

Adult smokers' complete switching away from cigarettes at 6, 9, and 12 months after initially purchasing a JUUL e-cigarette

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Abstract

Background: Electronic nicotine delivery systems (ENDS) have the potential to benefit public health if smokers completely switch from cigarettes to ENDS.

Methods: A cohort of adult smokers (age \geq 21) who purchased a JUUL Starter Kit was followed for 12 months after the initial purchase. We examined factors associated with achievement and maintenance of self-reported repeated point-prevalence switching (RPPS) at three follow-ups, i.e., no past-30-day smoking at months 6, 9, and 12.

Results: RPPS was reported by 21.6% of the 12,537 evaluable smokers. Smokers with lighter baseline smoking history and lower baseline cigarette dependence were more likely to report RPPS. RPPS was also associated with patterns of and responses to JUUL use: Daily use of JUUL at month 3 (OR=2.25; 95% CI=1.96–2.60) and month 6 (OR=1.81; 95% CI=1.48–2.22) was associated with higher rates of RPPS, and as were greater subjective reinforcing effects from JUUL use (assessed by the mCEQ, month-3: OR=1.70, 95% CI=1.57–1.83; month-6: OR=1.15; 95% CI=1.06–1.25). Even among smokers who did not meet the criteria of RPPS (i.e., who smoked at least once), 35.5% reported past 30-day point-prevalence switching on at least one follow-up, and their cigarette consumption was substantially reduced compared to baseline.

Conclusions: Approximately one-fifth of adult smokers reported 30-day point-prevalence abstinence at 6, 9, and 12 months after purchasing JUUL. Greater use of JUUL and stronger subjective reinforcing effects were associated with non-smoking, validating the potential for ENDS to substitute for smoking, with potential for positive impacts on individual and population health.

Background

Although smoking rates have declined in the US and internationally, cigarette smoking continues to be the leading cause of preventable morbidity and mortality worldwide.[1] The health benefits of smoking cessation are time-dependent: some benefits are seen immediately within hours of cessation, but most benefits accrue over years.[2] Not surprisingly, sustained smoking cessation remains highly challenging for many smokers, even with pharmacological and behavioral support and strong motivation to stop smoking.[3, 4]

A substantial proportion of adult smokers are not ready to quit at any given time[5] and the majority of individual quit attempts are unsuccessful.[5, 6] Compared to smoking combustible cigarettes, switching completely to electronic nicotine delivery systems (ENDS) significantly reduces exposure to smoking-related carcinogens and toxicants that are primarily produced by the combustion of tobacco.[7–10] Accordingly, switching to ENDS has emerged as a potential harm reduction strategy for smokers who would not otherwise quit smoking in the near term.[11, 12]

A growing body of evidence demonstrates that adult smokers can switch to ENDS,[13–21] with a 30-day point-prevalence (i.e., no smoking in the past 30 days) at one year as a typical end-point.[16, 19] However, to fully take advantage of the potential benefits of ENDS, complete switching would need to be sustained for an extended period of time. Additionally, most of these naturalistic longitudinal studies examined switching in samples using a heterogeneous variety of ENDS, which can vary in nicotine delivery as well as other product features,[22, 23] for varying periods of time.

In a recent study, Goldenson et al.[24] followed a cohort of smokers using the same ENDS product – JUUL, which is a closed-system pod-based ENDS brand widely used in the US.[25] Participants in the Adult JUUL User Switching and Smoking Trajectories (ADJUSST) study were enrolled when they had just purchased a JUUL Starter Kit (JSK) for the first time, and were followed for 12 months without intervention and without being provided with any products. Goldenson et al. report that about half of the baseline adult established smokers reported switching away from smoking (no past-30-day smoking) 12 months after their JSK purchase, and about one third reported no past-30-day smoking at both the 9 and 12 month follow-ups.[24] However, the predictors and dynamic processes associated with achieving and maintaining the status of complete switching over a longer period of time remain unknown. Using the ADJUSST study data, the present secondary analysis examines factors associated with self-reported repeated point-prevalence of switching (RPPS) at three time-points over a period of 6

months at the end of a year, at months 6, 9, and 12 after the initial JSK purchase. Analyses consider predictors from baseline characteristics, from smoking and JUUL use patterns at a prior assessment at 3 months, and predictors of continued abstinence among those who were abstinent at 6 months.

Methods

This is a secondary analysis of the ADJUSST study,[26] a naturalistic longitudinal follow-up of US adults 21 + who purchased a JSK (a JUUL device, a USB charging dock, and 4 JUUL pods), either online or in retail outlets between June and October 2018 and were invited to participate in an online longitudinal survey study. After a baseline assessment, participants were invited to complete follow-ups at 1, 2, 3, 6, 9, and 12 months. Participants were eligible for all follow-ups, regardless of smoking, JUUL use, or completion of prior surveys. The study was a non-interventional naturalistic longitudinal follow-up: participants were not recruited or selected based on having any behavior-change goal (such as reducing or stopping smoking), no goals were communicated to them, no intervention was offered, and participants were not provided with JUUL products, but could purchase them in the marketplace and use them (or not) as they saw fit. The study was approved by the Advarra IRB (<https://www.advarra.com>), and participants provided informed consent and were compensated \$30 for each completed survey. Study methods have been detailed in a previous publication,[26] as have a number of substantive analyses.[24, 27, 28]

