Repeated point-prevalence of switching away from smoking after electronic nicotine delivery systems (ENDS) purchase

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Abstract

Background Adults who smoke cigarettes can benefit from switching completely to electronic nicotine delivery systems (ENDS). Research is needed to examine longer-term switching trajectories beyond one year of follow-up.

Methods This analysis of a previously-described longitudinal cohort study of adults who smoke and purchased JUUL focused on $N = 11,153$ who completed the 12-month (12 M) follow-up and ≥ 1 of 4 surveys in the second year (Y2; at 15, 18, 21, and 24 months). Outcomes were repeated point prevalence of product use over the past-30-days (P30D) at each Y2 follow-up: repeated point prevalence-switching (i.e., no P30D smoking at any available Y2 follow-ups), repeated point prevalence-smoking, or varying status. Associations between product use status at 12M (switched, exclusive smoking, or dual used) and Y2 product use patterns were examined.

Results Most adults who smoked at baseline and were switched at 12 M reported repeated point prevalence-switching over Y2 (69.5%); repeated point prevalence-smoking was rare (6.2%). In contrast, > 50% of those who were smoking at 12 M (exclusively or with ENDS [JUUL or other brand]) persistently smoked over Y2. Supplementary analyses showed that among adults who exclusively used ENDS at 12 M, those who used ENDS *daily* were more likely to persistently switch over Y2; similarly, among adults who smoked at 12 M (either exclusively or dual-use with ENDS) those who smoked *nondaily* were more likely to persistently switch over Y2. Over half of adults who dual used at both 12 M and 24 M substantially reduced (i.e., by 50%+) their baseline cigarette consumption.

Conclusions For the majority of participants, product use status at 12 M was consistent with use patterns in the second year: most adults who smoked at baseline and were switched at 12 M reported repeated point prevalence-switching over Y2, while *any* smoking at 12 M– especially daily smoking– was usually followed by repeated point prevalence-smoking. These findings indicate that switching and smoking behavior is generally maintained and remains stable one year after purchasing ENDS.

Keywords Electronic nicotine delivery systems, ENDS, Persistent switching, Longitudinal cohort study

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Background

Cigarette smoking remains a major cause of morbidity and mortality in the U.S., leading to more than 480,000 premature deaths every year [1]. Adults who smoke and otherwise would not quit in the near term are likely to benefit from switching completely to noncombustible nicotine products that expose consumers to lower levels of toxic chemicals and may pose lesser harm [2–5], a public health strategy known as tobacco harm reduction. E-cigarettes, or electronic nicotine delivery systems (ENDS), have emerged as promising lower-risk products for tobacco harm reduction: systematic reviews of clinical trials demonstrate that ENDS are more effective than nicotine replacement therapy (NRT) for smoking cessation [6]. Importantly, given that only approximately 15% of adults who smoke at any given time are planning to quit smoking within the next 30 days [7] (standard criterion for provision of smoking cessation treatment), ENDS also have wider reach than medicinal treatments, to the majority of adults who smoke and are *not* immediately willing to quit or seek medication. Many adults who smoke and initiate ENDS use outside of a smoking cessation treatment context switch completely away from cigarettes [8–17], often following a transient stage of dual (concurrent) use of both products [18]. The proportion of adults who used ENDS to stop smoking is high and increasing nationwide [16, 17, 19]. However, many of these studies had short-term follow-up periods of one year or less [13, 15–17, 19–21], thus it is important to understand longer-term (> 1 year) trajectories of tobacco and nicotine product use behaviors in adults who smoke and adopt ENDS.

A few prior papers have examined longer-term switching by analyzing multiple waves of the Population Assessment of Tobacco and Health (PATH) Study. For instance, among adults who smoked and used ENDS daily in Wave 1, 21% reported that they did not smoke at all in the past 30 days (P30D) two years later at Wave 3, and 11% reported no P30D smoking at *both* Waves 2 and 3 [10]. Similarly, among adults who dual used (i.e., both cigarettes and ENDS) at Wave 1, 8.3% discontinued all tobacco/nicotine products two years later (Wave 3), and 5.4% reported using ENDS exclusively [22]. However, these studies are limited by the coarse temporal resolution of PATH: outcomes were P30D point prevalence at each annual follow-up, which may not necessarily represent *repeated or persistent* switching over that year and does not fully elucidate the trajectory of product use over that period. Additionally, a focus on those who are dual using at baseline omits adults who previously smoked but had already successfully switched to ENDS, likely underestimating switching rates.

