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Characterizing ENDS use in young adults with ecological momentary assessment: Results from a pilot study

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Abstract

Introduction: Ecological Momentary Assessment (EMA) allows for assessment of electronic nicotine delivery systems (ENDS) use in real-time. This EMA study aimed to 1) describe study participation rates; 2) evaluate the concordance of EMA and survey items measuring frequency and quantity of ENDS use; and 3) assess the relationships between EMA items measuring frequency and quantity of ENDS use with ENDS dependence, measured at baseline and with saliva cotinine collected at follow-up.

Methods: Fifty young adult ENDS users completed baseline surveys, EMAs (i.e., random, event-based, daily diaries), and follow-up questionnaires over a 14-day period. Spearman correlations were conducted to determine concordance of survey items. Linear regression models assessed the relationships between EMA ENDS use characteristics (e.g., puffs, number of days used, quantity of e-liquid) with dependence items at baseline and saliva cotinine at follow-up.

Results: Overall completion for the prompted EMAs (random and daily diaries) was 68%. Correlations between EMA measures assessing ENDS use ranged from weak ($\rho = -0.02$; NS) to strong ($\rho = 0.69$, $p < .001$); EMA to follow-up items ranged from weak ($\rho = 0.16$; $p < .05$) to moderate ($\rho = 0.54$; $p < .001$). Significant associations were found between ENDS use measured via random and daily diary EMAs and saliva cotinine at follow-up after controlling for cigarette smoking ($B = 0.70$ – 1.76 ; $p < .01$), but not for event-based EMAs. Items measuring frequency/quantity of use from random EMAs were consistently associated with ENDS dependence at baseline ($B = 0.74$ – 1.58 ; $p < .01$).

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Contributors

All authors contributed to the study's concept and design. MRC, KRC and KAR conducted literature searches. MRC and KRC conducted the statistical analysis with guidance from MSB and ETH. MRC, KRC and KAR wrote the first draft of the manuscript and all authors contributed to and have approved the final manuscript.

Conflict of interest

The authors have no conflicts of interest to disclose.

Conclusion: EMA represents a promising methodology to capture real-time ENDS use behaviors, primarily through daily diary and random EMAs.

Keywords

E-cigarettes; Young adults; Tobacco use; Measurement; Alternative tobacco products

1. Introduction

It is well documented that awareness of Electronic Nicotine Delivery Systems (ENDS) and the prevalence of their use have grown precipitously since ENDS were first introduced in the U.S. a decade ago (Loukas, Batanova, Fernandez, & Agarwal, 2015). Among the adult population, studies have found that the prevalence of ENDS use is highest among young adults, (Choi & Forster, 2013; McMillen, Gottlieb, Shaefer, Winickoff, & Klein, 2015; Pearson, Richardson, Niaura, Vallone, & Abrams, 2012; Regan, Promoff, Dube, & Arrazola, 2013) especially young adults ages 18–24 compared with all other adult age groups (McMillen et al., 2015).

Ecological Momentary Assessment (EMA) has emerged as a promising data collection method as the use of mobile and wireless devices (i.e., smart phones and tablets) has increased. Its potential is highlighted in the ability to 1) collect behavioral data in real-time resulting in less recall bias than retrospective surveys, and 2) reduce participant burden and help with participant recruitment by using a device participants already have and are accustomed to using daily (Ginexi, Riley, Atienza, & Mabry, 2014). This technology may be especially well-suited for collecting data among young adults as 92% of 18–29 year olds in the U.S. own a smartphone, compared with 77% of U.S. adults in general (Smith, 2017).

There are four distinguishing characteristics of EMA: 1) measurements are obtained in a participant's daily environment; 2) EMA asks about current behaviors and other factors which may influence behavior; 3) times of measurement or "moments" can be chosen at random to occur throughout the day or at specific times when a particular behavior occurs; and 4) multiple assessments are collected during the study period to provide insight into differences in behavior and factors associated with behavior over time (Shiffman, Stone, & Hufford, 2008). EMA permits assessment of a wide range of ENDS use behaviors—such as frequency of ENDS sessions and approximate number of puffs—allowing researchers to ask more in-depth questions about characteristics of use as compared to population-based retrospective surveys (Shiffman et al., 2008; Shiffman & Kirchner, 2009). Other studies have measured ENDS use topography by using ENDS equipped with personal use monitors. Some found great variability between subjects in terms of puff topography, (Ko mider, Jackson, Leigh, O'Connor, & Goniewicz, 2018; Robinson, Hensel, Morabito, & Roundtree, 2015) and a study specific to young adults found puff topography varied not only between participants but within them as well (Robinson et al., 2016). Another study used a blue-tooth enabled ENDS to record real-time device use, and described patterns of ENDS use in the context of smoking cessation (Blank, Hoek, George, et al., 2018). However, there is little research documenting the success or failure of using EMA to collect real time ENDS use data in a young adult population.