A detailed analysis of patterns of missed follow-ups in ADJUSST concluded that the potential for outcome bias due to missing data was limited.[26] Specifically, there was very little difference in demographics or smoking history between participants who completed all follow-ups, no follow-up, or some follow-ups. Further, differences that were observed did not consistently suggest that participants with missing data were less likely to switch. Also, in a re-contact study with month-12 non-responders, almost half reported they had switched away from smoking, and very few reported that their non-response was due to having “started smoking” or “stopped using JUUL” (each less than 5%); rather, 81% reported exclusively survey-related reasons (i.e., missing the survey widow, compensation too small, etc.) for non-response.[26]

Sample

Study eligibility criteria were: 1) age 21 or older, 2) a permanent resident of the US, 3) a first-time purchaser of JSK within the past 7 days, 4) neither employee nor family member of employees of Juul Labs, Inc. or PAX Labs, Inc. The present analyses focus on 12,537 ADJUSST enrollees who were established smokers at baseline (smoked in the past 30 days, smoked every day or some days, and had smoked 100 + cigarettes) whose RPPS status could be ascertained (as described below).

Measures

Self-reported repeated point-prevalence of switching (RPPS) at months 6, 9, and 12

Switching at each follow-up was defined as a “No” response to the question “In the past 30 days, have you smoked a cigarette, even one or 2 puffs?” RPPS was defined as reporting no smoking at all three consecutive follow-up assessments, at 6, 9, and 12 months (regardless of JUUL use). Although RPPS may include some participants who smoked in non-survey months, repeated reports of past-month cigarette abstinence have been used as a proxy of sustained cigarette abstinence[19] and mutually exclusive multi-year behavioral trajectories in the PATH study.[29, 30] The 6-month point was selected as the start of the RPPS interval because previous data showed that rates of past-30-day switching were rising steeply up to that point.[24] Therefore, starting at an earlier time-point would exclude many participants who took longer to switch (which was particularly likely among those with heavier smoking history), but might nevertheless achieve RPPS.

Those reporting no past-30-day smoking at all three time-points were deemed to have achieved RPPS; those who reported any smoking at any of the three time-points were deemed to not have achieved RPPS, regardless of their smoking status or missingness at other time-points. Participants who reported abstinence at one or two time-points, but had a missing status for the others, or were missing all three time-points, were deemed unevaluable. See Supplementary Table 1.

JUUL use behaviors

Participants' JUUL use and related responses were measured at each follow-up. Analyses examined the 3- and 6-month data in relation to later RPPS. Daily JUUL use (all 30 days vs. less than 30 days) was assessed, as was the number of JUUL sessions (defined as the use of around 15 puffs, or 10 minutes[31]) on days used JUUL. Dependence on JUUL was evaluated with the 16-item Adult Tobacco Dependence Index (TDI), which is validated for assessing dependence on ENDS.[32, 33] Participants also completed the modified Cigarette Evaluation Questionnaire (mCEQ, adapted for JUUL), which has previously been used to assess subjective responses to ENDS.[34, 35] Preliminary analyses showed that the subscales of mCEQ (satisfaction, psychological rewards, enjoyment of respiratory tract sensations, reduction in cigarette cravings) were highly correlated (averaging $r = 0.54$) and constituted a unidimensional scale (first principal component eigenvalue was 2.64, accounting for 66% of the variance; all others were < 0.60). This presented a collinearity problem for their simultaneous inclusion in a multivariable model. Therefore, subscales were averaged to represent the overall positive reinforcing effects of JUUL use in the multivariate models.

Covariates

Sociodemographic factors analyzed included race/ethnicity, sex, age, household income, educational attainment, and marital status (see Table 1). Baseline smoking history assessed smoking frequency (number of days smoked in the past 30 days), cigarettes per day (averaged over 30 days), cigarette dependence (using the TDI), baseline readiness to quit smoking (planning to quit in the next 30 days [yes/no][36]), and years of regular smoking.

Table 1
 Characteristics of baseline smokers, stratified by later sustained switching statuses (N = 12,537)