Another source of information on long-term switching among adults who smoke is the Adult JUUL Switching and Smoking Trajectories (ADJUSST) study, a longitudinal naturalistic observational study of US adults who purchased a Starter Kit of JUUL [23], a widely-used pod-based brand of ENDS. Previous analyses of ADJUSST data show that more than half (51.2%) of adults who currently smoked and had an established smoking history at baseline were completely switched away from smoking (defined as no smoking in P30D) at Month 12 [24]. Additionally, 21.6% of adults who smoked at baseline reported repeated point prevalence (RPP) of switching (i.e., past-30-day abstinence from smoking at each survey wave) over the second half of the first year, which could indicate sustained or persistent switching over six months [25].

In ADJUSST, most of the adults who smoked at baseline and did not switch completely at follow-up dual-used JUUL and cigarettes. While some studies have raised concern about the possibility that dual use could increase cumulative exposures to toxicants [26, 27] and prolong cigarette smoking [28, 29], the ADJUSST study instead found dual use to be a transitional state towards complete switching: dual use was initially common (~72.3% at 1 M) but declined over time (to 43.2% at 12 M) [18], giving way to complete switching. Moreover, the majority of adults who dual used substantially reduced (by 50%+) their baseline cigarette consumption [18]– a degree of reduction which produces material reductions in exposure to tobacco-related toxicants and carcinogens [30–32].

However, dual use is a heterogenous state, spanning the spectrum from predominant smoking with occasional ENDS use, to predominant ENDS use with occasional smoking, in addition to a range in absolute consumption levels (e.g., cigarettes per day). For example, analyses of PATH data have found biomarkers of exposure to toxic compounds differed widely across subcategories of dual use, with the highest exposures in adults whose dual use patterns involved frequent smoking (i.e. on 20 + days out of P30D) [33] and who smoked more heavily (i.e., 10 + cigarettes per day (CPD)) [34]. Thus, the public health implications, and possibly the behavioral implications, differ by subcategory of dual use, making it important to stratify analyses of dual use.

More recent data are now available from a second year of follow-up in ADJUSST, showing that switching increased to 58.6% by Month 24 (from 51.2% at Month 12) [35]. However, that analysis only considered point-prevalence switching (i.e., in the P30D at each time point). It would be informative to understand patterns of *repeated* point-prevalence of switching (RPP-switching) over multiple time points in the second year, and to shed light on how such patterns are related to behavior in the first year. The current analysis also examines product use status at the end of the first year (switched, dual used, or exclusively smoking in P30D at 12 M) among adults

who smoked at baseline and how 12 M product use status relates to RPP patterns of product use over the second year of follow-up. The analysis also examines how patterns of dual use at 12 M relates to Y2 product use patterns.

Methods
Participants
Data were drawn from the previously-described ADJUSST Study, a naturalistic prospective observational study of adults (21+) who purchased a JUUL Starter Kit in late 2018 and were invited to follow-up surveys ten times over two years (at 1, 2, 3, 6, 9, 12, 15, 18, 21, and 24 months). The study assessed participants' naturalistic smoking behavior and use of JUUL and other (non-JUUL) ENDS, without any expectations of quitting or switching away from smoking, and without any intervention or provision of products. At baseline, $N = 22,905$ participants were smoking "some days" or "every day" in P30D and had an established smoking history (100 + lifetime cigarettes). Of these, $N = 11,153$ completed the 12-month (12 M) follow-up as well as 1 + follow-up(s) in the second year (15, 18, 21, or 24 M)—this was the final set of participants. Participants who missed a follow-up could participate in subsequent ones; approximately 80% of analyzed participants completed any given Y2 follow-up.[1] Previous analyses indicate that the potential for bias due to nonresponse is low [23]. As missing follow-ups contain ambiguity about product use status, we present supplementary analyses of $N = 5956$ participants with complete data from 12 to 24 M (see Analyses). The ADJUSST study was approved by the Advarra® Institutional Review Board (IRB). All participants provided written informed consent and were compensated $30 for each survey completed, without respect to their smoking or JUUL use.

Measures
12 M point-prevalence product use
P30D point prevalence of product use at 12 M was categorized as *switching* completely away from cigarettes (i.e., no smoking in P30D, not even a puff– regardless of JUUL or other ENDS use), *dual use* of both cigarettes and ENDS (JUUL or other) in P30D, or *exclusive smoking* (i.e., smoked in P30D but did not use any ENDS). A limitation is that P30D JUUL use and other ENDS use were not assessed equivalently ("even a puff" vs. "used fairly regularly," respectively), which may under-capture other ENDS use.