Given the paucity of research using EMA both in young adults and for measuring ENDS use behaviors, the current study reports data from a pilot project aimed to determine whether EMA methods could be used to assess ENDS use in this population. We aim to 1) describe participation and completion rates for study assessments; 2) evaluate the concordance of EMA data and survey items measuring frequency and quantity of ENDS use (between daily, event, and random-EMAs and between EMA and follow-up survey); and 3) assess the relationships between EMA items that measure frequency and quantity of ENDS use with self-reported ENDS dependence, measured at baseline, and with saliva cotinine, collected at follow-up, in a sample of young adult ENDS users. There is little research documenting saliva cotinine as biochemical verification of nicotine use in ENDS products. While some studies have suggested poor nicotine delivery with ENDS, (Farsalinos et al., 2014) our study addressed this research question by assessing the relationship between saliva cotinine and ENDS use.

2. Materials and methods

2.1. Participants

Study participants were recruited online through the University of [blinded for review] Events Calendar and local [Craigslist.org](https://www.craigslist.org) classified listing. Additional recruitment flyers were posted at local vape shops. An online Qualtrics survey was used to screen for study eligibility. Participants had to 1) be between the ages of 18 and 29; 2) report use of ENDS with nicotine on some days, most days, or every day over the past month; and 3) own a personal Apple or Android smartphone or tablet with a data plan.

2.2. Measures

2.2.1. Baseline assessment—The baseline assessment was a 45-item, online questionnaire completed via Qualtrics. The assessment measured participant demographic characteristics, tobacco use history, ENDS use, social normative beliefs about tobacco products, and intrapersonal factors. Items adapted from the Population Assessment of Tobacco and Health (PATH) study¹⁵ queried about conventional cigarette use including ever use and past 30 day use. One item inquired about nicotine concentration (“Thinking of the ENDS device you use the most, what is the usual concentration of liquid nicotine?” Responses ranged from 1 to 12 mg or 0.1–0.6% to 25 mg or higher or 1.9% or higher and I don’t know). One item inquired about type of ENDS device (“What type(s) of ENDS device have you ever used? e-cigarette [including vape pens and personal vaporizers], e-cigar, e-hookah, e-pipe, other”). ENDS dependence was measured with one item (“How soon after you wake up do you use your first electronic nicotine device? after 60 min, 31–60 min, 6–30 min, within 5 min”) which was adapted from the Fagerström Test for Nicotine Dependence (Heatherton, Kozlowski, Frecker, & Fagerstrom, 1991). Frequency of ENDS used was measured using one item adapted from another survey (i.e., “How often do you currently use ENDS? daily; less than daily, but at least once weekly; less than weekly, but at least once a month; less than monthly; I don’t know”) (Hitchman, Brose, Brown, Robson, & McNeill, 2015).

2.2.2. EMA—Participants completed three types of EMAs over a two-week period: daily diary, random assessments, and event-based assessments. Each assessment was accessed via a commercial mobile application (“app”) downloaded to the participant’s personal smartphone or tablet. The EMA items were adapted from an appendix of items, some of which were originally developed for the assessment of conventional cigarette use (Shiffman et al., 1997; Shiffman, Paty, Gnys, Kassel, & Hickcox, 1996; Stone, Schwartz, Neale, et al., 1998) and have been used in previous smoking cessation studies (Businelle et al., 2016a; Businelle et al., 2016b; Businelle, Ma, Kendzor, et al., 2014). EMA items measured various constructs including tobacco use behaviors (e.g., ENDS, cigarette and other tobacco product use), current emotional state (affect and mood), current environment as well as ENDS satisfaction, pleasure, expectancies, and cravings. While the study included measures on many constructs, the current manuscript examines items related only to ENDS use frequency, quantity, nicotine dependence and saliva cotinine as described below.