| | | Reported RPPS N (row percentage); Mean (SD) | Reported smoking N (row percentage); Mean (SD) | Total N (column percentage); Mean (SD) |
|--|--------------------------------|---|--|--|
| N (percentage) | | 2708 (21.6%) | 9829 (78.4%) | 12537 |
| Baseline sociodemographic | | | | |
| Race/ethnicity | NH White | 1982 (21.6%) | 7184 (78.4%) | 9166 (78.1%) |
| | NH Black | 88 (24.4%) | 273 (75.6%) | 361 (3.1%) |
| | NH Asian | 130 (19.2%) | 548 (80.8%) | 678 (5.8%) |
| | NH Others | 113 (21.0%) | 425 (79.0%) | 538 (4.6%) |
| | Hispanic | 218 (22.1%) | 770 (77.9%) | 988 (8.4%) |
| Sex | Male | 1454 (21.4%) | 5340 (78.6%) | 6794 (54.6%) |
| | Female | 1212 (21.7%) | 4374 (78.3%) | 5586 (44.9%) |
| | Transgender | 14 (20.9%) | 53 (79.1%) | 67 (0.5%) |
| Age* | | 32.25 (9.97) | 33.09 (11.06) | 32.91 (10.84) |
| Income* | < \$50k | 1200 (20.3%) | 4707 (79.7%) | 5907 (54.3%) |
| | \$50k – \$100k | 735 (22.9%) | 2481 (77.1%) | 3216 (29.5%) |
| | > \$100k | 402 (22.8%) | 1360 (77.2%) | 1762 (16.2%) |
| Education | HS or less | 692 (21.0%) | 2603 (79.0%) | 3295 (28.0%) |
| | Some college or associates | 1064 (20.8%) | 4044 (79.2%) | 5108 (43.4%) |
| | Bachelor's or more | 759 (22.6%) | 2595 (77.4%) | 3354 (28.5%) |
| Marital status* | Married | 847 (24.2%) | 2648 (75.8%) | 3495 (28.3%) |
| | Divorced/Separated/ Widowed | 354 (19.0%) | 1508 (81.0%) | 1862 (15.1%) |
| | Never married | 1463 (20.9%) | 5542 (79.1%) | 7005 (56.7%) |
| | | | | |
| Baseline smoking and history | | | | |
| Years of regular smoking* | | 11.50 (9.65) | 13.21 (11.07) | 12.84 (10.80) |
| Smoking days/month* | | 22.00 (10.15) | 24.23 (8.91) | 23.75 (9.24) |
| Daily smoking* | Non-daily | 1387 (25.2%) | 4110 (74.8%) | 5497 (44.4%) |
| | Daily | 1284 (18.6%) | 5607 (81.4%) | 6891 (55.6%) |
| Average cigarettes/day* | | 10.14 (8.02) | 11.74 (8.23) | 11.39 (8.21) |
| Cigarette dependence (TDI, 1–5) ^{1,*} | | 2.91 (1.11) | 3.11 (1.06) | 3.07 (1.07) |
| Planning to quit in next 30 days* | Yes | 1581 (25.1%) | 4719 (74.9%) | 6300 (50.3%) |
| | | | | |

| | | Reported RPPS N (row percentage); Mean (SD) | Reported smoking N (row percentage); Mean (SD) | Total N (column percentage); Mean (SD) |
|---|-----------|---|--|--|
| No | | 1127 (18.1%) | 5110 (81.9%) | 6237 (49.7%) |
| Month 3 smoking and JUUL use behaviors ² | | | | |
| Smoking status* | Yes | 525 (8.1%) | 5996 (91.9%) | 6521 (64.7%) |
| | No | 1908 (53.5%) | 1656 (46.5%) | 3564 (35.3%) |
| JUUL use days/month | | 27.09 (6.50) | 23.54 (8.85) | 24.42 (8.47) |
| Daily JUUL use* | Non-daily | 564 (14.8%) | 3242 (85.2%) | 3806 (40.5%) |
| | Daily | 1749 (31.3%) | 3833 (68.7%) | 5582 (59.5%) |
| JUUL sessions/day ^{3,*} (median (IQR)) | | 10 (5–15) | 6 (3–10) | 7 (4–15) |
| JUUL dependence (TDI, 1–5) ^{1,*} | | 2.52 (0.94) | 2.34 (0.92) | 2.39 (0.93) |
| Averaged score for reinforcing effects of JUUL ^{1,4,*} | | 4.42 (0.82) | 3.96 (0.87) | 4.11 (0.88) |
| Month 6 JUUL use behaviors ⁵ | | | | |
| JUUL use days/month | | 26.72 (7.14) | 23.08 (9.14) | 24.08 (8.79) |
| Daily JUUL use ^{4,*} | Non-daily | 597 (16.0%) | 3136 (84.0%) | 3733 (40.7%) |
| | Daily | 1911 (35.1%) | 3538 (64.9%) | 5449 (59.3%) |
| JUUL sessions/day (median (IQR)) | | 10 (5–15) | 6 (4–12) | 7 (4–15) |
| JUUL dependence (TDI, 1–5) ¹ | | 2.58 (0.97) | 2.43 (0.95) | 2.47 (0.96) |
| Averaged score for reinforcing effects of JUUL ^{1,4,*} | | 5.22 (1.08) | 4.7 (1.1) | 4.87 (1.12) |
| RPPS: repeated point-prevalence of switching, NH: Non-Hispanic, HS: High school, IQR: interquartile range | | | | |
| ¹ A higher score indicates stronger agreement | | | | |
| ² At month 3, 434 participants reported that they did not use JUUL in the past month. Sustained switching rate of this group was 18.2%, which was not different from the Month-3 JUUL nondaily user group (14.8%, chi-squared test: $p = 0.0732$), but lower than that of Month-3 JUUL daily users (31.3%, $p < 0.001$). | | | | |
| ³ One session was defined as “the use of around 15 puffs, or 10 minutes.” | | | | |
| ⁴ Average score of satisfaction, psychological reward, enjoyment of sensation, and craving reduction domains of the mCEQ | | | | |
| ⁵ At month 6, 681 participants reported that they did not use JUUL in the past month. Sustained switching rate of this group was 19.7%, which was higher than that of the nondaily users (16.0%, chi-squared test: $p = 0.0202$) but lower than that of daily users (35.1%, $p < 0.001$). | | | | |
| Count (percentage) for categorical variables; mean (standard deviation) for continuous variables; Asterisks (*) represent significant univariate differences between sustained switcher group and smoker group. Univariate associations of month-6 JUUL use behaviors and sustained switching were examined within the month-6 complete switcher group. See Table 2 for Odds ratios | | | | |

