Nicotine and Tobacco Research, 2022, **24**, 1089–1094
https://doi.org/10.1093/ntr/ntab268
Advance access publication 22 December 2021
Original Investigation

E-Cigarette Dependence in Youth

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Abstract

Introduction: The majority of e-cigarette vaping youth use nicotine when vaping. Some then become dependent on the nicotine, which can result in subsequent health effects. There has been limited evaluation of convergent validity of e-cigarette dependence measures for use specifically in youth. The aim of this study was to investigate and validate various e-cigarette dependence measures for use in youth populations.

Aims and Methods: One thousand two hundred and five Canadian youth aged 16–24 who completed a cross-sectional online survey reported vaping at least monthly and were thus included in the analysis. E-cigarette dependence was assessed using a modified Penn State Electronic Cigarette Dependence Index (PS-ECDI), the E-Cigarette Dependence Scale (EDS), a self-perceived vaping dependence question, and time to first vape after waking. Internal consistency, convergent validity, and concurrent validity of the measures were assessed.

Results: Both the PS-ECDI and the EDS exhibited a good degree of internal consistency ($\alpha = 0.8472$ and 0.8405, respectively). All measures exhibited convergent validity against each other and against time to first vape upon waking ($p < .001$), as well as concurrent validity against vaping frequency and nicotine concentration ($p < .001$). The PS-ECDI was inferior to the EDS, self-perceived measure, and time from waking when predicting daily vaping frequency, but, along with the self-perceived measure, was superior to the EDS and time from waking when predicting monthly vaping.

Conclusions: All measures exhibit convergent and concurrent validity, as well as internal consistency. Depending on the needs of the study, it would be appropriate to use any of these measures when assessing e-cigarette dependence in adolescent and young-adult populations.

Implications: The PS-ECDI and the self-perceived measure are equally effective in predicting monthly vaping, but the self-perceived measure was superior in predicting daily vaping. Thus, the one-item self-perceived measure of dependence is appropriate for use and preferable to the 11-item PS-ECDI or the 4-item EDS in situations of limited time or where subjects are at risk of respondent fatigue, and is superior to time to first vape after waking to predict vaping frequency.

Introduction

Vaping use and frequency levels among youth have been increasing in recent years, in part a result of the legalization of nicotine e-cigarettes in the Tobacco and Vaping Act 2018. Past 30-day vaping by Canadian adolescents aged 16–19 years has increased from 8.4% in 2017 to 14.6% in 2018.[1] Though 28.6% of 16–18-year-old e-cigarette users are never-smokers, 92.8% of e-cigarette-using youth from the same cohort reported using nicotine when vaping either always or very often.[2] Nicotine e-cigarettes, such as JUUL and JUUL-like pod devices, often have very high nicotine content, producing peak nicotine levels similar or greater than those of combustible cigarettes, resulting in subsequent nicotine dependence. While vaping e-cigarettes is considered to be less harmful than smoking cigarettes,[3] studies have identified potential negative cardiovascular and respiratory health effects,[4,5] among others, along with the identification of carcinogens in e-cigarette aerosol.[6] As vapers become dependent to nicotine, resulting in increased frequency and duration of e-cigarette use over time, the risk of negative health outcomes increases.[7]

While there is substantial evidence in adults that e-cigarette use results in dependence, there is limited existing knowledge on the onset and natural history of e-cigarette dependence among youth. As age has been associated with vaping frequency and levels of dependence, risk factors, timelines, and process of dependence are expected to differ between adults and youth, due to social, psychological, and biological factors.[8] Reliable measures of e-cigarette dependence with high validity are required for accurate identification of dependence, to improve prevention, surveillance, diagnosis, and treatment of e-cigarette dependence, tailored and specific to adolescents and young adults.

Up to this point, there has been limited evaluation of convergent validity of e-cigarette dependence measures for use specifically in youth. Morean et al. assessed the convergent validity of the E-Cigarette Dependence Scale (EDS) against the Penn State Electronic Cigarette Dependence Index (PS-ECDI), however their evaluation only included adults, with a mean age of 35.81.[9] Similarly, Buu et al., who aimed to validate three EDSs (PS-ECDI, e-FTCD, and e-WISDM) among dual-users of e-cigarettes and combustible cigarettes, had an eligibility criterion of at least 18 years old, and a mean subject age of 37.57.[10] While Morean et al. assessed the internal validity of the EDS (then PROMIS-E) in an adolescent cohort with mean age 16.22 years, the authors did not assess convergent validity with other existing measures of e-cigarette dependence.[11] Similarly, while time to first cigarette is a

Received: August 12, 2021. **Revised:** November 25, 2021. **Accepted:** December 20, 2021

well-validated predictor of nicotine dependence among smoking adults, time to first e-cigarette as a measure of dependence among youth is lacking in validation.[12,13] There is an existing knowledge gap pertaining to the absence of e-cigarette dependence measures that have been convergently validated specifically for use in adolescent and young-adult populations.

