



## JUUL electronic cigarettes: Nicotine exposure and the user experience

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### ABSTRACT

**Background:** As of March 2019, JUUL electronic cigarettes are the most popular e-cigarette on the U.S. market, but little is known of nicotine exposure and dependence on JUUL and user experience.

**Methods:** JUUL users participated in a community-based study involving questionnaires, saliva collection and a qualitative interview.

**Results:** Fifteen participants were enrolled (80% male, 53% White) and had an average age of 29.8 (standard deviation = 10) years. Daily exposure to nicotine assessed via salivary cotinine was similar to those reported for other e-cigarette and tobacco cigarette users in general. The majority reported low to moderate nicotine dependence. Qualitative interview themes included: the importance of social networks in adoption and use of the product; device features such as small size and vapor cloud reinforced product use; the product provided satisfaction compared to a tobacco cigarette; and a perceived sense of addiction to the product.

**Conclusions:** JUUL e-cigarettes expose users to levels of nicotine similar to other e-cigarettes but may be more satisfying due to unique device features. JUUL may be quite acceptable to tobacco cigarette smokers who are seeking to quit. However, it holds addictive potential and can reinforce long-term nicotine use.

## 1. Introduction

Electronic cigarettes are popular among adults and adolescents in the United States (U.S.). Among U.S. adults, prevalence of e-cigarette use every day or on some days was 5.5% in 2013–2014, 4.5% in 2016, and 2.8% in 2017 (Coleman et al., 2017; Mirbolouk et al., 2018; Wang et al., 2018). This represents 7–10 million U.S. adults across those years. In U.S. adolescents, it is estimated that 1.2% are using e-cigarettes at least some days (Jaber et al., 2018), and in 2018 approximately 3.6 million middle and high schoolers used an e-cigarette at least once in the past 30-days (Cullen et al., 2018). In general, e-cigarettes are considered a less harmful alternative to combusted tobacco cigarettes (Chen et al., 2017; Public Health England, 2015a; 2015b), and recent results from a randomized clinical trial indicate they can be efficacious in helping tobacco smokers quit cigarettes (Hajek et al., 2019).

JUUL e-cigarettes were introduced to the U.S. market in 2015. As of January 2018, JUUL had become the most popular e-cigarette in the U.S with Nielsen data estimating that JUUL represents approximately 70% of the e-cigarette retail store market share (Herzog and Kanada, 2018). This estimate does not include vape shop sales; therefore, it may

artificially inflate JUUL sales relative to other e-cigarette devices. Indeed, other estimates have indicated that JUUL represents approximately 30% of the overall e-vapor category (Altria Group (MO), 2018).

JUUL is a closed system (non-refillable) e-cigarette with disposable pods containing 0.7 mL of e-liquid in Virginia tobacco, classic tobacco, crème, fruit, mint, mango, menthol or cucumber flavors. JUUL Labs, the parent company, indicates these flavor pods contain 5% nicotine by weight (Juul Labs Inc, 2019). Independent analyses measured nicotine levels at 61.6 (Pankow et al., 2017) mg/mL and, depending on flavor, between 63–94 mg nicotine per gram e-liquid consumed with 30%/70% propylene glycol/glycerol ratios (Reilly et al., 2018), making JUUL e-liquids one of the highest nicotine content e-liquids available on the U.S. market. As of August 21, 2018, JUUL pods containing 3% nicotine by weight were also made available to consumers.

Youth initiation of JUUL is of current concern, with a dramatic rise of use in middle and high schoolers (NY Times, 2018) and survey data indicating that between 7% and 10% of 15–17-year-olds had ever used JUUL (Vallone et al., 2018; Willett et al., 2018) and 6% were currently (at least once in the past 30 days) using JUUL (Vallone et al., 2018). Some survey data of high schoolers indicated that JUUL was the most

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popular device among e-cigarette ever users and current users (Krishnan-Sarin et al., 2019), while other surveys have indicated JUUL to be the second most popular brand (Hammond et al., 2018). Still, the popularity of JUUL has garnered widespread attention. The U.S. Food and Drug Administration (FDA) recently announced a comprehensive plan to reduce the sale of e-cigarettes to minors, identifying JUUL as in violation of selling to minors and targeting minors in product marketing (U.S. Food and Drug Administration, 2018).