2.2.2.1. Daily diary. The daily diary was composed of 17 items that queried participants about ENDS use for the previous day. This assessment alert was sent to participants once a day at 9 A.M. and the response window was open for 2 h. One item asked about frequency of ENDS use during the previous day (“On how many separate occasions did you use an electronic nicotine device yesterday?” Responses ranged from 1 to 3 occasions to 23 or more occasions and did not use). To calculate the number of days used during the study period, responses were collapsed so that one or more ENDS use occasions was considered an ENDS use day (0 = no ENDS use; 1 = ENDS use). Participants who reported ENDS use on the previous day were queried about the quantity of e-liquid used (“How many milliliters of e-liquid did you use yesterday?” Responses ranged from less than 1 ml to more than 3 ml, and I am not sure) (U.S., 2015).

2.2.2.2. Random assessment. The smartphone app prompted random EMAs three times per day. Three assessment alerts were randomly delivered between the hours of 11 A.M. and 9 P.M. Random EMAs remained available to participants for 15 min following the alert, after which participants could no longer complete the survey. One item asked about the participant’s last ENDS use “Since your last survey, on how many separate occasions did you use an electronic nicotine device?” Response options ranged from I did not use an electronic nicotine device since my last survey to 23 or more occasions) (Sobell & Sobell, 1992). Participants who reported using ENDS that day were queried on puffs that day with an item adapted from PATH (“Today, how many puffs did you take on your ENDS?” Responses ranged from 1 puff to 10 or more puffs) (U.S., 2015).

2.2.2.3. Event-based assessment. Participants were trained to complete the 12-item event-based EMA immediately after using ENDS. Using items adapted from PATH, (U.S., 2015) participants were queried on number of puffs (“How many puffs did you just take on your electronic nicotine device?” Responses ranged from 1 puff to 10 or more puffs) and quantity of e-liquid (“How much e-liquid did you just use?” Responses ranged from less than 1 ml to more than 3 ml, and I am not sure). For each participant, we calculated the total number of ENDS use events over the two-week period, and the number of ENDS use events per day.

2.2.3. Follow-up assessment—The follow-up assessment was conducted in-person at our research office. Participants completed a 9-item survey and provided a saliva sample. The NicAlert™ test for cotinine, which has been previously validated in nicotine-containing products, (Cooke et al., 2008; V & M, 2015) was used as biochemical verification of self-reported nicotine use. The follow up survey was comprised of retrospective measures of quantity, frequency, and duration of ENDS use (Biener & Hargraves, 2015; Foulds, Veldheer, & Berg, 2011; Goniewicz, Lingas, & Hajek, 2013; Hitchman et al., 2015; Schmidt, Reidmohr, Harwell, & Helgersen, 2014). One item measured the number of days of ENDS use (“During the past 30 days, on how many days did you use electronic nicotine devices such as Blu, 21st Century Smoke or NJOY?”). Number of ENDS uses per day was measured via one item (“How many times a day do you use electronic nicotine devices? less than 5 times; 6–15 times; 16–25 times; more than 25 times”).

2.3. Procedure

The Institutional Review Board at The University of Texas Health Science at Houston (UTHealth) granted approval and informed consent was obtained from all participants before any data collection began. Upon completion of the baseline survey, the research team sent each participant an e-mail with instructions for downloading and using the EMA app during the study. A 20-min training session was conducted via telephone before the beginning of each participant’s two-week study period during which investigators ensured participants had successfully downloaded the app and reiterated the study protocol and reimbursement structure. Participants were instructed not to complete EMAs in unsafe situations (i.e. while driving).

A reminder email was sent the day before the two-week EMA study period was set to begin. Reminder text messages were sent to participants every three days throughout the study period providing them with their percentage of completed EMAs. Participants were then sent a follow-up appointment reminder and completed the follow-up assessment in-person during the 24 h period following the last day of EMA participation. At the follow-up assessment, participants were asked two questions to collect general feedback on the study: 1) How did you hear about our study? and 2) Did you have any challenges in completing any parts of the study? Responses were documented, and although systematic coding of qualitative data was not undertaken, high-level findings were summarized.