This study will assess the convergent validity between the EDS (formerly PROMIS-E), the PS-ECDI, time to first vape after waking (all very commonly used measures/predictors of nicotine dependence), and a self-perceived measure of e-cigarette dependence among a cohort of 3000 Canadian youth aged 16–24. In addition, the concurrent validity of each of these measures will also be assessed. The aim of this study is to establish these measures as having high concurrent and convergent validity for measuring e-cigarette dependence in youth, thus determining if they are appropriate measures for use in future studies of e-cigarette dependence in adolescent and young-adult cohorts.

Methods

Study Population

Adolescents and young adults aged 16–25 living in Canada were eligible to participate in the Ontario Tobacco Research Unit Youth and Young Adult Research Registration Panel. Participants were recruited into the Panel via social media and completed questionnaires between August 2020 and March 2021. Social media advertisements to join the Panel were conducted targeting youth and young adults who use cigarettes or e-cigarettes between August 2020 and February 2021. Incentives were provided via gift cards of increasing value per each additional survey completed, along with entry into a draw for an additional gift card. Following initial convenience sampling, targeted recruitment was used to achieve quotas for vaping/smoking status and sex. Three thousand eighty-two subjects completed the survey, of which 2150 (69.76%) reported having ever vaped. 1205 (39.10%) subjects reported vaping at least once a month and were included in the analysis.

Measures

Questions from the 10-item PS-ECDI and 4-item EDS were asked during the survey. The 10-item PS-ECDI was modified to an 11-item version by separating daily vaping frequency into weekend days and weekdays. This was done due to expected differences in vaping frequency between weekdays and weekends, in consideration of typical weekday activities such as school and work that may decrease freedom to vape and thus frequency. Self-perceived perceived vaping addiction was measured via the question "Would you say that you are…? Very addicted to vaping; somewhat addicted to vaping; not at all addicted to vaping; or I don't know." Responses of "I don't know" were excluded from the analysis. Time to first vape after waking was assessed via a multiple choice question, "On days that you can vape freely, how soon after you wake up do you have the first vape of the day?", with varying time ranges of options, from 0–5 minutes up to greater than 120 minutes. All measure scores were standardized by dividing the scores by the mean value and dividing by their standard deviations. Participants also answered questions pertaining to motivations to start and continue vaping, health history, and future intentions to quit vaping. Self-reported information about e-cigarette device type (disposable cigarette-like vaping device, rechargeable cigarette-like vaping device, simple pen-like device, advanced box or tubular device, pod system or pod vape, other, don't know), flavor use (fruit, candy, dessert, beverage, mint/menthol, tobacco, food, other, don't know), and nicotine e-liquid use and concentration (0%, 0.1%–0.4%, 0.5%–0.8%, 0.9%–1.4%, 1.5%–2.0%, 2.1%–2.4%, 2.5%, 2.6%–6.0%, don't know) was collected via multiple choice questions.

Participants were also asked about current and previous history of use of combustible cigarettes, marijuana, alcohol, hookah, and other tobacco products (cigars, pipes, chewing tobacco, bidis, kreteks). Self-perceived demographics (age in years, sex at birth, highest level of education completed, marital status, being a parent or legal guardian of any children, and race) were collected.

Analysis

Measurement invariance by sex was assessed for the modified 11-item PS-ECDI and the EDS. Each measure was assessed for configural, metric, and scalar invariance, following methodology outlined by Brunet et al.[14] Invariance at each step was established if a ΔCFI $\leq$ 0.010 was supplemented by a ΔRMSEA $\leq$ 0.015.

Cronbach's alpha was calculated for the PS-ECDI and EDS dependence measures to assess internal consistency. This was not assessed for the self-perceived e-cigarette addiction measure or time to first vape after waking as a minimum of two variables are required.

Convergent validity of the three measures of e-cigarette dependence were examined using analyses consistent with the methodology of Morean et al.[9] Bivariate (Pearson) correlations were examined between the EDS and the PS-ECDI, between the EDS and the self-perceived measure, and between the PS-ECDI and the self-perceived measure. Bivariate correlation analyses were also conducted between all three measures and time to first e-cigarette use in the morning and intention to quit, known indices of dependence, as an additional measure of convergent validity.