Despite these concerns about JUUL, little independent data is available on the user experience of the product. A qualitative study of pod-users, including some who used JUUL, indicated that users found pod devices to have a pleasurable sensory experience with strong nicotine delivery and less harsh sensory effects in the throat than tobacco cigarettes (Keamy-Minor et al., 2019). An analysis of user conversations on Twitter and Reddit found that the term “juul” is often used as a verb, i.e., “to juul” instead of “to vape”, and users were attracted to JUUL’s small flash-drive like appearance, spoke most about mint flavor, and discussed using in concealed places such as bathrooms, classrooms and cafeterias (Kavuluru et al., 2019). Media have similarly reported that the discreet nature of the JUUL aerosol makes it an appealing product for youth to use in classrooms (Chen, 2017).

Data informing the addictive potential of JUUL is sparse. The high nicotine content of the JUUL e-liquids raises concerns about creating a new population of dependent nicotine users, particularly among youth non-smokers. On the other hand, these e-liquids have the potential to deliver satisfactory nicotine levels to assist tobacco cigarette smokers in switching from cigarettes. Nicotine exposure is of specific interest, as it can inform both the product’s addictive potential and potential for therapeutic benefit.

Levels of urinary cotinine (the major proximate metabolite of nicotine) in a small sample of adolescent and young adult JUUL users have been reported (Goniewicz et al., 2018). Levels were on average 135 ng/mL, which is lower than that of an average tobacco cigarette smoker (Etter et al., 2000). On average urinary concentrations are 4.5 times higher than in blood, so the corresponding blood level of these JUUL users would be ~30 ng/mL. Cotinine levels in adult JUUL users have not been reported and may be higher given that adults generally have less barriers to use. Dependence levels have not been reported, other than users qualitatively mentioning dependence-related terms such as “crave”, “cravings” and “addiction” (Kavuluru et al., 2019). To address questions about risks vs. benefits of JUUL use in adults, it is important to understand more about users: why product initiation occurs, what sustains product use, and to measure nicotine exposure biochemically.

The aims of the current study were to assess in adult JUUL users: (1) daily nicotine exposure, (2) level of nicotine dependence, and (3) qualitative analysis of reasons for uptake of the JUUL product, current reasons for use and patterns of use.

## 2. Methods

### 2.1. Participants

We recruited participants between May 2018 and January 2019 within the city of San Francisco via Craigslist, community flyers and newspaper ads. Participants needed to be 18 years or older, regular users of JUUL e-cigarettes (using at least 10 days in the past 30), not seeking to quit vaping within the next 60 days, and not currently using any nicotine replacement therapies. Participants could be tobacco cigarette smokers but could not use any other tobacco products (i.e., cigarillos, cigars, blunts, spliffs, little cigars) more than 9 times in the past month.

### 2.2. Materials

We collected demographic data and information on participants’

combustible cigarette smoking and e-cigarette use, including past and current tobacco cigarette smoking status, length of time using JUUL, reasons for use and flavor preference. We assessed dependence on JUUL with the 10-item Penn State Electronic Cigarette Dependence Index (PSECDI) (Foulds et al., 2014) asking participants to complete it based on their JUUL e-cigarette use. We conducted semi-structured interviews containing specific discussion topics, but the wording and order of questions were flexible with detailed probing allowed (Kvale, 1996; Patton, 2002). We explored the uptake of the JUUL product, reasons for current use and patterns of use.

### 2.3. Procedures

Participants completed their study visit at the UCSF Tobacco Research Center, located centrally in the city of San Francisco. After providing informed consent, participants completed questionnaires and provided a saliva sample before undergoing the audio-taped semi-structured interview. Participants were instructed to bring their JUUL and pods with them to the visit so we could verify they were owners of the device. We aimed to recruit a minimum of 15 participants provided that saturation, meaning no new themes emerged after two consecutive interviews, was achieved. Interviews lasted for approximately 25 min (range: 15–35 min). Participants were paid for their time.