Analyses

Associations of sociodemographic factors, smoking history, JUUL use behaviors, and RPPS were initially assessed using univariate logistic regression, and then in three multivariable models predicting RPPS from different sets of regressors: (1) “Baseline model” adjusted for baseline sociodemographic and smoking characteristics; (2) “Month-3 model” added month-3 JUUL use behaviors to the Baseline model, assessing what month-3 behaviors predicted subsequent *achievement* of RPPS; and (3) “Month-6 model” added month-6 JUUL use behaviors to the Baseline model, assessing what month-6 behaviors predicted subsequent *maintenance* of switching among those who were already not smoking at 6 months. Models assessing JUUL use behaviors were based on past-months users of JUUL at the respective month (95.7% at Month-3 and 93.4% at Month-6).

A secondary analysis of 6,521 participants who were still smoking at month 3 assessed associations of characteristics and subsequent RPPS. Another analysis among 9,829 participants who did not achieve RPPS assessed average cigarette-per-day (CPD) in those who reported switching at one or two of the relevant follow-ups (but not all three, N = 3,488), compared to those who did not (N = 6,341). All statistical analyses were conducted in R version 4.0.2.[37]

Results

As shown in Supplemental Table 1, RPPS across months 6, 9, and 12 was evaluable for 12,537 participants. As in the overall ADJUSST sample,[26] evaluable participants were majority non-Hispanic White, male, and daily smokers (Table 1). On average, they were 32.9 years old, smoked for 12.8 years, and smoked 11.4 cigarettes per day at baseline.

Overall, 21.6% met the criteria for 6-month RPPS, i.e., reported past-month complete switching at months 6, 9, and 12; the remainder reported smoking (at least a puff) on at least one of those follow-ups (see Supplemental Table 1).

Table 1 compares the characteristics of participants by their RPPS status. On a univariate basis, compared to those who smoked at ≥ 1 follow-up at 6, 9, or 12 months, those reporting RPPS were younger, had higher household income, and were more likely to be married. At baseline, those reporting RPPS had a lighter smoking history and profile: they had a shorter history of regular smoking, smoked less frequently and fewer cigarettes-per-day, had a lower level of cigarette dependence, and were more likely to be ready to quit.

In addition to predictors from baseline, several parameters of JUUL use at month 3 were prospectively associated with subsequent RPPS across months 6 to 12. Those who at 3 months were daily (vs. non-daily) JUUL users, used JUUL more times per day, were more dependent on JUUL, and rated JUUL as more reinforcing (i.e., perceiving JUUL use satisfying and psychologically rewarding, enjoying the sensation in the throat, and having their cravings for cigarettes effectively alleviated) were more likely to achieve RPPS. Similarly, smokers who had already switched at month 6 were more likely to achieve RPPS over the following 6 months if, at 6 months, they used JUUL daily and found JUUL more reinforcing. Associations with a daily quantity of JUUL use and JUUL dependence were not statistically significant among those already switched at month 6.

The relationships between participant characteristics and later RPPS were further examined in multivariable regression analyses (Table 2). The first multivariable model with baseline sociodemographic and smoking characteristics (“Baseline model”) largely confirmed the associations between smoking history and RPPS seen in univariate analyses. Those with lighter smoking history and patterns were more likely to achieve RPPS. With the multivariable adjustment, Non-Hispanic Asians had 21% lower odds of RPPS than non-Hispanic Whites, and the associations of age and income with RPPS were no longer statistically significant.

Table 2

Factors associated with repeated point-prevalence of switching: Results from univariate and multivariable modeling (N = 12537)

| | | Univariate model | Baseline model | Month-3 model ³ | Month-6 model ⁴ |
|---------------------------|----------------|-----------------------------|---|--|--|
| Components | | – | Sociodemographics Baseline smoking | Sociodemographics Baseline smoking Month 3 JUUL | Sociodemographics Baseline smoking Month 6 JUUL |
| Baseline sociodemographic | | | | | |
| Race/ethnicity | NH White | Reference | | | |
| | NH Black | 1.17 (0.91–1.49) | 1.21 (0.92–1.58) | 1.27 (0.91–1.77) | 1.21 (0.75–1.98) |
| | NH Asian | 0.86 (0.70–1.04) | 0.79 (0.63–0.99) | 0.70 (0.53–0.92) | 0.69 (0.48–1.003) |
| | NH Others | 0.96 (0.78–1.19) | 0.96 (0.76–1.21) | 1.03 (0.83–1.26) | 0.94 (0.71–1.27) |
| | Hispanic | 1.03 (0.87–1.20) | 0.97 (0.81–1.15) | 0.96 (0.73–1.26) | 0.81 (0.55–1.22) |
| Sex | Male | Reference | | | |
| | Female | 1.02 (0.93–1.11) | 1.08 (0.98–1.20) | 0.99 (0.88–1.12) | 1.11 (0.93–1.33) |
| | Transgender | 0.97 (0.52–1.70) | 0.89 (0.43–1.67) | 1.08 (0.49–2.20) | 0.85 (0.29–2.63) |
| Age (by decades) | | 0.93 (0.89–0.97) | 1.07 (0.97–1.18) | 1.13 (1.002–1.27) | 1.35 (1.12–1.65) |
| Income | < \$50k | Reference | | | |
| | \$50k – \$100k | 1.16 (1.05–1.29) | 1.12 (0.995–1.26) | 1.20 (1.04–1.38) | 1.13 (0.92–1.39) |