Participants earned up to \$120 in the form of electronic gift cards for their participation in this study. Participants who completed 50–74% of the prompted (random and daily diary) EMAs earned \$40; 75–89% earned \$60; and 90% or more earned \$80. Compensation was not awarded to participants who completed less than 50% of the prompted EMAs. Event-based EMAs were not compensated. In addition, participants earned \$30 for completing the baseline assessment and \$10 for completing the in person follow-up assessment. Participants received incentives via e-mail at two study time periods: 1) within 24 h of completing the baseline survey (\$30); and 2) within 24 h of completing their follow-up assessment (up to \$90 depending on EMA participation rate). Participants who did not attend their follow-up assessment in person were sent a link to the survey and were e-mailed the incentive for their

EMA participation only, but not for the follow-up assessment. For these participants ($n = 5$), saliva samples were not collected. The data collection period spanned April to October 2016.

2.4. Statistical analysis

Descriptive statistics, including demographic characteristics and conventional cigarette/ENDS use behaviors, were analyzed from baseline survey data (Table 1). To achieve the first study objective, EMA completion rates were calculated as the proportion of prompted EMAs that were completed (Table 2). To achieve the second study objective, Spearman correlations were conducted to determine agreement between 1) ENDS use reported via three types of EMAs and 2) ENDS use reported via EMA versus follow-up (Table 3). For each EMA item, within day aggregate measures for each participant were calculated. Number of puffs (measured via event-based EMAs) were summed per day for each participant, and number of puffs (measured via random EMAs) were collapsed per day for each participant where the maximum value reported per day was used; these values were correlated. Number of periods of use (measured via random and event-based EMAs) were summed per day for each participant and were correlated. Daily quantities of e-liquid used (measured via daily diary EMA and event-based EMA) were summed per day for each participant and were correlated.

To achieve the third study objective, linear regression models assessed the relationship between ENDS use reported via EMA (the outcome variable) with measures of dependence at baseline and saliva cotinine measured at follow-up (entered as the primary predictor variable in each model). We summed the total number of days that the participant indicated using ENDS on the daily diary, on the random assessment, and on the event-based assessment, respectively. Outcome measures related to puffs, quantity of e-liquid, and nicotine concentration were summed per day (except for puffs measured via random EMA where the maximum value per day was used), and collapsed by participant. Regression models included number of cigarettes per day as a covariate to control for effects of cigarette smoking (Table 4).

Additionally, to address the concern of the half-life of saliva cotinine, a sensitivity analysis was conducted. Cotinine remains detectable in saliva for approximately three days, (Carey & Abrams, 1988) so it is possible that an intermittent user could have abstained from using nicotine in the final study days and have been classified as a non-user based on their biomarker data. The sensitivity analysis consisted of rerunning the models in which cotinine was the predictor to include only responses from participants' last three days of the EMA period. Stata 14.0 (College Station, TX) was used for statistical analyses, and the threshold for statistical significance was set to $p < .05$.

3. Results

The final sample comprised of 50 current ENDS users (26% female), ranging from 18 to 29 years of age. The baseline survey indicated that 92% of the sample had ever used conventional cigarettes while 63% of the sample had used cigarettes in the past 30 days. The most common type of ENDS device participants had ever used was an e-cigarette, which included vape pens and personal vaporizers (98%), followed by e-hookah (22%). The

majority of participants (72%) reported their usual concentration of liquid nicotine was 1–12 mg per milliliter. The majority of participants (76%) reported using ENDS every day. See Table 1.

3.1. Participation and completion rates

All participants completed the baseline and follow-up survey and completed daily diary and random EMAs (Table 2). Forty-five participants (90%) provided a saliva sample for the NicAlert™ test. Forty-one (82%) participants initiated at least one event-based EMA, and 495 event-based EMAs were completed overall. Completion rates for the prompted EMAs were 67.8% overall (75.2% of daily diary EMAs were completed and 65.2% of random EMAs were completed). During the two-week period, participants completed daily diary EMAs on an average of 10.5 days ($SD = 3.1$) and random EMAs on 12.9 days ($SD = 2.2$ days). Event-based EMAs were completed on an average of 5.4 days ($SD = 3.9$).