### 2.4. Data analysis

The Penn State Electronic Cigarette Dependence Index was scored with total scores of 0–3 indicating non-dependence, 4–8 indicating low dependence, 9–12 indicating medium dependence, and 13+ indicating high dependence (Foulds et al., 2014).

We utilized an inductive, thematic analysis approach to analyze our qualitative interview data (Braun and Clarke, 2006). In this approach we queried specific pre-existing questions in a semi-structured manner; however, the data was not collected with a pre-existing theoretical commitment, and we allowed for the development of emergent themes. All themes identified were driven from the responses of participants in the interviews. All interviews were transcribed verbatim. NN conducted all interviews, and SM performed all transcriptions. NN and NA independently reviewed the first five interview transcripts and generated an initial set of codes, which were then reviewed, discussed, compared and collated into potential themes. Interview transcripts were then coded, using a line-by-line open-coding approach to refine the initial categories. Ongoing review of transcriptions helped generate clear definitions for each theme. We assigned participants a pseudonym to use when attributing quotes.

### 2.5. Analytical chemistry

Cotinine concentration in saliva was determined using gas chromatography with nitrogen-phosphorus detection (Jacob et al., 1981). The limit of quantitation was 10 ng/mL. For participants with cotinine below the limit of quantitation (BLQ), cotinine levels were imputed as limit of quantification (10 ng/mL) divided by the square root of 2 (i.e., 7.1 ng/mL).

## 3. Results

Fifteen participants were enrolled (12 males, 3 females), with ages ranging from 21 to 51 (average = 29.8 years old, standard deviation = 10). Most participants were non-Hispanic (93%) and by race were white ( $N = 8$ ), Asian ( $N = 6$ ), and Mixed ( $N = 1$ ). Less than half of the sample ( $N = 6$ ; 40%) were exclusive JUUL users, and all 6 were former tobacco cigarette smokers. Of the 9 (60%) dual users, 3 smoked tobacco cigarettes weekly, 5 smoked monthly, and 1 smoked daily. About half of participants had experience in the past using other e-cigarettes (53%), but all were currently only using JUUL as their e-

**Table 1**  
Participant characteristics, dependence and saliva cotinine.

Participant Pseudonym	Age	Sex	Race	Ethnicity	Cigarette Smoking status	Primary Flavor	Vaped day of visit?	Vaping # of days/ past 30	Dependence Score	Saliva cotinine ng/mL
Harry	34	Male	Asian	Not Hispanic	Former smoker	Virginia Tobacco	No	10	1	BLQ
Charlie	44	Male	white	Hispanic/Latino	Monthly	Fruit	Yes	30	3	BLQ
Kyle	24	Male	white	Not Hispanic	Weekly	Mint <sup>‡</sup>	No	25	8	15.2
Michael	25	Male	white	Not Hispanic	Former smoker	Mint	Yes	30	6	50.3
Jenn	21	Female	white	Not Hispanic	Weekly	Menthol	Yes	30	12	60.3
Ian	23	Male	Asian	Not Hispanic	Monthly	Cucumber	Yes	30	9	110.5
Paul	28	Male	Asian	Not Hispanic	Monthly	Fruit	Yes	30	6	122.6
John	25	Male	Asian	Not Hispanic	Weekly	Virginia Tobacco	No	25	8	131.2
Damien	23	Male	Asian	Not Hispanic	Monthly	Mint	Yes	30	9	145.6
Greg	25	Male	white	Not Hispanic	Former smoker	Virginia Tobacco	Yes	30	10	182.8
Kate	49	Female	Asian	Not Hispanic	Daily	Mango	Yes	25	2	206.6
Chris	30	Male	white	Not Hispanic	Former smoker	Mint	Yes	30	13	307.0
Russel	51	Male	white	Not Hispanic	Former smoker	Mint	Yes	30	6	313.1
Sara	22	Female	Mixed**	Not Hispanic	Former smoker	Mint	No	25	—	—
Dave	24	Male	white	Not Hispanic	Monthly	Fruit	Yes	28	12	—

\* sample interference, unable to be assayed.