NH: Non-Hispanic, HS: High school, TDI: Adult Tobacco Dependence Index

¹ A higher score indicates stronger agreement² Assessed for the past-month JUUL users at month 3 (N = 9719)³ One session was defined as “the use of around 15 puffs, or 10 minutes”⁴ Average score of satisfaction, psychological reward, enjoyment of sensation, and craving reduction domains of the mCEQ⁵ Assessed for the those who reported past-month JUUL use and non-smoking at month 6 (N = 3774)

| | | Univariate model | Baseline model | Month-3 model ³ | Month-6 model ⁴ |
|---|---|----------------------------|-------------------------|----------------------------|----------------------------|
| | > \$100k | 1.16 (1.02–1.32) | 1.04 (0.89–1.20) | 1.15 (0.96–1.38) | 0.98 (0.75–1.29) |
| Education | HS or less | Reference | | | |
| | Some college or associate's | 0.99 (0.89–1.10) | 0.95 (0.84–1.07) | 0.95 (0.82–1.10) | 1.00 (0.81–1.23) |
| | Bachelor's or more | 1.10 (0.98–1.24) | 0.99 (0.86–1.14) | 1.04 (0.88–1.24) | 1.19 (0.92–1.53) |
| Marital status | Married | Reference | | | |
| | Divorced/Separated/ Widowed | 0.73 (0.64–0.84) | 0.77 (0.65–0.91) | 0.73 (0.60–0.90) | 0.71 (0.52–0.97) |
| | Never married | 0.83 (0.75–0.91) | 0.72 (0.63–0.82) | 0.73 (0.63–0.86) | 0.84 (0.67–1.06) |
| Baseline smoking and history | | | | | |
| | Years of regular smoking (by decades) | 0.86 (0.82–0.89) | 0.84 (0.76–0.92) | 0.79 (0.71–0.89) | 0.98 (0.80–1.18) |
| | Smoking frequency (by weeks in the past month) | 0.84 (0.82–0.87) | 0.90 (0.87–0.95) | 0.93 (0.89–0.99) | 1.06 (0.98–1.14) |
| | Average cigarettes/day (by 5 cigarettes) | 0.88 (0.85–0.95) | 0.95 (0.91–0.99) | 0.97 (0.92–1.01) | 1.02 (0.95–1.09) |
| | Cigarette dependence (TDI, 1–5) ¹ | 0.83 (0.80–0.87) | 0.97 (0.91–1.03) | 0.83 (0.77–0.90) | 0.88 (0.79–0.98) |
| Planning to quit in next 30 days | No | Reference | | | |
| | Yes | 1.52 (1.39–1.66) | 1.50 (1.36–1.66) | 1.34 (1.19–1.51) | 1.08 (0.91–1.28) |
| Month 3 JUUL use ² | | | | | |
| Daily JUUL use | Non-daily | Reference | | Reference | |
| NH: Non-Hispanic, HS: High school, TDI: Adult Tobacco Dependence Index | | | | | |
| ¹ A higher score indicates stronger agreement | | | | | |
| ² Assessed for the past-month JUUL users at month 3 (N = 9719) | | | | | |
| ³ One session was defined as “the use of around 15 puffs, or 10 minutes” | | | | | |
| ⁴ Average score of satisfaction, psychological reward, enjoyment of sensation, and craving reduction domains of the mCEQ | | | | | |
| ⁵ Assessed for the those who reported past-month JUUL use and non-smoking at month 6 (N = 3774) | | | | | |

| | Univariate model | Baseline model | Month-3 model ³ | Month-6 model ⁴ |
|---|----------------------------|----------------------------|----------------------------|----------------------------|
| Daily | 2.62 (2.36–2.92) | | 2.25 (1.96–2.60) | |
| JUUL sessions/day ³ (by 5 sessions) | 1.07 (1.05–1.09) | | 1.02 (0.998–1.05) | |
| JUUL dependence (TDI, 1–5) ¹ | 1.22 (1.16–1.28) | | 1.03 (0.96–1.10) | |
| Averaged score for reinforcing effects of JUUL ^{1,4} | 1.89 (1.78–2.01) | | 1.70 (1.57–1.83) | |
| Month 6 JUUL use ⁵ | | | | |
| Daily JUUL use | Non-daily | Reference | | Reference |
| | Daily | 1.92 (1.65–2.23) | | 1.81 (1.48–2.22) |
| JUUL sessions/day ² (by 5 sessions) | 1.00 (0.97–1.03) | | | 1.00 (0.96–1.03) |
| JUUL dependence (TDI, 1–5) | 0.95 (0.89–1.02) | | | 0.93 (0.84–1.03) |
| Averaged score for reinforcing effects of JUUL ^{1,4} | 1.15 (1.08–1.23) | | | 1.15 (1.06–1.25) |
| NH: Non-Hispanic, HS: High school, TDI: Adult Tobacco Dependence Index | | | | |
| ¹ A higher score indicates stronger agreement | | | | |
| ² Assessed for the past-month JUUL users at month 3 (N = 9719) | | | | |
| ³ One session was defined as “the use of around 15 puffs, or 10 minutes” | | | | |
| ⁴ Average score of satisfaction, psychological reward, enjoyment of sensation, and craving reduction domains of the mCEQ | | | | |
| ⁵ Assessed for the those who reported past-month JUUL use and non-smoking at month 6 (N = 3774) | | | | |

