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Measuring e-cigarette addiction among adolescents

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ABSTRACT

Background and objectives With high rates of use and uncertain consequences, valid electronic cigarette (e-cigarette) use frequency and addiction measures for adolescents are needed. This cross-sectional study examined correlations for multiple measures of adolescent e-cigarette use with nicotine exposure quantified with salivary cotinine levels.

Methods Adolescents (N=173, age 13–18) who reported past-month e-cigarette use were recruited from the San Francisco Bay Area. Participants self-reported: (1) days of e-cigarette use in a typical month, (2) number of e-cigarette sessions in a typical day (sessions per day; SPD) and the (3) E-Cigarette Addiction Severity Index (EASI). Participants also completed the 10-item Penn State Electronic Cigarette Dependence Index (ECDI), which we examined in full and as a 2-item Heaviness of Vaping Index (HVI; the sum of the ECDI items on use frequency and time to first vaping on waking). Sessions per month (SPM) were calculated using days per month and SPD. Cotinine levels, SPD and SPM were log-transformed.

Results Among frequency measures, SPM correlated most strongly with cotinine ($r=0.59$), followed closely by days per month ($r=0.58$) and SPD ($r=0.57$), $p<0.001$. Among dependence measures, the EASI correlated most strongly with cotinine ($r=0.51$), closely followed by the ECDI and HVI (r 's=0.50), all p 's<0.001.

Conclusions Adolescents' reports of frequency of e-cigarette use and degree of addiction correlated significantly with cotinine as a biomarker of nicotine exposure. We recommend the EASI and days per month as brief general measures. SPM and the ECDI are more extensive measures that may yield a more nuanced understanding of use.

INTRODUCTION

Electronic cigarette (e-cigarette) use among adolescents is a public health concern. E-cigarette use (also known as vaping) exposes adolescents to nicotine and toxicants,^{1–9} and may increase the risk for initiating combustible cigarette use.^{10 11} Most epidemiological investigations of adolescent e-cigarette use to date have assessed lifetime or past month use, rather than heaviness of use. To better approximate estimates of safety and harm, in research and in clinical practice, valid measures of adolescents' e-cigarette use frequency and dependence are needed. Furthermore, few studies have biochemically validated adolescents' self-reported e-cigarette use. Consensus in measurement is needed to compare results across studies. The relative strength of associations between biochemical markers of e-cigarette use and self-reported measures of adolescent e-cigarette frequency and the development of e-cigarette addiction has not yet been examined. The current study sought to fill these gaps.

Some studies have measured frequency of e-cigarette use in reported daily number of cartridges¹² which would not be applicable to those who do not use cartridges or who share e-cigarettes with friends. In the extant literature to date, days of e-cigarette use per month has been the most popular measure of adolescent e-cigarette use frequency.^{13–15} Although days per month may capture differences between daily use and social (eg, weekend only) use, it does not differentiate between using once versus multiple times per day. Instead, the number of use sessions per day (SPD) may be important to measure and may serve as an analogue for cigarettes per day, an established measure of smoking heaviness.¹⁶ Alternatively, a combination measure of sessions per month (SPM) may be the most accurate measure of adolescents' e-cigarette use frequency, as it accounts for both days per month and SPD.

As with combustible cigarette smoking, nicotine exposure is critical to the development of addiction to e-cigarettes.¹⁷ Consequently, a strong correlation should exist between nicotine exposure and perceived e-cigarette addiction among adolescent e-cigarette users. The Penn State E-Cigarette Dependence Index¹⁸ (ECDI) has been validated in adults and has been used limitedly to measure dependence in adolescents.¹⁵ To the best of our knowledge, the ECDI has not been examined in association with actual nicotine exposure in adolescents. Heaviness of vaping (HVI), an index combining time to first e-cigarette use on awakening and number of daily sessions, is another potentially useful measure of e-cigarette dependence.¹⁹ HVI is based on the Heaviness of Smoking Index,¹⁶ which was derived from the classic Fagerström Test of Cigarette Dependence. Since e-cigarettes are more easily concealed than combustible cigarettes, they can be used surreptitiously in an adolescent's home first thing in the morning. Therefore, time to first e-cigarette and frequency of use may be more applicable as a combined measure of adolescents' e-cigarette dependence than they were for adolescents' traditional cigarette dependence. Finally, self-described level of e-cigarette addiction, as a single item, may be an efficient and helpful measure of adolescents' dependence on e-cigarettes. The item, which we call the E-Cigarette Addiction Severity Index (EASI), is based on a parallel item for combustible cigarettes, which in adolescent smokers we found to correlate significantly with cotinine.²⁰