RPP patterns of product use over Y2
RPP patterns of product use over Y2 were categorized as a three-level variable: RPP-switching (i.e., no smoking in the P30D at all available Y2 follow-ups), RPP-smoking (i.e., P30D smoking at all available Y2 follow-ups), or varying status. For participants who missed some follow-ups, their Y2 RPP product use could not always be known with certainty; however, supplementary analyses found no notable distinction between "known" RPP status (i.e., reported at all Y2 time points) vs. "possible" RPP status (i.e., missing some Y2 time points); available reports showed a consistent status with no evidence of variation (Supplementary Fig. 1). Thus, for parsimony, the main analyses combined known and possible RPP statuses.

Subcategories of dual use at 12 M
Based on prior research showing that dual use is a heterogeneous category with respect to frequency of smoking and ENDS use [33, 34, 36], we categorized respondents' dual use at 12 M into subcategories based on daily vs. nondaily smoking and/or ENDS use. These subcategories were derived from separate questions about cigarette use in P30D, and use of JUUL and other ENDS "now," each as use on "some days" (nondaily) vs. "every day" (daily). Responses for JUUL and non-JUUL ENDS were combined as: daily ENDS use (of at least one brand category (JUUL or non-JUUL)) vs. nondaily ENDS use (for all brand categories that were used). For participants who used both JUUL and other ENDS on "some days," it was unknown whether total ENDS use amounted to daily or nondaily use. In the main analyses, we assume concurrent nondaily JUUL use and nondaily use of other ENDS amounts to nondaily use of ENDS overall, and examine the alternate assumption (i.e., that together this results in daily use) in supplementary sensitivity analyses. This assumption affected only 1.9% of adults who exclusively used ENDS at 12 M with valid data on daily/nondaily use, and 4.2% of adults who dual used at 12 M with valid data on daily/nondaily ENDS use and smoking, and did not materially alter the main findings (compare Supplementary Figures S2 and S3).

Baseline smoking characteristics
Covariates included several measures of smoking behavior and history at baseline. Cigarettes per day (CPD) was calculated as an average over P30D, including over nonsmoking days (i.e., CPD on smoking days × number of days smoked in P30D / 30 days). As a separate variable, smoking frequency was the number of days smoked in P30D at baseline, as was years of smoking duration. Baseline cigarette dependence was assessed with the Adult Tobacco Dependence (TD) Index, a composite measure of 16 items ranging from 1 (low dependence) to 5 (high

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[1] Ns at each Y2 follow-up are as follows: N at 15 M = 9202; N at 18 M = 8955; N at 21 M = 9025; N at 24 M = 8888.

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dependence), which has been previously validated in the PATH Study [37, 38].

Analyses

Descriptive analyses examined the association between 12 M point-prevalence product use (switched, dual used, or exclusively smoked at 12 M) and RPP patterns of product use over Y2 (persistent switching, varying status, and persistent smoking). Within each 12 M group, supplementary analyses examined whether there were further differences by *frequency* of use (see Supplementary Methods 1; Supplementary Figs. 2–4 which include sensitivity tests with different variable definitions).

Multinomial logistic regression analyses examined the association between 12 M point-prevalence product use (switched, dual used, or exclusively smoked in P30D) and RPP patterns of product use across Y2, while adjusting for sociodemographic factors (age, sex, race/ethnicity, education, and income) and baseline smoking characteristics (CPD, smoking frequency, smoking duration, and cigarette dependence); all variables were retained as they were not strongly collinear (all variance inflation factors (VIF) < 2.12, well below the common thresholds of 4–10 that are considered to bias estimates [39]). Follow-up supplemental analyses examined whether frequency of corresponding product use *within* each 12 M product use category were further associated with Y2 RPP product use (Supplementary Methods 1; Supplementary Table S2).

Since missed follow-ups in Y2 introduce ambiguity into product use categories, additional supplementary analyses examine the main analyses above among the subset of $N = 5956$ participants who completed all relevant follow-up assessments (12-24 M) (see Supplemental Methods 1; Supplementary Figure S5 for descriptive association; Supplementary Tables S3 and S4 for multinomial regression results).