In the Month-3 multivariable model, some JUUL use characteristics were no longer significant when mutually adjusted, but those who used JUUL daily still had over twice the odds of reporting RPPS (OR = 2.25), and those reporting greater reinforcing effects with JUUL use were also more likely to achieve RPPS. Being switched at month 3 was strongly correlated with later RPPS, as 53.5% of those already switched at month 3 continued to report RPPS (Table 1), while only 8.1% of month-3 smokers achieved subsequent RPPS. Factors associated with RPPS among month-3 past-30-day smokers were examined separately (see below).

The “Month-6 model” tested how 6-month JUUL use characteristics among those switched at month 6 related to reported abstinence at both 9 and 12 months (i.e., RPPS). For these smokers, who already achieved past-30-day non-smoking at month 6, most baseline smoking characteristics were no longer associated with the maintenance of switching, but those who were

more cigarette-dependent at baseline were still less likely to sustain RPPS at 9 and 12 months. Daily JUUL use and stronger reinforcing effects of JUUL at month 6 predicted RPPS through month 12.

Analyses among those smoking at month 3

As noted above, only a small minority (8.1%) of those still smoking at month 3 subsequently reported RPPS (Table 1). To understand factors associated with such conversion, we examined predictors of RPPS among month-3 smokers (i.e., those not switched at 3 months). As seen in Table 3, on a univariate basis, month-3 smokers who later showed RPPS had a lighter smoking profile (less smoking and lower dependence) at baseline and were also smoking less at month 3. As in the overall sample, those who used JUUL daily had more JUUL-use sessions per day, reported higher dependence, and perceive the reinforcing effects of JUUL more strongly were more likely to subsequently convert to RPPS.

Table 3

Factors associated with repeated point-prevalence of switching: Results from Month-3 smokers (N = 6521)

| | | Univariable models | Multivariable model ³ |
|--|--------------------------------|-------------------------|----------------------------------|
| Baseline sociodemographic | | | |
| Race/ethnicity | NH White | Reference | |
| | NH Black | 0.90 (0.48–1.54) | 1.09 (0.45–2.28) |
| | NH Asian | 0.54 (0.30–0.89) | 0.36 (0.15–0.74) |
| | NH Others | 1.10 (0.70–1.64) | 1.08 (0.65–1.69) |
| | Hispanic | 1.07 (0.76–1.46) | 0.94 (0.48–1.68) |
| Sex | Male | Reference | |
| | Female | 0.97 (0.81–1.16) | 1.03 (0.78–1.37) |
| | Transgender | 0.89 (0.21–2.49) | 0.53 (0.03–2.67) |
| Age (by decades) | | 1.08 (0.999–1.16) | 1.15 (0.87–1.51) |
| Income | < \$50k | Reference | |
| | \$50k – \$100k | 1.23 (0.99–1.52) | 1.30 (0.94–1.78) |
| | > \$100k | 1.36 (1.05–1.76) | 1.46 (0.96–2.17) |
| Education | HS or less | Reference | |
| | Some college or associate's | 1.17 (0.93–1.48) | 0.90 (0.65–1.25) |
| | Bachelor's or more | 1.22 (0.95–1.57) | 0.95 (0.64–1.39) |
| Marital status | Married | Reference | |
| | Divorced/Separated/ Widowed | 0.91 (0.68–1.22) | 0.96 (0.61–1.49) |
| | Never married | 1.23 (0.997–1.52) | 1.08 (0.75–1.56) |
| | | | |
| Baseline smoking history | | | |
| Years of regular smoking (by decades) | | 0.80 (0.73–0.73) | 0.88 (0.68–1.16) |
| Smoking frequency (by weeks in the past month) | | 0.85 (0.79–0.91) | 1.00 (0.87–1.14) |
| Average cigarettes/day (by 5 cigarettes) | | 0.90 (0.84–0.95) | 1.07 (0.96–1.18) |
| Cigarette dependence (TDI, 1–5) ¹ | | 0.87 (0.80–0.94) | 1.01 (0.85–1.20) |
| Planning to quit in next 30 days | No | Reference | |

NH: Non-Hispanic, HS: High school, TDI: Adult Tobacco Dependence Index

¹ A higher score indicates stronger agreement² One session was defined as “the use of around 15 puffs, or 10 minutes.”³ Assessed for the past-month JUUL users and smokers at month 3 (N = 6228)⁴ Average score of satisfaction, psychological reward, enjoyment of sensation, and craving reduction domains of the mCEQ