\*\* Black or African American & white.

‡ 3% nicotine level.

### cigarette product.

The majority of participants were introduced to JUUL via a friend or family member (93%). One participant was introduced to JUUL through a JUUL company promotion. The majority of participants (67%) continued to purchase their pods at a brick and mortar store. Approximately half of the sample (53%) had previously used a different electronic cigarette before using JUUL. Pod flavor use was 6 = mint, 3 = fruit, 3 = Virginia tobacco, and 1 each for menthol, cucumber and mango. All participants had tried other pod flavors, and 67% were actively rotating between flavors. Only one participant was currently using the 3% or 30 mg/mL nicotine pod (pseudonym Kyle). Reasons for using JUUL included the following: 9 = to reduce risk from tobacco cigarettes; 4 = to cut down on the number of tobacco cigarettes smoked; 9 = to quit tobacco cigarettes; 1 = vaping enjoyment; and 5 = JUUL use was unrelated to tobacco cigarette use. The majority (73%) of participants said they would like to quit using JUUL in the future.

### 3.1. Cotinine levels, exclusive and dual users

Saliva cotinine levels are shown in Table 1 for 13 participants. Two participants are omitted from this table. One of these participants (pseudonym Sara) indicated during the qualitative interview that she had quit using JUUL within the past week. Another participant's cotinine levels could not be quantified due to assay interference. Two participants had BLQ levels. Both of these participants reported non-dependence on JUUL, so it is likely that they were only intermittently using the JUUL product.

Of the remaining 4 exclusive JUUL users, cotinine levels ranged from 50.3 to 313 ng/mL (geometric mean = 172 ng/mL; 95% CI = 50–294), and of the remaining 7 dual users cotinine levels ranged from 15.2 to 207 ng/mL (geometric mean = 90 ng/mL; 95% CI = 44–136). If we include only those using JUUL pods with 5% nicotine levels (excluding Kyle) the geometric mean of salivary cotinine was 122 ng/mL (95% CI = 83–160).

If we include our two BLQ cotinine participants (1 exclusive and 1 dual), our cotinine levels for exclusive users are ( $N = 5$ ); geometric mean = 91 ng/mL; 95% CI = 84–266 and for dual users ( $N = 8$ ); geometric mean = 81 ng/mL; 95% CI = 25–136). However, we are uncertain of the validity of the use patterns of these two BLQ participants.

### 3.2. Dependence

Based on the PSECDI, the majority of participants ( $N = 8$ , 57%) were within the non-dependent ( $N = 3$ ) or low dependence ( $N = 5$ ) range, 5 reported medium dependence, and 1 reported high dependence. Dependence scores on average were 7.5, indicating low dependence for the entire sample. Dependence scores averaged 8.8 for exclusive JUUL users and 7.8 for dual users.

### 3.3. Qualitative interview themes

#### 3.3.1. Network, peer groups and social use

Peer groups were an important influencing factor in introduction to the JUUL product and use of the product. Many participants noted first trying their friends' JUULs before deciding to purchase for themselves. Others described how their use was primarily in social settings, while some felt embarrassed to use JUUL socially, especially around tobacco cigarette smokers.

Harry described who introduced him to JUUL, "...It was a friend of mine that was a big smoker. I asked him what it is, and he says - oh it's one of these new electronic cigarettes."

Sara described how many peers in college were also using JUUL, "...Everyone on my campus had one so it just kind of became so easy and people could just pass it to you and you could hit it... whenever I was out I would kind of just ask people to hit theirs."

Kate said she learned about JUUL from her college-aged son, "...I was visiting my son in college and there were so many kids that were using it. I had heard a lot about it from a lot of younger people."

Harry indicated that not only did he discover JUUL from his peer group but that his JUUL usage was primarily social. He said, "...For me it's kind of like a social thing, I do it with people. I don't JUUL by myself at home that often."

Conversely, Kate mentioned how she feels less comfortable using a JUUL in a social environment compared to smoking a tobacco cigarette socially, "...Puffing on a JUUL does not look that cool to me. I actually don't do it in public. I would actually smoke a cigarette in public, but I wouldn't JUUL in public."