To determine the most accurate self-report methods for estimating nicotine intake among adolescent e-cigarette users, the present study assessed the concordance between multiple self-report measures of e-cigarette frequency and dependence and salivary cotinine, a biomarker of nicotine exposure. Because adolescent dual users of e-cigarettes and combustible cigarettes are exposed to



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nicotine from both sources, a secondary analysis included only those participants without significant recent nicotine exposure from combustible cigarettes.

PATIENTS AND METHODS

Participants and procedures

Adolescent e-cigarette users (ages 13–18, N=173) who reported past month e-cigarette use were recruited from the San Francisco Bay Area using advertisements posted on social media and in the community and by word-of-mouth. Eligibility criteria (assessed during phone screening) were past-month e-cigarette use and at least 10 lifetime use sessions. Eligible participants were scheduled for an initial, in-person session during which they provided informed consent, completed self-report measures and provided saliva and urine samples for biomarker testing. Sessions took place between 5/27/15 and 4/7/17. Compensation was \$30.

Measures

Descriptive characteristics

Participants provided basic demographic information, characteristics of their e-cigarette use (eg, age of first use, preferred device, nicotine content)¹⁵ and past 30 days' and past 24 hours' tobacco smoking.

E-cigarette use frequency measures

Participants self-reported e-cigarette use days in a typical month and e-cigarette use sessions on each day of a typical week. Specifically, they answered: 'In a typical month (ie, 30 days), on how many days do you use e-cigarettes?' (0–30) and, 'In a typical week, please write the number of sessions you typically use your e-cigarette on each day' (seven items, measuring sessions from Monday to Sunday). 'Sessions' were defined for participants as, 'a period or block of time when you are vaping'.

E-cigarette dependence/addiction

We evaluated three measures of e-cigarette dependence/addiction. The first was the 10-item *Penn State Electronic Cigarette Dependence Index (ECDI)*.¹⁸ In addition to SPD, the ECDI included items such as, 'Do you use an e-cigarette now because it is really hard to quit?' (yes/no) and 'Do you ever have strong cravings to use an electronic cigarette?' (yes/no). From the ECDI items, we also calculated a Heaviness of Vaping Index (HVI) summing the items measuring frequency of use in a day and time to first e-cigarette assessed as: 'On days that you can use your electronic cigarette freely, how soon after you wake up do you first use your electronic cigarette?' (coded as 0–5 min=5, 6–15 min=4, 16–30 min=3, 31–60 min=2, 61–120 min=1, 121+min=0).^{21 22} Lastly, we tested a novel single item, the EASI, self-reported as: 'On a scale of 0%–100% (not addicted to extremely addicted), how addicted to e-cigarettes do you think you are?' Full scoring information for frequency and dependence measures is presented in online supplementary table 1.

Biomarkers of nicotine and tobacco exposure

Salivary cotinine was measured as a biochemical marker of nicotine exposure. Cotinine has a half-life of approximately 16–19 hours and remains detectable for up to 3 days after nicotine exposure.²³ Urinary nitrosamine 4-(methylnitrosamino)-1-(3-pyridyl)-1-butanol (NNAL), a tobacco-specific metabolite, was measured to detect recent combustible tobacco use. NNAL has a half-life of 10–18 days and remains detectable for 6–12 weeks after combustible tobacco exposure.²⁴ NNAL concentrations were normalised for creatinine²⁵ and should not be present in

levels above 10 pg/mg creatinine in adolescents with no recent active smoking and either past smoking or light secondhand smoke exposure (neither of which would be expected to significantly affect cotinine).²⁶ Saliva and urine samples were analysed at the Clinical Pharmacology Laboratory at the University of California, San Francisco. Analyses were performed using liquid chromatography-tandem mass spectrometry.²⁷

Statistical analysis

An averaged SPD variable was computed from dividing the item assessing 'sessions per day of the week' by seven. A calculated SPM variable was created by multiplying SPD by 'days of use per month'. Due to non-normal distributions, SPD, SPM and cotinine level were log-transformed. Correlations were examined for cotinine with days per month, SPD, SPM, self-described degree of e-cigarette addiction, the 10-item ECDI total score and the 2-item HVI. There were no missing data on the variables of interest. Analyses were conducted in both the full sample (N=173) and in the subsample of e-cigarette only users (N=144). As described above, e-cigarette only users were defined as adolescents who reported no combustible cigarette use in the past 24 hours and had NNAL levels <10 pg/mL creatinine.²⁶ Due to rapid changes in e-cigarette product availability and regulation, partial correlations were also examined, adjusting for date of assessment (ie, days passed from assessment date to present date).