To assess concurrent validity of each dependence measure, bivariate correlations were also examined between each of the measures, including time to first vape after waking, and vaping frequency (per month and per day) and e-liquid nicotine concentration. Bivariate correlation coefficients between measures were then assessed for significant differences between coefficients. Univariate general linear models (GLMs) were then run, wherein dependence by each measure was examined as a predictor of vaping frequency and nicotine concentration, adjusting for sex, age, race, cigarette smoking status, and other tobacco product use. The first two PS-ECDI items assess e-cigarette use frequency per weekend day and weekday, respectively, so they were omitted from the total scale score when the PS-ECDI was included in models predicting e-cigarette use daily frequency per day to prevent overlapping. Additional univariate GLMs were run for the same outcomes wherein all the measures were included simultaneously. Covariate-only GLMs were run, and the differences in R^2 between models were determined. Missing values were determined to be missing at random and were excluded from the analysis. All analyses were conducted on Stata/IC 16.1.

Results

Descriptive Statistics

Descriptive summary statistics for each dependence measure, demographic variables, and nicotine use and smoking histories can be found in Supplementary Table 1. The mean age of participants was 19.5 years (SD = 2.5), and the majority of subjects were female (72.0%) and white (81.8%). The large majority of subjects reported using nicotine e-cigarettes (95.3%), and being either somewhat addicted (42.7%) or very addicted (31.5%) to vaping (N = 1161). PS-ECDI scores and EDS scores approximated a normal distribution. The mean PS-ECDI score was 19.5 (SD = 7.5; N = 1170) with a possible score range of 4–31. The mean EDS score was 7.3 (SD = 4.0; N = 1184) with a possible score range of 0–16. Of the 211 participants that had never smoked cigarettes or any other tobacco products, 185 (87.7%) had previously used nicotine when vaping.

Measurement Invariance

Both the modified PS-ECDI and the EDS exhibit configural, metric, and scalar invariance across sex (Table 1).

Internal Consistencies of E-Cigarette Dependence Measures

The Cronbach's Alpha for the PD-ECDI scale yielded an α of 0.8472 compared with an α of 0.8405 for the EDS measure. These alphas are evidence of good internal consistency.

Convergent Validity of E-Cigarette Dependence Measures

Bivariate correlations between each of the PS-ECDI, the EDS, and the self-perceived measure provided evidence of significant convergent validity (p < .001 for each between-measure analysis) (Table 2). Bivariate correlations between each measure and time to first e-cigarette use upon waking yielded similar results (p < .001 for each measure). However, evidence of convergent validity was less consistent between measures and intention to quit (EDS: p < .05; self-perceived: p < .01). However, there was also a notably significant correlation between time to first vape after waking and intention to quit (p < .001). Correlation coefficients show a significant difference between PS-ECDI and both EDS and self-perceived coefficients when predicting time to first vape upon waking (p < .001; Supplementary Table 2).

Concurrent Validity of E-Cigarette Dependence Measures

Bivariate correlations between each of the four measures (PS-ECDI, EDS, the self-reported measure, and time to first vape) and vaping frequency (daily and monthly) and nicotine use (and concentration among users) all yielded results signifying evidence of concurrent validity of the measures (p < .001 for all analyses) (Table 3). Correlation coefficients show a significant difference between PS-ECDI and EDS the self-perceived measure, and time from waking coefficients when predicting frequency of vaping per weekend day and per weekday (p < .001; Table 4). There is also a significant difference in correlations of frequency of vaping per month between PS-ECDI and EDS (p < .01), between EDS and the self-perceived measure (p < .05), and between time from waking and both PS-ECDI and the self-perceived measure (p < .001 for both). Additionally, there is a significant difference in correlations of nicotine concentration between EDS and time from waking (p < .05).