Finally, supplemental analyses examined changes from baseline cigarette consumption among adults who dual used at both 12 M and 24 M (Supplementary Methods 1; Supplementary Table S5; Supplementary Results 3). All analyses were performed in R version 4.3.2, and multinomial regressions were performed using the mlogit package [40]. This study's design and its analysis were not pre-registered. Supplemental figures and tables are in the online supplemental materials. The analyzed data are not publicly available. Analytical code used to conduct the analyses is available upon a reasonable request to the corresponding author. The survey instrument for the current survey is publicly available at: https://www.juullabs.com/wp-content/uploads/2021/03/ADJUSST-Baseline-and-Follow-Up.pdf.

Results

Participant characteristics

The final set of participants was just over half male (54.3%), majority non-Hispanic white (77.7%) and was age 30 on average (Supplementary Table S1). Just over 40% had attended some college or obtained an associate's degree, and just under 30% had a bachelor's degree or higher. Slightly over half of analyzed participants (54.1%) had an annual income of $50,000 USD or less. Adults who smoked at baseline and were switched at 12 M were younger than those who smoked at 12 M (either exclusively, or dual used), though the difference was modest (median age 29 years vs. 31 and 31.5, respectively, $p < .0001$). The final set of participants did not differ with respect to other sociodemographic differences according to their product use status at 12M ($p > .05$ for all; Supplementary Table S1).

At baseline, the final set of participants averaged 8.3 cigarettes per day, most smoked daily (median 30 days), had smoked for approximately 10 years, and had fairly high cigarette dependence relative to the US population of adults who smoke in the PATH Study (median score 3.1 on the 1–5 TD index) [41]. Adults who smoked at baseline and were switched at 12 M had lower baseline CPD than those who dual used or exclusively smoked (6.7 vs. 10 in both groups, respectively, $p < .0001$), smoked less frequently (28 days vs. 30 days out of the past 30 in both groups, respectively, $p < .0001$), had smoked for fewer years (8 vs. $10 \sim 11$ years, respectively, $p < .0001$), and had materially lower baseline cigarette dependence (2.9 vs. 3.1–3.2, respectively, $p < .0001$) (see Supplementary Table 1), consistent with a similar analysis of these participants on switching over all Y1 timepoints [24].

Year 2 product use patterns by 12 M status

When examining RPP patterns of product use over Y2 by 12 M status (Fig. 1), the majority (69.5%) of participants who were switched at 12 M reported RPP-switching over Y2, and returning to RPP-smoking was rare (6.2%); the remaining 24.4% had varying status over Y2. Conversely, over half (59.5%) of participants who exclusively smoked at 12 M reported RPP-smoking over Y2, while approximately one-third (30.1%) had varying status and approximately one-tenth (10.3%) reported RPP-switching. Adults who dual used at 12 M overall had similar outcomes to those who exclusively smoked at 12 M, with over half (55.4%) reporting RPP-smoking over Y2, approximately one-third (32.2%) having had varying status, and just over one-tenth (12.4%) reporting RPP-switching.

Supplementary analyses examined additional stratification within each 12 M product use category, by frequency of smoking and/or ENDS use (Supplementary Figures S2-S4, Supplementary Results 1): among participants who exclusively used ENDS at 12 M, those who used them
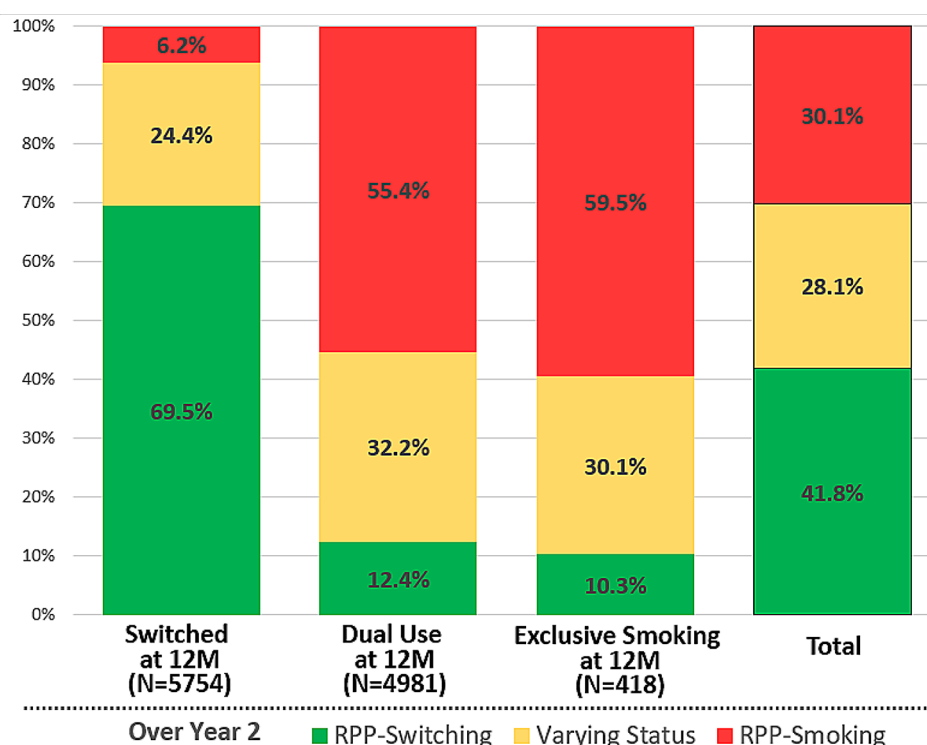
Fig. 1 Repeated point-prevalence (RPP) patterns of product use over the second year of follow-up, by 12 M product use status. Note. Participants are *N* = 11,153 adults who currently smoked at baseline, had an established smoking history at baseline, and completed the 12 M follow-up as well as 1 + follow-up in Y2