| | | Univariable models | Multivariable model ³ |
|---|---|-------------------------|----------------------------------|
| | Yes | 1.12 (0.94–1.34) | 0.94 (0.72–1.23) |
| Month 3 smoking | | | |
| | Smoking frequency (by weeks in the past month) | 0.67 (0.62–0.72) | 0.70 (0.62–0.78) |
| | Average cigarettes per day (by 5 cigarettes) | 0.67 (0.60–0.75) | 0.89 (0.75–1.03) |
| Month 3 JUUL use ³ | | | |
| Daily JUUL use | Non-daily | Reference | |
| | Daily | 2.18 (1.79–2.67) | 1.38 (1.01–1.89) |
| | JUUL sessions/day ² (by 5 sessions) | 1.09 (1.05–1.12) | 1.03 (0.98–1.09) |
| | JUUL dependence (TDI, 1–5) ¹ | 1.47 (1.33–1.62) | 1.30 (1.09–1.56) |
| | Averaged score for reinforcing effects of JUUL ^{1,4} | 1.59 (1.42–1.78) | 0.92 (0.77–1.10) |
| NH: Non-Hispanic, HS: High school, TDI: Adult Tobacco Dependence Index | | | |
| ¹ A higher score indicates stronger agreement | | | |
| ² One session was defined as “the use of around 15 puffs, or 10 minutes.” | | | |
| ³ Assessed for the past-month JUUL users and smokers at month 3 (N = 6228) | | | |
| ⁴ Average score of satisfaction, psychological reward, enjoyment of sensation, and craving reduction domains of the mCEQ | | | |

When mutually adjusted in multivariable analyses, baseline smoking characteristics were rendered non-significant, but participants who smoked more days per month at month 3 continued to be less likely to subsequently achieve RPPS. Also, participants who at month 3 were using JUUL daily, and those who reported greater dependence on JUUL, were more likely to achieve RPPS.

Cigarette consumption among smokers who did not achieve RPPS

As seen in Supplemental Table 1, the cohort that did not achieve RPPS was heterogeneous, with some having reported switching at one or two time-points during months 6, 9, and 12, while others had not reported any switching in this time frame. To better understand the smoking behavior of these two cohorts, we compared the average CPD for those who were smoking at months 6, 9, and 12, respectively. Supplemental Table 2 shows that those who were not smoking at one or two follow-ups were lighter smokers at baseline. Both of the cohorts reported reducing their cigarette consumption (compared to baseline) considerably, but the reduction was greater among those who had switched away from smoking on at least one of the follow-ups. Among those who did not switch, the median cigarette reduction was 60%, and 60% of participants had reduced their cigarette consumption at least by half. In the group that switched once or twice, the median reduction was 90%, and > 80% had reduced their consumption by half or more. When they were smoking, this group’s cigarette consumption averaged < 3 cigarettes per day across all three follow-ups.

Discussion

The analyses presented here assessed the predictors of self-reported past-30-day abstinence from smoking in 3 consecutive surveys at months 6, 9, and 12. in a sample of adult smokers who purchased a JSK. In the evaluable sample, 21.6% reported such repeated point prevalence switching away from smoking. While considerably lower than the single point-prevalence switching rates of 47% – 51% at those months,[24] this is a substantial proportion of these smokers, particularly considering

that half them were not ready to quit smoking when they first purchased a JSK (Table 1). Also, even among those not ready to quit at baseline, 18% reported RPPS over the last 6 months of the following year. The data also indicate that over three-quarters of those who achieved RPPS during months 6 to 12 had already switched away from smoking at month 3, suggesting that switching was often more prolonged than was captured by the RPPS end-point used here.

As expected, individuals with a lighter smoking history (lower baseline smoking frequency, quantity, duration, and dependence) were more likely to achieve RPPS, consistent with predictors of clinical smoking cessation.[38–42] Studies on switching with ENDS also showed similar results: lighter and less dependent smokers at baseline were more likely to report complete cigarette abstinence[19] and reduced their cigarette consumption more greatly.[43] As heavier smokers may take longer to achieve complete switching,[24] further follow-up beyond the initial first year would be informative.

Interestingly, the strongest predictors of subsequent RPPS reflected how participants were using and reacting to JUUL. Those who at 3 months were using JUUL daily and using it more times per day, who scored higher on JUUL dependence, and who reported greater reinforcing effects from using JUUL were more likely to subsequently achieve RPPS. Similarly, even among those who were already switched at month 6, daily use of JUUL and greater perceived reinforcing effects increased the odds of maintaining the switched status at months 9 and 12. These findings are consistent with prior studies that have similarly reported that daily ENDS use is associated with switching.[15–20, 44] Previous research has shown that switchers (i.e., former smokers who are currently using ENDS) report that the subjective sensations from ENDS were important in their transition from cigarette smoking to exclusive ENDS use.[35] Indeed, users' subjective responses on ENDS, such as reduction in cigarette craving and ENDS liking, were associated with higher odds of switching and greater smoking reduction.[24, 45] The present finding extends that association to RPPS, consistent with the hypothesized role of ENDS to displace cigarette smoking.[46, 47]

Collectively, the present findings suggest the role of ENDS/JUUL use, and its potential to substitute for cigarettes, as an important factor in switching away from smoking. This is consistent with the conceptualization of ENDS as substitutes for cigarettes, and with Abrams et al.'s conceptual model,[46] which emphasizes that ENDS need to provide satisfaction sufficient to promote and reinforce use in order to compete with cigarettes and facilitate switching (see also Gray et al.[47]). The importance of 'abuse liability' of ENDS in facilitating smokers' switching has been similarly recognized by the Food and Drug Administration's Center for Tobacco Products.[48]