Univariate GLM of individual measures provided further evidence of concurrent validity after adjusting for sex, age, race, combustible cigarette smoking status, and other tobacco product use (Supplementary Table 3). All dependence measures individually accounted for significant variance in e-cigarette use frequency (both monthly and per weekend day and weekday, p < .001), and nicotine concentrations among nicotine e-cigarette users (PS-ECDI: $\eta_p^2 = 0.040$; EDS: $\eta_p^2 = 0.034$; self-perceived: $\eta_p^2 = 0.056$, time from waking: $\eta_p^2 = 0.060$; p < .001). Additionally, current smokers were more likely to report increased monthly vaping frequency (p < .001 across all measures). Females had a lower daily vaping frequency compared with males for the PS-ECDI and EDS measures only. Among nicotine e-cigarette users, females were less likely to use a higher concentration of nicotine compared with males across all dependence measures. The covariate-only GLMs for PS-ECDI, EDS, the self-perceived measure, and time from waking returned R^2 values of 0.0171, 0.0177, 0.0137, and 0.038, respectively. Change in R^2 between models was relatively consistent between predictors of dependence, except for a notably smaller change in R^2 for the PS-ECDI and daily vaping frequency measures (Supplementary Table 3).

Univariate GLMs of all measures simultaneously show the degree to which each measure accounts for each outcome when controlling for the other measures (Table 5). The PS-ECDI, the self-perceived measure, and time from waking all accounted for significant variance in monthly vaping frequency (PS-ECDI: $\eta_p^2 = 0.111$; self-perceived: $\eta_p^2 = 0.048$, time from waking: $\eta_p^2 = 0.052$; p < 0001), and all four measures accounted for a significant variance in daily smoking frequencies (PS-ECDI p < .01; EDS, self-perceived, and time from waking p < .001). The self-perceived measure and

Table 1. Fit Indices for the Analyses Testing Sex Invariance for the PS-ECDI and EDS

	X^2	*df*	CFI	|ΔCFI|	RMSEA	|ΔRMSEA|	SRMR
PS-ECDI							
Configural invariance	2075.140	54	0.516		0.253		0.120
Metric invariance	2089.820	63	0.515	0.001	0.235	0.018	0.127
Scalar invariance	2138.335	72	0.505	0.010	0.222	0.013	0.127
EDS							
Configural invariance	28.641	4	0.986		0.103		0.019
Metric invariance	29.934	8	0.988	0.002	0.068	0.035	0.025
Scalar invariance	40.875	12	0.984	0.004	0.064	0.004	0.026

EDS = E-Cigarette Dependence Scale; PS-ECDI = Penn State Electronic Cigarette Dependence Index.

Table 2. Bivariate Correlations Between Standardized Dependence Measures and Indices of Dependence Providing Evidence of Convergent Validity

	PS-ECDI	EDS	Self-perceived addiction	Intention to quit
PS-ECDI	—	—		−0.0335
				$n = 1166$
EDS	0.7119***	—		−0.0706*
	$n = 1164$			$n = 1180$
Self-perceived addiction	0.6749***	0.7187***		−0.0829**
	$n = 1143$	$n = 1156$		$n = 1161$
Time from waking	0.4858***	0.6399***	0.6061***	−0.1076***
	$n = 1170$	$n = 1184$	$n = 1161$	$n = 1185$

EDS = E-Cigarette Dependence Scale; PS-ECDI = Penn State Electronic Cigarette Dependence Index.
*$p < .05$.
**$p < .01$.
***$p < .001$.

Table 3. Bivariate Correlations Between Dependence Measures and Outcomes of Interest Providing Evidence of Concurrent Validity, With Overlapping Variables Excluded From Dependence Measures

	Vape per month	Vape per weekend day	Vape per weekday	Nicotine concentration
PS-ECDI	0.6184***	0.1050***	0.1247***	0.1590***
	$n = 1153$	$n = 1171$	$n = 1171$	$n = 1042$
EDS	0.5448***	0.5827***	0.6099***	0.1459***
	$n = 1167$	$n = 1174$	$n = 1174$	$n = 1057$
Self-perceived addiction	0.6107***	0.5637***	0.5858***	0.2169***
	$n = 1145$	$n = 1152$	$n = 1152$	$n = 1043$
Time from waking	0.5168***	0.5969***	0.6141***	0.2343***
	$n = 1174$	$n = 1181$	$n = 1181$	$n = 1062$

EDS = E-Cigarette Dependence Scale; PS-ECDI = Penn State Electronic Cigarette Dependence Index.
***$p < .001$.

