* 2016;25(e1):e24–e29.
- 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(1):50–59.
- Stanton CA, Sharma E, Edwards KC, et al. Longitudinal transitions of exclusive and polytobacco electronic nicotine delivery systems (ENDS) use among youth, young adults and adults in the USA: findings from the PATH study waves 1–3 (2013–2016). *Tob Control.* 2020;29(Suppl 3):s147–s154.
- Tam J, Brouwer AF. Comparison of e-cigarette use prevalence and frequency by smoking status among youth in the United States, 2014–19. *Addiction.* 2021;116(9):2486–2497.
- Wei L, Muhammad-Kah RS, Hannel T, et al. The impact of cigarette and e-cigarette use history on transition patterns: a longitudinal analysis of the population assessment of tobacco and health (PATH) study, 2013–2015. *Harm Reduct J.* 2020;17(1):45.
- 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.* 2022;31:424–431.
- Azagba S, Qeadan F, Shan L, Latham K, Wolfson M. E-Cigarette use and transition in adult smoking frequency: a longitudinal study. *Am J Prev Med.* 2020;59(3):367–376.
- Cobb CO, Villanti AC, Graham AL, et al. Markov modeling to estimate the population impact of emerging tobacco products: a proof-of-concept study. *Tob Regul Sci.* 2015;1(2):12941.
- Everard CD, Silveira ML, Kimmel HL, et al. Association of electronic nicotine delivery system use with cigarette smoking relapse among former smokers in the United States. *JAMA Netw Open.* 2020;3(6):e204813.
- 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(5):647–654.
- Villanti AC, Pearson JL, Glasser AM, et al. Frequency of youth e-cigarette and tobacco use patterns in the United States: measurement precision is critical to inform public health. *Nicotine Tob Res.* 2017;19(11):1345–1350.
- Kaufman AR, Land S, Parascandola M, Augustson E, Backinger CL. Tobacco use transitions in the United States: the national longitudinal study of adolescent health. *Prev Med.* 2015;21(4):458–468.
- Hair EC, Romberg AR, Niaura R, et al. Longitudinal tobacco use transitions among adolescents and young adults: 2014–2016. *Nicotine Tob Res.* 2018;1:11.
- National Institute on Drug Abuse, Food and Drug Administration Center for Tobacco Products. *Population Assessment of Tobacco and Health (PATH) Study [United States] Public-Use Files User Guide*; 2019. Ann Arbor, MI: Inter-university Consortium for Political and Social Research [distributor], 2019-11-21.
- Durrett R. *Essentials of Stochastic Processes*. New York, NY: Springer; 1999.
- Jackson C. Package “msm”; 2019. <https://cran.r-project.org/web/packages/msm/msm.pdf>.
- Owusu D, Huang J, Weaver SR, et al. Patterns and trends of dual use of e-cigarettes and cigarettes among U.S. adults, 2015–2018. *Prev Med Rep.* 2019;16:101009.
- Sawdey MD, Chang JT, Cullen KA, et al. Trends and associations of menthol cigarette smoking among US Middle and High School students-national youth tobacco survey, 2011–2018. *Nicotine Tob Res.* 2020;22(10):1726–1735.
- Harlow AF, Fetterman JL, Ross CS, et al. Association of device type, flavours and vaping behaviour with tobacco product transitions among adult electronic cigarette users in the USA. *Tob Control.* 2021. doi:10.1136/tobaccocontrol-2020-055999
- Hammond D, Reid JL, Rynard VL, et al. Prevalence of vaping and smoking among adolescents in Canada, England, and the United States: repeat national cross sectional surveys. *BMJ.* 2019;365:l2219.
- Cullen KA, Ambrose BK, Gentzke AS, et al. Notes from the field: use of electronic cigarettes and any tobacco product among middle and high school students - United States, 2011–2018. *MMWR Morb Mortal Wkly Rep.* 2018;67(45):1276–1277.
- Miech R, Johnston L, O'Malley PM, Bachman JG, Patrick ME. Trends in adolescent vaping, 2017–2019. *N Engl J Med.* 2019;381(15):1490–1491.
- Pierce JP, Chen R, Leas EC, et al. Use of E-cigarettes and other tobacco products and progression to daily cigarette smoking. *Pediatrics.* 2021;147(2):e2020025122.
- Dawkins LE, Kimber CF, Doig M, Feyerabend C, Corcoran O. Self-titration by experienced e-cigarette users: blood nicotine delivery and subjective effects. *Psychopharmacology (Berl).* 2016;233(15):2933–2941.
- Huang J, Duan Z, Kwok J, et al. Vaping versus JUULing: how the extraordinary growth and marketing of JUUL transformed the US retail e-cigarette market. *Tob Control.* 2019;28(2):146–151.
- Delnevo C, Giovenco DP, Hrywna M. Rapid proliferation of illegal pod-mod disposable e-cigarettes. *Tob Control.* 2020;29(e1):e150–e151.