RESULTS

Three hundred and eighty-six adolescents were screened, 229 were found to be eligible and 180 agreed to participate. Of the 180 who completed a baseline survey, 173 adolescents met criteria for using an e-cigarette at least once in the prior 30 days and at least 10 lifetime uses. The sample was 75.1% male and 54.9% non-Hispanic white with a mean age of 16.6 years (SD=1.2, range 13–18). The mean age of initiating e-cigarette use was age 14.8 (SD=1.3, range 10–17); 26.6% reported smoking a cigarette in the past 30 days and 5.0% smoked a cigarette in the past 24 hours. On average, participants reported using e-cigarettes approximately every other day (days per month M=15.4, SD=9.8). Median SPD were 1.4 (IQR: 2.7), and median SPM were 17.3 (IQR: 74.4). Participants' e-cigarette use characteristics and cotinine levels are presented in table 1.

Distributions of the sample's responses on the measures are reported in table 2. Among frequency measures, SPM (r=0.59) was most strongly correlated with cotinine levels, followed by days per month (r=0.58) and SPD (r=0.57). All three dependence measures correlated significantly with cotinine: the single item EASI (r=0.51), the 2-item HVI (r=0.50) and the 10-item ECDI (r=0.50). Mean scores on the EASI (M=24.6%, SD=25%), ECDI (M=3.4, SD=3.9) and HVI (M=1.8, SD=2.3) reflected fairly low dependence in the sample. The proportion scoring as moderately to heavily addicted or dependent were: 15.6% with an EASI score >50%, 13.3% with an ECDI score >8 and 4.6% with an HVI score >6 out of 10. Correlations between all measures are presented in online supplementary table 2.

Correlations remained strong when adjusting for date of assessment (all p's<0.001). In the subsample of e-cigarette only users (ie, those whose recent nicotine exposure was not from tobacco), all measures remained significantly correlated with cotinine (p's<0.001): SPM r=0.52, SPD r=0.49, days per month r=0.54, HVI r=0.43, ECDI r=0.41, EASI r=0.42.

Table 1 Cotinine levels by e-cigarette use characteristics

| | Salivary cotinine (ng/mL) | | | |
|-----------------------------------|---------------------------|---------------|--------|---------|
| | n (%) | M (SD) | Median | Range |
| Full sample | 173 (100.0) | | | |
| Current nicotine use | | | | |
| All e-cigarettes contain nicotine | 72 (41.6) | 61.9 (87.3) | 17.4 | 0–369.3 |
| Some contain nicotine | 67 (38.7) | 31.3 (111.7) | 0.0 | 0–864.6 |
| None contain nicotine | 13 (7.5) | 2.3 (7.7) | 0.0 | 0–27.9 |
| Unknown nicotine content | 21 (12.1) | 2.5 (9.6) | 0.0 | 0–44.1 |
| Type of e-cigarette used | | | | |
| Customisable/Mod | 56 (32.4) | 59.5 (133.5) | 6.5 | 0–864.6 |
| Juul | 38 (22.0) | 54.3 (90.1) | 6.1 | 0–302.8 |
| Vape pen | 59 (34.1) | 18.2 (38.9) | 0.0 | 0–161.5 |
| Other or unknown | 20 (11.6) | 8.5 (23.2) | 0.0 | 0–98.8 |
| Daily/non-daily e-cigarette use | | | | |
| Daily | 25 (14.5) | 114.6 (103.1) | 88.8 | 0–369.3 |
| Non-daily | 148 (85.5) | 25.5 (83.7) | 0.55 | 0–864.6 |
| E-Cigarette only users | 144 (83.2) | | | |
| Current nicotine use | | | | |
| All e-cigarettes contain nicotine | 51 (35.4) | 47.4 (82.3) | 9.1 | 0–369.3 |
| Some contain nicotine | 60 (41.7) | 24.9 (114.1) | 0.0 | 0–864.6 |
| None contain nicotine | 12 (8.3) | 0.1 (0.5) | 0.0 | 0–1.7 |
| Unknown nicotine content | 21 (14.6) | 2.5 (9.6) | 0.0 | 0–44.1 |
| Type of e-cigarette used | | | | |
| Customisable/Mod | 48 (33.3) | 51.5 (137.3) | 3.7 | 0–864.6 |
| Juul | 31 (21.5) | 36.1 (75.1) | 1.5 | 0–283.0 |
| Vape pen | 49 (34.0) | 7.6 (26.7) | 0.0 | 0–161.5 |
| Other or unknown | 16 (11.1) | 0.3 (0.9) | 0.0 | 0–3.3 |
| Daily/non-daily e-cigarette use | | | | |
| Daily | 15 (10.4) | 93.0 (100.4) | 57.8 | 0–369.3 |
| Non-daily | 129 (89.6) | 19.9 (85.6) | 0.0 | 0–864.6 |