Others mentioned feeling a stigma from tobacco cigarette smokers when they are seen JUULing in public. Harry said about how he is treated by smokers when he is using JUUL, "...I get teased sometimes

about it. It's like you're not smoking a real cigarette. You know, that's like a fake cigarette."

Similarly, Damien described how he thinks tobacco cigarette smokers perceive him as a JUUL user, "...I think the general impression is that it's [JUUL use] seen as a negative thing I guess. It was a friendly but derogative kind of— oh what are you doing?"

Greg described, "I feel like there's more of a stigma towards people who are using the JUUL who didn't smoke cigarettes before. It's kind of like— what are you doing?"

### 3.3.2. Device features

Participants described several device features of the JUUL as what attracted them to the product. Most commonly mentioned were features such as small size, small vapor cloud and a style mimicking other electronics. They also described the convenience of being able to take a hit without pressing a button and being able to vape indoors without a distinct smell. Several participants contrasted the JUUL to tobacco cigarettes and specifically noted the lack of smell with the JUUL device as a positive feature.

Chris described how the tech-nature of the device appealed to him: "I thought it was just cool. It was just electronic. It was super convenient. You'd assume that it'd be a pretty well made, high tech. Everything's sealed. Really discrete, you can fit it into your pocket. It's very easy to use. It's very simple, and it's designed that way... lighter weight, easier to carry around."

Michael described the ease of being able to use JUUL indoors, in an area where traditional tobacco smoking would be prohibited, thus being able to use nicotine while doing school work. ... "We really could not smoke in our college apartments. It was an easy way to get around not being able to smoke, and then being able to smoke something while you're working on something."

Similarly, Charlie noted how important it is to him to be able to vape indoors. "...I'll just be smoking [vaping] like this in my room, because I don't have to go outside anymore. I can just smoke on my bed. I smoke at work, and it doesn't even smell. That's important."

Jenn drew comparisons between JUUL and other e-cigarettes, noting that the lack of a vapor cloud was appealing, along with the smaller size. "... There's something about JUUL that is more attractive than other vapes. It's smaller. You don't have to press a button when you hit it, and you don't get as much smoke when you hit it."

Harry explained how not needing a lighter and not having a tobacco smell and ash are positives to using the JUUL over smoking. "...It didn't smell tobacco-y. You don't need a lighter. You don't have to always worry about disposing of the cigarette somewhere - there's no ashes - you don't have to worry about like burning your clothes or anything."

Paul noted similarly that not smelling like tobacco cigarettes has its benefits. "...The convenience factor is just incomparable because no smell, you're not carrying like a big pack that's stinking up everything...friends and family and dates— they don't smell it on you."

### 3.3.3. Satisfaction compared to a tobacco cigarette

Several participants noted the nicotine effects from the JUUL were similar to that of a tobacco cigarette. The JUUL was able to satisfy their need for nicotine while concurrently adding the sensory flavor benefit and not including the noxious aspect of cigarette smell. John described, "...It gives you pretty strong hits similar to what a cigarette does. It gives you a pretty good nicotine buzz. They somehow found a way to give it a for-real hit, similar to a cigarette. It's a little tastier than a cigarette too."

Paul described how JUUL was effective in extinguishing the craving for a tobacco cigarette, "...It's the closest thing I've ever come to mimicking the same feeling of hitting a cigarette, and I'd argue that it's almost indistinguishable, 'cause after one hit I don't want a cigarette period." Ian described feeling like his nicotine craving was satisfied after using JUUL, "...I do feel like I get a head rush, and then I feel relaxed. I get that craving out of the way I think I can focus a little more. If I'm studying or something I think that helps a little bit."

Charlie explained that he no longer feels cravings for cigarettes as

long as he can use his JUUL. "...I don't really get these crazy craving, because I'll just grab JUUL and then it makes me think that I'm basically smoking. I still don't want cigarettes."