more frequently were more likely to persistently switch over Y2, while among participants who smoked at 12 M (either exclusively or dual use with ENDS), those who smoked cigarettes more frequently were more likely to intermittently or persistently smoke over Y2. These findings were robust across different assumptions about dual use subcategories and different categorizations of frequency of ENDS use.

Supplementary analyses of the subset with complete data over 12-24 M showed modestly lower rates of RRP-switching over Y2 (< 5% points), but very similar associations with 12 M product use status (Supplementary Figure S5, Supplementary Results 1).

Multinomial regression of RPP patterns of product use over Y2 on 12 M product use

After adjusting for baseline smoking behavior (Table 1), participants who were switched at 12 M had over 60 times the odds of reporting RPP-switching over Y2 (vs. RPP-smoking) than did participants who exclusively smoked at 12 M (aOR [95% CI] = 61.53 [43.28–87.48], *p* <.0001). Additionally, participants who were switched at 12 M and *did* smoke in Y2 had over 7 times the odds of having only *intermittently* smoked (i.e. varying status) over Y2 (vs. RPP-smoking; aOR[95% CI] = 7.10 [5.51–9.16], *p* <.0001). Adults who dual used at 12 M, on the other hand, had similar odds of RPP patterns of product

use over Y2 as adults who exclusively smoked at 12M (*p* >.05 for all comparisons). With respect to baseline smoking behavior, participants who had higher cigarette consumption and smoked more frequently had lower odds of RPP-switching and varying status over Y2 (vs. RPP-smoking) over Y2.

Supplementary analyses showed that within each 12 M product use category, frequency of product use was additionally associated with RPP product use patterns over Y2 (Supplementary Table S2, Supplementary Results 2). Briefly, among adults who exclusively used ENDS at 12 M, those who did so daily had significantly higher odds of RPP-switching over Y2, while among those who smoked at 12 M (either exclusively or dual-use with ENDS), those who did so *infrequently* were more likely to persistently switch over Y2. Additional sensitivity analyses using the subset of participants who provided complete data over 12-24 M showed broadly consistent results (Supplementary Tables S3-S4; Supplementary Results 2).

Changes in cigarette consumption among adults who dual used

Changes in cigarette consumption were examined among adults who dual used at both 12 M and 24 M (Supplementary Table S5, Supplementary Results 3). Briefly, over half of adults who dual used at both 12 and 24 M

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Table 1 RPP patterns of product use over 2nd year as function of 12 M status

		RPP-Switching (vs. RPP-Smoking)			Varying Status (vs. RPP-Smoking)		
		aOR[a]	CI	P	aOR[a]	CI	P
Behavior at 12 M	Switched (N=5754)	**61.53**	**43.28–87.48**	**< 0.0001**	**7.10**	**5.51–9.16**	**< 0.0001**
	Dual Used (N=4981)	1.30	0.92–1.84	0.1324	1.13	0.90–1.43	0.2940
	Exclusively smoked (N=418)	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Baseline cigarette consumption[b]		**0.99**	**0.98–1.00**	**0.0031**	**0.99**	**0.98–0.99**	**0.0003**
Baseline smoking frequency[c]		**0.98**	**0.97–0.99**	**0.0012**	**0.99**	**0.98–1.00**	**0.0044**
Baseline smoking duration[d]		**0.98**	**0.97–0.98**	**< 0.0001**	**0.96**	**0.95–0.96**	**< 0.0001**
Baseline cigarette dependence[e]		0.98	0.91–1.05	0.4819	0.99	0.93–1.06	0.8153