It was notable that among the participants who did not achieve RPPS, but who had switched at one or more follow-ups at 6, 9, and 12 months, reported much-reduced cigarette consumption, with over 80% reporting reductions of at least 50%. Some of these participants may have been getting close to achieving abstinence at all three time points. The substantial reductions in cigarette consumption observed in those who did not achieve RPPS are consistent with Selya et al.'s report[28] that most ADJUSST participants who were engaged in dual-use had reduced their cigarette consumption by at least 50%, a degree of reduction that has been associated with very substantial reductions in exposures to smoking-related toxicants,[8, 10] and has been associated with reductions in disease risk, particularly for cancer.[7, 9, 10]

Although cigarette- and JUUL-related variables were the strongest predictors of RPPS, two demographic factors also emerged as predictors in adjusted models. Married smokers were more likely to achieve RPPS. This association has also been observed in smoking cessation,[39] and likely reflects the availability of social support and other psychosocial resources. Consistent with Kim et al.'s observations from ADJUSST,[27] non-Hispanic Asian smokers were slightly less likely to achieve RPPS, even after controlling for other variables. It is not clear why this is so, and this is a topic worthy of further research.

This study has several limitations that should be taken into account. The ADJUSST study had no control group or randomization, precluding strong causal inferences. Nevertheless, the consistent associations of greater JUUL use and JUUL reinforcement with RPPS suggest that JUUL use may play a role in RPPS. The scope of this study was limited to cigarette smoking and JUUL use behaviors, and it did not capture the use of noncigarette tobacco products (i.e., cigar, cigarillo, hookah, etc.) at baseline or follow-up.

RPPS was defined based on self-report, without biochemical verification, consistent with other observational studies on switching.[13–17] As in many longitudinal surveys, some participants did not complete all follow-up surveys, resulting in missing data. In some cases, missing data made it impossible to establish participants' RPPS status over all three follow-ups. While there is a possibility of selective drop-out (i.e., those who switched continued responding while those who returned to smoking stopped responding to the survey), analyses of survey response in ADJUSST suggests that the potential for bias from differential response rates was limited.[26] Nevertheless, it remains a limitation.

While a similar definition has been used to assess multi-year sustained switching with PATH data by Kalkhoran and colleagues,[19] RPPS does not necessarily imply *continuous* abstinence over the 6-month period. Conversely, even the reports of smoking at a follow-up do not necessarily imply a full return to smoking, as even reporting one puff of smoking in the month preceding any of the three assessments assigned the participants in the 'non-RPPS' group. A dynamic analysis of more detailed trajectories might provide useful additional insight.

Participants were recruited based on their purchase of JSK, so may not necessarily represent the general population of cigarette smokers or even all ENDS users, which are often defined on the basis of any use in the past 30 days, and thus including experimental triers.[49] Purchase of a JSK likely indicates a degree of commitment to JUUL use, and this may help explain higher rates of complete switching at 12 months, compared to other studies.[13–17] The study also followed smokers from their first JSK purchase, so may better capture trajectories over time. Many longitudinal studies start with many ENDS users who are dual users at baseline and therefore may omit smokers who already have successfully switched and overrepresent those unable to switch.

This study focused on users of JUUL, a particular pod-based nicotine-salt ENDS product, and it is not clear how results might apply to other ENDS, which are highly heterogeneous in nicotine delivery and other factors.[22] Some studies have reported that JUUL can deliver nicotine in a manner similar to cigarettes,[50, 51] which has been suggested as an important feature of ENDS that facilitates smokers to switch.[46, 50, 51] Thus, the generalizability of the findings to the range of other ENDS products is unknown.

The study also had multiple strengths. This study extended follow-up analyses from a single time-point to RPPS over a six-month period. We analyzed a large sample of baseline smokers who had just purchased JUUL, addressing the limitations of some previous studies, including small sample sizes. The participants represent real-world adopters of ENDS, and were followed forward from their initial purchase, making the results of this study more readily interpretable in terms of smokers' trajectories, and perhaps more applicable to real-world use. The analyses included details of smoking history and JUUL use patterns that enabled informative predictive models.

Conclusions

ENDS have emerged as potential substitutes for cigarette smokers who are otherwise not likely to quit in the near term. Complete switching away from cigarettes would reduce their exposure to combustion-related toxicants[10] and thus reduce smoking-related harm.[52, 53] Approximately one-fifth of adult smokers who purchased JUUL at baseline reported complete switching at months 6, 9, and 12. Lighter baseline smoking and greater use of JUUL (especially daily use) and stronger perceived reinforcing effects of JUUL predicted RPPS. These results suggest that, consistent with models of ENDS' role in harm reduction, products such as JUUL may help smokers switch away from smoking, ultimately improving the population health.

Declarations

Ethics approval and consent to participate

This study was approved by the Advarra® Institutional Review Board.

Consent for publication

Not applicable

Availability of data and materials

The data analyzed for this study is not currently publicly available.

Competing interests

SK and SS provide consulting services on tobacco harm reduction on an exclusive basis to Juul Labs Inc through PinneyAssociates Inc. SS holds a patent for a novel nicotine medication that has not been developed or commercialized. NIG is a full-time employee of Juul Labs, Inc.

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Authors' contributions

SS conceptualized and designed the study. SK conducted the analyses and prepared the initial draft of the manuscript. SS and NIG provided feedback and revised the manuscript. All authors reviewed and approved the final version of this article.

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Authors' information

Not applicable

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