### 3.3.4. Perceived dependence on nicotine

Several participants noted that they perceived their addiction to nicotine and use of JUUL to be stronger and more frequent than their use of tobacco cigarettes. Reasons for a greater perceived addiction to JUUL included not only the nicotine delivery but also the ease of use and being able to use indoors. Ian described specifically how being able to use indoors and not smelling of smoke increased his sense of perceived dependence, "...To be honest I think I did get more addicted to nicotine from before...if I see how much I was smoking cigarettes before, compared to how much I'm using this. This I can do it in my house, and it doesn't smell. It's much easier to use, but cigarettes I would have to go outside. It's just much more convenient, so I think I'm more and more dependent on it."

Sara described, "... I got really addicted to the JUUL. I have tried to quit, because it's so expensive. When I go out it's really hard because I crave [JUUL]. I was at work, and I literally had to leave. I'd leave and go to the bathroom to vape, because I was really craving it during the day."

Similarly, Russel described how the easy continuous use makes it harder to grasp how his addiction might have increased. "...Sometimes I just carry it with me, with this being constantly on. I can even in my car just puff on it without having that demarcation between puffs, so then I don't know how many puffs per day. I'm not sure how much in fact my nicotine addiction may have gone up with this."

Though not emerging as distinct themes, other items within the qualitative interviews mentioned by participants were: the perception that the nicotine salt base made the experience with the device more satisfying; participants felt well informed about the contents of their pods as JUUL lists ingredients on the packaging and taking "quick-hits" off the JUUL was mentioned as a topography pattern.

## 4. Discussion

The aims of the current study were to assess daily nicotine exposure in adult JUUL users, level of nicotine dependence, and to perform a qualitative analysis to understand the user experience.

Saliva cotinine levels in JUUL users of 5% nicotine pods showed exposure levels in exclusive JUUL users (172 ng/mL) and dual JUUL and tobacco cigarette users (122 ng/mL) were similar to our previous study of exclusive and dual electronic cigarette users (177 ng/mL and 166 ng/mL, respectively) (Nardone et al., 2019). They are also similar to if not slightly lower than saliva and serum cotinine levels of tobacco cigarette smokers previously reported (Jarvis et al., 2008; Rostron, 2012). Still, some JUUL users reached concentrations of cotinine much higher than these averages. One user (Charlie) reported using JUUL 30 days in the past 30, and his cotinine levels were below the limit of quantification, suggesting either misreporting of product use or not inhaling the aerosol. The participant (Kyle) who used the 3% mg/mL nicotine pods had lower cotinine levels compared to the rest of the sample.

Dependence scores were mostly low to moderate dependence. This is consistent with previous work showing that electronic cigarette users report less severe dependence than tobacco cigarette smokers (Gonzalez-Roz et al., 2017; Foulds et al., 2014). Given this, and that the theme of perceived nicotine dependence emerged from the qualitative interviews, it is possible that our dependence measure did not adequately capture the construct in JUUL users. Additionally, many in our sample were concurrently using tobacco cigarettes, so our dependence measure is reflective of nicotine dependence and not JUUL-product specific dependence. More research is needed to further evaluate dependence in exclusive JUUL users.

Results from our qualitative interviews suggest that social networks are an important influencer in participants learning about and using the

JUUL product. Notably, most participants heard about JUUL from a friend or family member, rather than media advertisements or vape shops, showing that information on this particular product spreads heavily through social networks. Not unlike cigarettes, there is a sharing aspect to using JUUL, e.g., taking a hit off of someone else's device or using primarily in social settings. This replicates findings from other qualitative interviews of pod users (Keamy-Minor et al., 2019). The finding that JUUL users perceive tobacco cigarette smokers to be biased against their JUUL use is novel and suggests that a cigarette smoker who is heavily influenced by a peer group of cigarette smokers may experience this bias and have difficulty switching to JUUL. Participants responded positively to device features such as small size, small vapor cloud and lack of smell. However, these features also seemed to encourage JUUL use in places where tobacco cigarette use is prohibited. Some participants who were previously experienced with tobacco cigarettes described being satisfied with the nicotine hit of the JUUL. They described how JUUL extinguished their craving for a tobacco cigarette. A downside emerged in that some participants reported an increase in perceived dependence on JUUL, in part due to JUUL's ease of use, lack of smell and ability to use without restriction indoors.