DISCUSSION

In a sample of adolescent past month e-cigarette users, brief, single-item measures (ie, days per month and the EASI) performed comparably with more complex indices for measuring e-cigarette use frequency and dependence, as validated by salivary cotinine. The measures evaluated in this study vary in their length and complexity. The frequency of use measures each required estimation of use over a week or a month's time, while the addiction/dependence measures ranged from a single item to 10 items. All measures correlated significantly with cotinine

as a biomarker of nicotine exposure, suggesting that they can be used in research and clinical practice to document adolescents' frequency of use and the development of e-cigarette addiction. This is the first study to validate multiple measures of adolescent e-cigarette use and addiction. Use of common, validated measures in research will aid comparison across studies.

Among the frequency measures, correlations were approximately equivalent (r 's=0.57–.59). As measured in the present study, SPD and SPM reflect the nuances of adolescents' e-cigarette use patterns across different days of the week. However,

Table 2 Distributions of key measures

| | Full sample (N=173) | | | E-cigarette only users (N=144) | | |
|-----------------|---------------------|--------|----------|--------------------------------|--------|---------|
| | M (SD) | Median | Range | M (SD) | Median | Range |
| Cotinine | 38.4 (92.0) | 2.1 | 0–864.6 | 27.5 (89.7) | 0.0 | 0–864.6 |
| Ln Cotinine* | 1.8 (2.0) | 1.1 | 0–6.8 | 1.3 (1.8) | 0.0 | 0–6.8 |
| Days per month* | 15.4 (9.8) | 15.0 | 0–30.0 | 14.2 (9.6) | 12.0 | 0–30.0 |
| SPD | 3.2 (5.6) | 1.4 | 0–54.1 | 2.4 (3.6) | 1.1 | 0–25.0 |
| Ln SPD* | 1.1 (0.8) | 0.9 | 0–4.0 | 0.9 (0.7) | 0.8 | 0–3.3 |
| SPM | 74.7 (167.1) | 17.3 | 0–1624.3 | 52.5 (103.1) | 13.4 | 0–725.0 |
| Ln SPM* | 3.0 (1.7) | 2.9 | 0–7.4 | 2.7 (1.6) | 2.7 | 0–6.6 |
| ECDI* | 3.4 (3.9) | 2.0 | 0–16.0 | 2.7 (3.3) | 1.0 | 0–15.0 |
| EASI* | 24.6 (25.0) | 17.0 | 0–100.0 | 20.7 (22.9) | 11.0 | 0–100.0 |
| HVI* | 1.8 (2.3) | 1.0 | 0–10.0 | 1.5 (2.0) | 1.0 | 0–9.0 |

*Used in analyses.

EASI, E-cigarette Addiction Severity Index; ECDI, Penn State Electronic Cigarette Dependence Index; HVI, Heaviness of Vaping Index; SPD, Sessions per Day; SPM, Sessions per Month.

these measures require 7–8 items. Therefore, the single-item measure of days per month may be the most practical and performed equally well.