3.2. Concordance between EMAs by EMA type and follow-up items

Correlations between items measuring frequency and quantity of ENDS use via EMA varied in strength and statistical significance (Table 3). Number of days of ENDS use reported via random EMA and daily diary EMA was significantly correlated ($\rho = 0.69$; $p < .001$) and reported via random EMA and event-based EMA was significantly correlated ($\rho = 0.32$; $p < .05$). Number of days of ENDS use reported via daily diary EMA and event-based EMA was not significantly correlated. Number of uses per day (reported via random EMA and event-based EMA) and quantity of e-liquid (reported via daily diary and event-based EMA) was not significantly correlated. Number of puffs per day reported via random EMA and event-based EMA was significantly correlated ($\rho = 0.29$; $p < .001$).

Number of days of ENDS use reported via daily diary EMA and random EMA was significantly correlated with the follow-up survey item measuring the number of days ENDS use in the past 30 days ($\rho = 0.54$; $p < .001$ and $\rho = 0.37$; $p < .01$, respectively). Number of days of ENDS use reported via event-based EMA was not significantly correlated with the follow-up item measuring the number of days ENDS use in the past 30 days. Number of uses per day reported via random EMA and event-based EMA was significantly correlated with the follow-up item measuring times per day of ENDS use ($\rho = 0.40$; $p < .001$ and $\rho = 0.16$; $p < .05$, respectively).

3.3. Concordance between EMA and biomarkers/ENDS dependence

As seen in Table 4, items measuring frequency and quantity of ENDS use via random EMA and daily diary EMA were significantly and positively associated with saliva cotinine collected at follow-up, controlling for number of cigarettes smoked per day ($B = 0.70$ – 1.76 , all $p < .01$). In the sensitivity analysis, significant associations for each model were also seen ($B = 0.34$ – 1.69 , all $p < .05$). Items measuring number of days of ENDS use and nicotine concentration via event-based EMA were not significantly associated with saliva cotinine, controlling for number of cigarettes smoked per day. Similarly, in the sensitivity analysis, these models were not statistically significant ($B = 0.47$ – 0.71 , $p > .05$).

Number of days of ENDS use measured via random EMA and event-based EMA were significantly and positively associated with self-reported ENDS dependence measured at baseline, controlling for number of cigarettes smoked per day ($B = 1.58$; $p < .01$ and $B = 1.64$; $p < .01$, respectively); however number of days of ENDS use reported via daily diary was not. The quantity of e-liquid used per day measured via daily diary EMA and the number of puffs per day measured via random EMA were significantly and positively associated with self-reported ENDS dependence measured at baseline, controlling for number of cigarettes smoked per day ($B = 0.91$; $p < .01$ and $B = 0.74$; $p < .001$, respectively). The average level of nicotine concentration measured via event-based EMA was also significantly and positively associated with ENDS dependence at baseline controlling for number of cigarettes smoked per day ($B = 0.14$; $p < .05$).

4. Discussion

This study adds to the limited literature which shows that EMA can be used to collect real-time data on ENDS use, and is one of the first EMA studies on ENDS conducted exclusively in young adults (Huh & Leventhal, 2016). Items from daily diary and random EMAs, but not event-based EMAs, were most consistently associated with 1) other EMA items measuring frequency and quantity of use; 2) follow-up survey items measuring frequency and quantity of use; 3) self-reported ENDS dependence at baseline; and 4) nicotine biomarkers collected after the EMA study period. While this study supports the use of daily diaries and random EMAs in ENDS research, future studies should explore ways to improve use of event-based EMAs to measure ENDS use.

All participants completed baseline and follow-up surveys (administered online) and daily diary and random EMAs via the app download to personal smartphones. Overall, 65.2% of prompted random EMAs were completed and 75.2% of prompted daily diary EMAs were completed—rates which are consistent with other observational EMA studies focusing on substance use (Buckner, Crosby, Silgado, Wonderlich, & Schmidt, 2012). Future studies could improve this rate by querying participants on their usual waking hours and programming prompted EMAs uniquely for each study participant. In the current study, notifications for prompted EMAs were delivered between 9 A.M. and 9 P.M. daily, which may not have been suitable for some young adult participants, most of whom were college students and may have kept schedules outside of our pre-determined time period. Our narrow 15-min window for completing random EMAs may have also hindered completion rates; future studies should consider 30-min windows.