#### 4.1. Limitations

Limitations include a small sample size and majority male sample. Although prior research indicates that proportionally more e-cigarette users are male (Piñeiro et al., 2016), not including an equal number of women in the sample limits our ability to generalize to that population. Additionally, our study had a limited number of exclusive JUUL users, limiting our ability to tease out the influence of tobacco cigarette use on exposure levels and nicotine dependence.

#### 4.2. Conclusions

The JUUL product appears to be quite acceptable to tobacco cigarette smokers who are seeking to quit combusted cigarette use, as it is effective in delivering nicotine and extinguishing nicotine cravings. Aspects of JUUL that potentially make the product highly addictive include fewer barriers of use and ability to use in places where smoking is restricted. How strongly JUUL may reinforce long term dependence on nicotine is an important question both for populations of tobacco cigarette smokers and for youth who are initiating product use.

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#### Contributors

All authors contributed to the writing and editing of the manuscript. NN, NA and SM contributed to qualitative interviews and coding. NN and NA performed data analysis. NLB designed and supervised the research and obtained funding. All authors have read and approved the final manuscript.

#### Declaration of Competing Interest

NLB is a consultant to pharmaceutical companies that market or are developing medications to aid smoking cessation and has served as a paid expert witness in litigation against tobacco companies. All other authors have no conflicts to declare.