Note. P30D: Past 30 days. Bold: $p < .05$. Participants are $N = 11,153$ adults who currently smoked at baseline, had an established smoking history at baseline, and completed the 12 M follow-up as well as 1+follow-up in Y2

a: In addition to adjusting for baseline smoking behavior and history, sociodemographic characteristics were also adjusted for in these models

b: Baseline cigarette consumption is an average of cigarettes per day (CPD) over P30D, including nonsmoking days (i.e. CPD on smoking days × number of days smoked in P30D / 30 days)

c: Number of smoking days in P30D

d: Years of smoking duration at baseline

e: Assessed using the Adult Tobacco Dependence (TD) Index, a composite of 16 items ranging from 1 (low dependence) to 5 (high dependence)

substantially reduced their baseline cigarette consumption by 50%+ at 12 M; among those who did, the median reduction was 83.3% (from 12.0 CPD at baseline to 1.5 CPD at 12 M). These reductions remained similar at 24 M. There was also notable variation in changes in cigarette consumption over subcategories of dual use, with greater reductions observed among adults whose dual use patterns involved daily ENDS use.

Discussion

Among these participants who smoked at baseline and were followed for two years after first purchasing a JUUL-brand ENDS starter kit, smoking behavior at 12 M was a strong predictor of smoking behavior over the second year of follow-up. Nearly 70% of adults who smoked at baseline and were switched at 12 M (i.e., no smoking in P30D) did not report smoking across the four timepoints in the second year of follow-up (15-24 M)– a pattern of use that is suggestive of persistent or sustained switching throughout the second year. Conversely, adults who smoked at baseline and continued to smoke *at all* in the P30D at 12 M (whether exclusive smoking or dual use with JUUL or other ENDS) were highly likely to smoke in Y2, either at repeated follow-ups (~55–60%; suggestive of persistent or sustained smoking over Y2) or intermittently (~30–32%). Among adults who dual used in a manner involving *nondaily* (s. daily) smoking at 12 M were comparatively more likely to report RPP-switching over Y2, all dual-use subgroups were nevertheless least likely to report RPP-switching (versus intermittent or sustained smoking (3-13% across subgroups). However, most adults who dual used in a pattern involving *nondaily* smoking (~63–83% across groups and time points) substantially reduced their baseline cigarette consumption (i.e., by 50%+) at 12 and 24 M; among those who did, total reductions in baseline CPD averaged 80–90%, and

those who did reduce baseline cigarette consumption to this degree had nearly three times the odds of RPP-switching over Y2 (versus RPP-smoking).

These findings suggest that adults smoked and who are able to completely switch (no past 30-day smoking) one year after adopting ENDS are often able to remain abstinent from smoking. Adults who smoked at baseline and were completely switched at 12 M were unlikely to return to smoking in Y2, and were especially unlikely to *persistently* smoke. Thus, adults who smoked at baseline and are switched at 12 M after adopting ENDS are likely to report repeated switching, which is suggestive of persistent or sustained switching through at least two years of follow-up; this behavior could potentially persist for longer periods of time, which is necessary for adults who smoke to experience the maximal health benefits of smoking abstinence. Indeed, a separate case-control study of adults who smoked at baseline and were followed long-term (average 3 years) found that those who switched to JUUL had a consistent and substantial reduction in various biomarkers representing the level of exposure to harmful chemicals (i.e., NNAL, HPMA3, etc.) and biological responses that precede disease development (e.g., lower systemic inflammation and oxidative stress) [42]. Together, these findings indicate that substantial proportions of adults who smoke and adopt ENDS subsequently switch completely away from cigarettes for extended periods of time (especially the majority that had switched at 12 M), which in turn, is associated with reduced exposure to harmful chemicals and tobacco-related harm.

In contrast, *any* smoking, but especially *daily* smoking at 12 M (either dual use or exclusive smoking), most often was followed by RPP-smoking over Y2 follow-ups, suggesting persistent or sustained smoking; conversely, RPP-switching over Y2 was rare for adults who smoked

at 12 M. This finding is an important divergence from a previous analysis on Y1 of the same ADJUSST participants: in Y1, dual use was a transient state, declining from 72.3% at 1 M to 43.2% at 12 M, with the vast majority of transitions leading to complete switching (vs. exclusive smoking) [18]. Together these findings suggest that while dual use is initially (< 1 year) part of the process of switching away from cigarettes, dual use that persists for longer periods (≥ 1 year) may be a signal of greater difficulty in complete switching away from cigarettes. Thus, most adults who smoke and adopt ENDS seem to stabilize their product use patterns by 12 M, and usually continue those patterns through all observed follow-ups in Y2, with only modest changes during the second year aside from a modest increase in switching.