Although 49 participants reported using ENDS on at least one daily diary EMA during the two-week period, only 41 (82%) completed self-initiated, event based EMAs when they used ENDS. Further, among those 41 who had completed at least one event-based EMA, ENDS use was under-reported. Specifically, participants reported ENDS use in daily diary EMAs on 84.4% of days (445 days out of 527 completed daily diary EMAs), but participants self-initiated assessments for ENDS use on only 5.4 days (38.6%) on average over the 14-day study period. While compliance rates associated with recording cigarette use events via EMA vary greatly in the literature, ranging from 22% to 90%, (Shiffman, 2009) our findings are consistent with a previous EMA ENDS pilot study which documented

under-reporting of puff counts and use in self-initiated EMAs (Pearson, Elmasry, Das, et al., 2017). Event-based EMAs were not built into our incentive structure, and participants were not reminded to complete event-based EMAs. In future studies these types of EMAs could be incentivized whereby participants receive bonus payments for reporting data consistently across EMA types. Study participants were queried at the follow-up visit regarding challenges they experienced throughout the study period. One participant noted the difficulty in completing the event-based EMAs given that he continuously used the product at home, and could not determine specific start and stop times. This finding is consistent with qualitative research which has found that ENDS users report highly variable patterns of use, with no common unit emerging to easily measure ENDS frequency (Kim, Davis, Dohack, & Clark, 2017). Given these quantification difficulties, event-based EMAs may have limited feasibility for studies on ENDS due to inherent differences in the way ENDS are used.

Biospecimen samples were not collected for five participants who missed their in-person follow up assessment, but the participants did complete the follow-up survey online. This completion rate for biospecimen samples could be improved upon in future studies by reducing participant burden and allowing participants to mail saliva samples to investigators rather than attend an in-person appointment. Some participants reported not receiving an alert for a prompted EMA, although it is difficult to quantify the number of prompted EMAs this might represent since the EMA platform indicated that all EMA prompts were sent. In these cases, EMAs were counted as missed.

EMA items measuring frequency and quantity of ENDS use were generally associated both with each other and with follow-up survey items, with the exception of several items measured via event-based EMA. Similarly, positive and significant associations were generally found for daily and random EMA items with ENDS dependence measured at baseline. Further, objective measures of nicotine use (cotinine, a biomarker of nicotine levels in saliva) collected after the study period support the validity of this methodology for measuring ENDS use. Self-reported frequency and quantity of ENDS use measured via daily diary and random EMAs was positively associated with cotinine levels, after controlling for number of cigarettes per day, adding to the limited evidence documenting the validity of measuring saliva cotinine levels to verify ENDS use (Berg, Barr, Stratton, Escoffery, & Kegler, 2014; Etter, 2016). Event-based EMAs, likely due to under-reporting noted above, were not significantly associated with saliva cotinine levels, but were positively and significantly associated with self-reported ENDS dependence measured at baseline. Future studies should examine ways to improve the concordance of ENDS use measured via event-based EMAs.

Limitations should be considered when interpreting study results. First, the completion rate for prompted EMAs (67.8%) may be one explanation as to why correlations between EMA types and survey follow up items were not higher. Specifically, the EMA data may not be fully representative of a typical period of ENDS use and may not capture all use behaviors. Next, even though the EMA schedule is similar to that used in previous research, (Businelle et al., 2014; Shiffman, 2009) the high burden of EMA response required overall, could have led to low completion of event-based EMAs in particular. The continuously evolving nature of ENDS products was another challenge. The data collection period occurred before Juul

and other pod devices were widely available, and as such those device types are not reflected in our data. Further, the EMA item assessing number of puffs had an upper bound limit of 10 puffs, which may have lead to a ceiling effect for heavy users.

Despite these limitations, our study adds to the limited empirical data regarding measuring ENDS use with EMA. The use of accurate methodologies for ENDS use is an important milestone in tobacco-related research as ENDS use is growing rapidly.

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HIGHLIGHTS

- This study adds to the limited empirical data regarding measuring ENDS use with EMA.
- This is one of the first EMA studies on ENDS use exclusively in young adults
- EMA represents a promising methodology to capture real-time ENDS use behaviors
- Daily diary and random EMAs were generally reliable in measuring ENDS use.
- Results are less supportive of event-based EMAs as reliable to measure ENDS use

Table 1

Baseline Demographic Characteristics and ENDS/Conventional Cigarette Use (n = 50).