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#### References

- Altria Group (MO), 2018. The Motley Fool, Alexandria, VAQ4 2018 Earnings Conference Call Transcript 2018. Q4 2018 Earnings Conference Call Transcript.
- Braun, V., Clarke, V., 2006. Using thematic analysis in psychology. *Qual. Res. Psychol.* 3, 77–101.
- Chen, A., 2017. Teenagers Embrace JUUL, Saying It's Discreet Enough to Vape in Class. National Public Radio, Washington, D.C.
- Chen, J., Bullen, C., Dirks, K., 2017. A comparative health risk assessment of electronic cigarettes and conventional cigarettes. *Int. J. Environ. Res. Public Health* 14, 382.
- Coleman, B.N., Rostron, B., Johnson, S.E., 2017. Electronic cigarette use among US adults in the Population Assessment of Tobacco and Health (PATH) Study, 2013–2014. *Tob. Control* 26, 117–126.
- Cullen, K.A., Ambrose, B.K., Gentzke, A.S., 2018. 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.* 67, 1276.
- Etter, J.F., Due, T.V., Perneger, T.V., 2000. Saliva cotinine levels in smokers and non-smokers. *Am. J. Epidemiol.* 151, 251–258.
- Foulds, J., Veldheer, S., Yings, J., Hrabovsky, S., Wilson, S.J., Nichols, T.T., Eissenberg, T., 2014. Development of a questionnaire for assessing dependence on electronic cigarettes among a large sample of ex-smoking E-cigarette users. *Nicotine Tob. Res.* 17, 186–192.
- Goniewicz, M.L., Boykan, R., Messina, C.R., 2018. High Exposure to Nicotine Among Adolescents Who Use Juul and Other Vape Pod Systems ('pods'). *Tob. Control Epub ahead of print.*
- Gonzalez-Roz, A., Secades-Villa, R., Weidberg, S., 2017. Evaluating nicotine dependence levels in e-cigarette users. *Adicciones* 9, 136–138.
- Hajek, P., Phillips-Waller, A., Przulj, D.P., 2019. A randomized trial of e-cigarettes versus nicotine-replacement therapy. *N. Engl. J. Med.* 380, 629–637.
- Hammond, D., Wackowski, O.A., Reid, J.L., O'Connor, R.J., 2018. Use of JUUL e-cigarettes Among Youth in the United States. *Nicotine Tob. Res. Epub ahead of print.*
- Herzog, B., Kanada, P., 2018. Nielsen Tobacco 'All Channel' Data 1/27/2018: Wells Fargo Equity Research Reports. Wells Fargo Securities, San Francisco, CA.
- Jaber, R.M., Mirbolouk, M., DeFilippis, A.P., 2018. Electronic cigarette use prevalence, associated factors, and pattern by cigarette smoking status in the United States from NHANES (National Health and Nutrition Examination Survey) 2013–2014. *J. Am. Heart Assoc.* 7, e008178.
- Jacob, P., Wilson, M., Benowitz, N.L., 1981. Improved gas chromatographic method for the determination of nicotine and cotinine in biologic fluids. *J. Chromatogr. B Biomed. Sci. Appl.* 222, 61–70.
- Jarvis, M.J., Fidler, J., Mindell, J., Feyerabend, C., West, R., 2008. Assessing smoking status in children, adolescents and adults: cotinine cut-points revisited. *Addiction* 103, 1553–1661.
- Juul Labs Inc, 2019. JUULpod Basics. Juul Labs, San Francisco, CA.
- Kavuluru, R., Han, S., Hahn, E.J., 2019. On the popularity of the USB flash drive-shaped electronic cigarette Juul. *Tob. Control* 28, 110–112.
- Keamy-Minor, E., McQuoid, J., Ling, P., 2019. Young adult perceptions of JUUL and other pod electronic cigarette devices in California: a qualitative study. *BMJ Open* 9, e026306.
- Krishnan-Sarin, S., Jackson, A., Morean, M., 2019. E-cigarette devices used by high-school youth. *Drug Alcohol Depend.* 194, 395–400.
- Kvale, S., 1996. *Interviews: An Introduction to Qualitative Research Interviewing*. Sage Publications, Thousand Oaks, CA.
- Mirbolouk, M., Charkchi, P., Kianoush, S., 2018. Prevalence and distribution of e-cigarette use among US adults: behavioral risk factor surveillance system 2016. *Ann. Intern. Med.* 169, 429–438.
- Nardone, N., Ko, J., St Helen, G., 2019. Nicotine intake, dependence, and characteristics of electronic cigarette and dual users. *Tob. Regul. Sci.* 5, 27–35.
- Pankow, J.F., Kim, K., McWhirter, K.J., 2017. Benzene formation in electronic cigarettes. *PLoS One*, e0173055.
- Patton, M.Q., 2002. *Qualitative Research and Evaluation Methods*, third ed. Sage Publications, Thousand Oaks, CA.
- Piñeiro, B., Correa, J.B., Simmons, V.N., Harrell, P.T., Menzie, N.S., Unrod, M., Meltzer, L.R., Brandon, T.H., 2016. Gender differences in use and expectancies of e-cigarettes: online survey results. *Addict. Behav.* 52, 91–97.
- Public Health England, 2015a. E-cigarettes: An Evidence Update. A Report Commissioned by Public Health England. Public Health England, London.
- Public Health England, 2015b. E-cigarettes: An Emerging Public Health Consensus. Gov.UK, London.
- Reilly, S.M., Bitzer, Z.T., Goel, R., 2018. Free Radical, Carbonyl, and Nicotine Levels Produced by Juul Electronic Cigarettes. *Nicotine Tob. Res. Epub ahead of print.*
- Rostron, B., 2012. NNAL exposure by race and menthol cigarette use among US smokers. *Nicotine Tob. Res.* 15, 950–960.
- U.S. Food and Drug Administration, 2018. Statement From FDA Commissioner Scott Gottlieb, M.D., on New Enforcement Actions and a Youth Tobacco Prevention Plan to Stop Youth Use of, and Access to, JUUL and Other e-cigarettes. U.S. Food and Drug Administration, Silver Spring, MD.
- Vallone, D.M., Bennett, M., Xiao, H., 2018. Prevalence and Correlates of JUUL Use Among a National Sample of Youth and Young Adults. *Tob. Control Epub ahead of print.*
- Wang, T.W., Asman, K., Gentzke, A.S., 2018. Tobacco product use among adults—United States, 2017. *MMWR Morb. Mortal. Wkly. Rep.* 67, 1225.
- Willett, J.G., Bennett, M., Hair, E.C., 2018. Recognition, use and perceptions of JUUL among youth and young adults. *Tob. Control* 28, 115–116.