Although smoking status at 12 M was the strongest predictor of Y2 product use patterns, supplementary analyses showed notable heterogeneity based on frequency (daily vs. nondaily) of product use, particularly for smoking frequency. Among adults who either exclusively smoked or dual used at 12 M, those who smoked daily were less likely to subsequently report RPP-switching over Y2 (by nearly 10% points), and more likely to report RPP-smoking (by ~ 30% points). Adults who dual used in a pattern involving *nondaily*-smoking (vs. daily smoking) had approximately twice the odds of RPP-switching in the 2nd year. This association may be related to substantial reductions (50%+) in cigarette consumption, as adults who dual used at 12 M and substantially reduced their baseline cigarette consumption had three times the odds of reporting RPP-switching over Y2. Nevertheless, it is important to note that RPP-smoking was the most common product use pattern over Y2 among adults who dual used at 12 M, even after accounting for the relative advantage of nondaily smoking.

ENDS use frequency was also associated with some differences in Y2 product use patterns, but only among adults who smoked at baseline and exclusively used ENDS at 12 M: those who used ENDS daily (vs. nondaily) at 12 M were more likely to report RPP-switching over Y2, though RPP-switching was the most common Y2 product use pattern for both groups (~ 72% vs. 62%, respectively). This suggests that persistent ENDS use could reduce risk of relapse to smoking among some adults who have successfully switched to ENDS, though further research is needed to evaluate this, especially in studies that have a comparison group of participants who did *not* use ENDS. These findings also concord with previous findings that dual use is a heterogeneous category that varies by frequency of use [36], and extend these to show heterogeneity in ENDS use and exclusive smoking as well.

With respect to changes in cigarette consumption, the subset of participants who were dual using at both 12 M and 24 M follow-ups had substantially reduced (by 50%+) their baseline cigarette consumption at both 12 M and 24 M. Among adults who dual used and substantially reduced their baseline cigarette consumption, actual reductions were much larger than the 50% threshold, exceeding 80%. These overall patterns varied across subcategories of dual use, with adults who dual used in a manner involving nondaily (vs. daily) smoking and/or daily (vs. nondaily) ENDS use exhibiting the largest reductions in cigarette consumption. Reductions persisted for most adults who dual used at 24 M; adults who dual used at 12 M in a manner involving daily smoking showed larger reductions (in terms of the proportion who substantially reduced, as well as the magnitude of reduction) at 24 M than at 12 M. While adults who dual used at 12 M in a manner involving *nondaily* smoking showed a partial reversal of reduction at 24 M (i.e., the proportion who substantially reduced was ~ 10% points lower vs. 12 M), this reversal was small in magnitude, restricted to those with low baseline cigarette consumption, and outweighed by the majority who did substantially reduce their baseline cigarette consumption. Substantial reductions of 50%+ in cigarette consumption are associated with significant reductions in toxicant exposure [30] which are considered to be a meaningful public health outcome by the US Food & Drug Administration (FDA) [43, 44]. Thus, despite complete switching being the optimal outcome for adults who smoke and are unlikely to quit, dual use is often likely associated with some degree of harm reduction as well, particularly among adults who dual use in a pattern involving nondaily smoking.

Limitations of this study include the observational nature of this study, and the lack of a comparison group of participants who did *not* purchase JUUL, precluding causal conclusions. The ADJUSST participants analyzed here are not representative of all adults who smoke or use ENDS; since these participants were selected based on their purchase of a JUUL Starter Kit and thus already had some level of commitment and interest in using the product, these findings may not generalize to adults who use ENDS more casually. Since the study included predominantly non-Hispanic and White participants, the findings may not generalize to non-White adults. Another limitation is possible bias from incomplete follow-up completion, especially if non-completion were associated with higher smoking rates; however, previous analyses of loss-to-follow-up concluded that non-completion was not strongly associated with smoking, and that the bias due to non-completion is likely to be small [23]. Moreover, supplementary analyses of the subset of participants who provided complete data at all Y2 follow-ups, which avoided ambiguity in product use at missed follow-ups, showed broadly similar findings. Data on P30D use of JUUL vs. other ENDS was not assessed equivalently,