Consistent with our prior research with adolescent combustible cigarette smokers (where participants were asked to rate their self-perceived level of addiction on tobacco cigarettes on a Likert scale from 'not at all addicted' to 'totally addicted'; $r=0.56$),²⁰ self-described degree of addiction (the EASI) was significantly correlated with cotinine levels in adolescent e-cigarette users. This single-item self-report measure is quick to complete, easy to incorporate in clinical and research assessments, and may be useful in identifying youth at risk of continued use and in need of treatment. The single-item EASI measure performed just as well in its association with cotinine as the more extensive 10-item ECDI and 2-item HVI. The ECDI captures a variety of aspects of dependence, including length of e-cigarette use sessions, nighttime and morning use, cravings and withdrawal symptoms. Developed for use with adults, items were derived from previously validated measures such as the Fagerström Test of Nicotine Dependence²¹ and the Hooked on Nicotine Checklist.²⁸ As such, the ECDI may serve as a relatively comprehensive measure of dependence symptoms, and our findings support its utility with adolescent e-cigarette users.

The present study fills gaps in the literature by evaluating multiple measures of adolescents' e-cigarette use frequency and the development of addiction/dependence with validation against cotinine as a biomarker of nicotine exposure. We used cotinine to validate self-report measures because it measures exposure to nicotine, the addictive component of e-cigarettes.¹¹ However, there are a few important considerations when using cotinine to validate self-reported e-cigarette use. First, high cotinine levels may also reflect combustible cigarette use, which was reported in the past 24 hours by 4.6% of the sample. However, in the subsample of e-cigarette only users, correlations between self-report measures and cotinine remained statistically significant and relatively high, suggesting that the self-report measures of e-cigarette dependence/addiction are not simply reflecting dependence on nicotine in combustible tobacco. Second, cotinine would not be elevated among users who only used nicotine-free e-liquid ($n=13$, 7.5% in our sample), even if they used frequently. However, we included this group in the analysis because frequency and dependence should be (and in fact were) low in this small subgroup, likely because nicotine is the addictive component of e-cigarettes.

With broad applicability, the measures appear to have utility among both adolescent dual users and e-cigarette only users. The study was adequately powered to test the significance of correlations among the measures of interest. Although participants were recruited from the San Francisco Bay Area, the demographics of our sample generally reflect those of adolescent e-cigarette users in the USA (ie, primarily white, male, older adolescents).²⁹ Nonetheless, future research could aim to validate measures in more diverse samples. Finally, since the completion of our trial, a new measure of e-cigarette dependence, the PROMIS-E,^{30 31} has been introduced and future research could include this and additional measures. However, our results suggest that brief measures of e-cigarette use frequency and dependence (eg, days of use per month, the EASI) are valuable screening tools and predictive measures for both clinicians and researchers in identifying particularly high-risk e-cigarette use among adolescents.

CONCLUSIONS

Use of common measures of e-cigarette frequency and dependence will aid clinicians and researchers in documenting exposure and identifying those adolescents at greatest risk for becoming addicted. The present study found days of use per month and self-reported degree of e-cigarette addiction performed comparably to the more extensive measures of e-cigarette use frequency and dependence in estimating cotinine as a biomarker of actual nicotine exposure. Therefore, we recommend the EASI and days per month as brief general measures.

What this paper adds

- ▶ Adolescent e-cigarette use is a public health concern.
- ▶ Electronic-cigarette (e-cigarette) use exposes adolescents to nicotine and toxicants.
- ▶ Validated measures of adolescent e-cigarette use frequency and dependence are needed in research and clinical practice to identify hazardous use patterns.
- ▶ We examined correlations between nicotine exposure determined by salivary cotinine and measures of adolescent e-cigarette use and dependence.
- ▶ Brief, single-item measures (ie, days per month and the E-cigarette Addiction Severity Index) showed utility in measuring e-cigarette use frequency and dependence.

Contributors EAV conceptualised and conducted data analyses, drafted the initial manuscript, and reviewed and revised the manuscript. JJP critically reviewed and revised the manuscript for important intellectual content. MLR conceptualised and designed the study, coordinated and supervised data collection, and reviewed and revised the manuscript for important intellectual content. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

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Competing interests JJP has provided consultation to pharmaceutical and technology companies that make medications and other treatments for quitting smoking and has served as an expert witness in lawsuits against the tobacco companies. MLR has consulted for Pfizer on research involving smoking cessation medication and for Carrot, Inc., which makes a tobacco cessation device.

Patient consent for publication Not required.

Ethics approval Study procedures were approved by the University of California, San Francisco Institutional Review Board (IRB). We obtained IRB approval to waive parental consent, per the state of California law 6929(b), which permits the treatment of minors for substance use without parental permission. Cessation information and local treatment options were provided.

Provenance and peer review Not commissioned; externally peer reviewed.

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