	Prevalence/Mean
Gender	
Male (n = 37)	74.0%
Female (n = 13)	26.0%
Age	23.02 (range = 18, 29)
Race	
White (n = 27)	54.0%
Hispanic (n = 10)	20.0%
Asian (n = 10)	20.0%
More than One Race (n = 3)	6.0%
Education Level	
High School (n = 10)	20.0%
Some College (n = 25)	50.0%
College Graduate (n = 15)	30.0%
Ever Cigarette Use	92.0%
Current Cigarette Use	63.0%
Types of ENDS Ever Used [check all that apply]	
E-cigarette, including vape pen (n = 49)	98.0%
E-hookah (n = 11)	22.0%
E-pipe (n = 4)	8.0%
Other (n = 2)	4.0%
E-cigar (n = 1)	2.0%
Usual concentration of liquid nicotine	
1–12 mg/ml (n = 36)	72.0%
13–17 mg/ml (n = 6)	12.0%
18–24 mg/ml (n = 6)	12.0%
I don't know (n = 2)	4.0%
How often currently use ENDS	
Daily (n = 38)	76.0%
Less than daily, at least 1×/week (n = 9)	18.0%
Less than monthly (n = 3)	6.0%
How soon after waking first use ENDS?	
After 60 min (n = 25)	50.0%
31–60 min (n = 9)	18.0%
6–30 min (n = 6)	12.0%
Within 5 min (n = 10)	20.0%

Table 2

Participation and Completion Rates for Study Assessments.

	Participants Completing Assessments		Total Assessments Completed (EMAs only)		Completion rate (prompted EMAs only)		Days Participating (EMAs only) out of 14 days	
	n (%)	n	n	%	%	Mean (sd)		
One-time Assessments								
Baseline Assessment	50 (100.0%)	-	-	-	-	-		
Follow-up Assessment	50 (100.0%)	-	-	-	-	-		
Saliva Cotinine Test	45 (90.0%)	-	-	-	-	-		
EMAs								
Daily Diary	50 (100.0%)	527	527	75.2%	75.2%	10.5 (3.1)		
Random Assessment	50 (100.0%)	1371	1371	65.2%	65.2%	12.9 (2.2)		
Event-based Assessment	41 (82.0%)	495	495	-	-	5.4 (3.9)		

Table 3Correlations (ρ) between EMAs and Post-EMA follow-up survey items ($n = 50$).

	EMA to EMA correlations (ρ)			EMA to Follow Up correlations (ρ)		
	Daily vs. Event	Random vs. Random	Event vs. Daily	Daily vs. Follow up	Random vs. Follow up	Event vs. Follow up
Puffs per day	–	–	0.29***	–	–	–
Quantity of e-liquid	0.05		–	–	–	–
Days used ENDS	0.26	0.69***	0.32*	0.54***	0.37**	0.17
Number of uses per day	–	–	–0.02	–	0.40***	0.16*

 ρ = Spearman correlation coefficient.* $p < .05$.** $p < .01$.*** $p < .001$.

Table 4

Linear regressions between ENDS use measured via EMA and biomarkers / ENDS dependence, adjusted for cigarette smoking.

	Ecological Momentary Assessments					
	Random Assessment		Daily Diary		Event Based Assessment	
	Number of days used ENDS	Puffs per day	E-liquid (ml) used	Number of days used ENDS	Number of days used ENDS	Nicotine concentration
Biomarker	Estimate (B) (95% CI)	Estimate (B) (95% CI)	Estimate (B) (95% CI)	Estimate (B) (95% CI)	Estimate (B) (95% CI)	Estimate (B) (95% CI)
Saliva Cotinine ^a (n=45)	1.76 *** (1.20–2.31)	0.70 *** (0.43–0.97)	0.77 *** (0.38–1.16)	1.21 *** (0.56–1.86)	0.43 (–0.54–1.41)	0.07 (–0.07–0.22)
Pre-EMA Survey						
ENDS Dependence ^b	1.58 ** (0.68–2.47)	0.74 *** (0.36–1.13)	0.91 ** (0.40–1.43)	0.88 (–0.01–1.76)	1.64 ** (0.71–2.56)	0.14 * (0.00–0.29)

B = beta coefficient.

CI = confidence interval.

^a Measured on 7-point scale from: 1–10 ng/ml to 2000+ ng/ml.

^b Time to first e-cigarette after waking was measured on a 4-point scale: After 60 min, 31–60 min, 6–30 min, Within 5 min..

* *p* < .05.

**

p < .01.

*** *p* < .001.