leading to possible underestimation of other ENDS use; however, this is unlikely to substantially impact overall findings, given the predominance of JUUL use among the participants analyzed here (e.g., see Supplementary Figure S3 which shows similar findings excluding other ENDS entirely). Similarly, data on frequency of smoking vs. JUUL/ENDS use was not assessed equivalently (in P30D vs. "now"); however, this difference in time frame would only impact people who have changed their frequency of use over the past month, so is unlikely to impact the main categorization of daily vs. nondaily use. Additionally, data are not available to assess truly continuous or persistent abstinence (i.e., between follow-ups in Y2), and it is possible that some participants reporting RPP-switching could have smoked in between follow-ups, as each follow-up assessed behavior only in the preceding month, but follow-ups were spaced three months apart in Y2. Further, use of tobacco or nicotine products other than cigarettes or ENDS was not assessed; thus, adults who reported using neither product were not necessarily abstaining entirely from nicotine. Finally, consistent with other nationally representative observational studies such as PATH [10, 22], data was based on self-reports that were not biochemically verified.

Strengths of the study include a large national set of participants who smoked at baseline, and multiple follow-ups over an extended time period (10 times over 2 years). The naturalistic aspect of the ADJUSST study is also a strength, as it allows an examination of the potential impact of JUUL and other ENDS across a large and heterogeneous real world set of participants who smoked at baseline, including those who were not planning to quit smoking (which comprise the majority of adults who smoke).

Conclusions

Among adults who smoked at baseline and adopted JUUL ENDS, smoking status at 12 M strongly predicted tobacco and nicotine product use patterns over Y2, with those who were switched at 12 M most often reporting repeated past 30-day abstinence from smoking over all available Y2 follow-ups, suggesting persistent switching. While *any* smoking at 12 M was most often followed by smoking in Y2, adults who dual used such that they smoked nondaily (vs. daily) were comparatively more likely to report RPP-switching over Y2. Moreover, most adults who dual used at 12 M had reduced their daily cigarette consumption, and those who meaningfully reduced their cigarette consumption had higher odds of reporting RPP-switching over Y2. These findings demonstrate ENDS' potential to facilitate complete and persistent switching away from cigarettes among adults who smoke, and to facilitate meaningful reductions in cigarette consumption among those who continue smoking,

to a degree that produces material reductions in biomarkers of exposure [30] that the FDA considers to contribute to the protection of public health [43, 44]. These findings indicate that switching and smoking behavior are stable one year after purchasing ENDS: maintaining complete switching away from cigarettes for extended periods has the greatest potential to benefit public health and future research should continue to evaluate factors associated with and mechanisms underlying patterns of long-term switching behavior.

Abbreviations

ADJUSST	the Adult JUUL Switching and Smoking Trajectories study
ENDS	Electronic Nicotine Delivery System
FDA	US Food and Drug Administration
P30D	Past 30-Day
PATH	Population Assessment of Tobacco and Health study
RRP	Repeated Point Prevalence

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12954-025-01231-x.

Supplementary Material 1

Data availability
The analyzed data are not publicly available. The survey instrument for the current survey is publicly available at: https://www.juullabs.com/wp-content/uploads/2021/03/ADJUSST-Baseline-and-Follow-Up.pdf.

Declarations

Ethics approval and consent to participate
The ADJUSST study was approved by the Advarra® Institutional Review Board (IRB). All participants provided written informed consent and were compensated $30 for each survey completed, without respect to their smoking or JUUL use.

Consent for publication
Not applicable.

Competing interests
This study was sponsored by JUUL Labs, Inc (JLI), and the preparation of this manuscript was supported by JLI. Authors AS, SK, and SS are affiliated with Pinney Associates, Inc. (PA). Since October 2019, PA has been and continues to consult to JLI on nicotine vapor products to advance tobacco harm reduction. In addition, in the past 3 years, Pinney Associates has consulted to Philip Morris International (PMI) solely on US regulatory pathways for non-combustible, non-tobacco, nicotine products. PA does not consult on

combustible tobacco products. AS also individually provides consulting services on behavioral science to the Center of Excellence for the Acceleration of Harm Reduction (CoEHAR) through ECLAT Srl, which received funding from the Foundation for a Smoke-Free World (FSFW; now the Global Action to End Smoking (GA)). Author NG is an employee of JLI. JLI reviewed and provided comments on a near-final draft of the manuscript. Neither PMI, CoEHAR, nor FSFW/GA had any role in, or oversight of, this manuscript.

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