Table 4. Absolute Test Statistics With Significance for Difference of Bivariate Correlation Coefficients Between Dependence Measures and Outcomes of Interest for Concurrent Validity

	Vape per month	Vape per weekend day	Vape per weekday	Nicotine concentration
PS-ECDI vs. EDS	2.681**	13.570***	14.108***	0.307
PS-ECDI vs. self-perceived	0.296	12.824***	13.138***	1.369
PS-ECDI vs. time from waking	3.624***	14.117***	14.291***	1.795
EDS vs. self-perceived	2.379*	0.682	0.903	1.681
EDS vs. time from waking	0.942	0.528	0.163	2.110*
Self-perceived vs. time from waking	3.320***	1.208	1.067	0.420

EDS = E-Cigarette Dependence Scale; PS-ECDI = Penn State Electronic Cigarette Dependence Index.
*$p < .05$.
**$p < .01$.
***$p < .001$.

time from waking both accounted for variance in nicotine concentration among nicotine users, with differing levels of significance (self-perceived: $\eta_p^2 = 0.010$, $p < .01$; time from waking: $\eta_p^2 = 0.017$, $p < .001$). The covariates-only GLM for all measures simultaneously returned an R^2 of 0.5643. No multicollinearity was detected.

Discussion

All measures of dependence, the PS-ECDI, the EDS, and the self-perceived measured, plus time until first vape after waking exhibited convergent validity with each other. This suggests that our existing measures of nicotine dependence exhibit consistency and reliability, but the relatively modest correlations suggest that further research is needed to understand the unique aspects of vaping dependence among youth. The association with self-perceived dependence and the more formal measures also suggests that the measures are associated with individual perceptions of their own addiction. However, the single-item self-perceived measure exhibited properties better than or close to the multi-item measures and should be considered in situations where minimizing question items is at a

Table 5. Univariate General Linear Models Simultaneously Between Standardized Dependence Measures and Outcomes of Interest, With Overlapping Variables Excluded From Dependence Measures, Including Change in Adjusted R^2 Compared With Covariate-Only Regression Models[a]

	t	η_p^2
	Vaping frequency (times per month)	
	***n* = 1099**	
	Adj R^2 = 0.4968	**Change in R^2 = 0.0675**
PS-ECDI	11.65	0.111***
EDS	−1.17	0.001
Self-perceived	7.40	0.048***
Time from waking	7.73	0.052***
Sex	0.65	0.000
Age	2.44	0.005*
Race	0.27	0.000
Smoking status	5.76	0.030***
Other tobacco product	0.26	0.000
	Vaping frequency (times per weekend day)	
	***n* = 1114**	
	Adj R^2 = 0.4465	**Change in R^2 = 0.1175**
PS-ECDI	−2.98	0.008**
EDS	7.33	0.047***
Self-perceived	6.47	0.037***
Time from waking	7.25	0.046***
Sex	−0.69	0.000
Age	0.57	0.000
Race	0.85	0.001
Smoking status	−0.29	0.000
Other tobacco product	−1.04	0.001
	Vaping frequency (times per weekday)	
	***n* = 1114**	
	Adj R^2 = 0.4787	**Change in R^2 = 0.0856**
PS-ECDI	−2.76	0.007**
EDS	8.03	0.055***
Self-perceived	6.74	0.040***
Time from waking	7.66	0.050***
Sex	−1.06	0.001
Age	0.39	0.000
Race	1.05	0.001
Smoking status	−1.44	0.002
Other tobacco product	0.25	0.000
	Nicotine concentration among nicotine users	
	***n* = 1009**	
	Adj R^2 = 0.2123	**Change in R^2 = 0.3520**
PS-ECDI	1.55	0.002
EDS	−1.18	0.001
Self-perceived	3.16	0.010**
Time from waking	4.14	0.017***
Sex	−2.87	0.008**
Age	−12.77	0.140***
Race	−0.06	0.000
Smoking status	1.17	0.001
Other tobacco product	0.47	0.000

EDS = E-Cigarette Dependence Scale; PS-ECDI = Penn State Electronic Cigarette Dependence Index.
[a]Variation in *N*s due to responses missing at random.
*$p < .05$.
**$p < .01$.
***$p < .001$.

premium such as rapid assessment by clinicians. Additionally, the self-perceived measure was found to be equal to time from waking in predicting daily vaping, but superior in predicting monthly vaping, suggesting that, between the two, the self-perceived measure is the superior choice for predicting overall vaping frequency.

These results mirror those of Morean et al.,[9] which found significant correlations between the EDS and both the PS-ECDI and time until first vape. When assessing for convergent validity, the results showed no correlation between PS-ECDI and intention to quit, and weak to moderate correlations between intention to quit and either the EDS or the self-perceived measure, respectively. In contrast, Camara-Medeiros et al. reported no correlation between the self-perceived measure and intention to quit vaping.[15] Interestingly, while the significance of correlations varied between intention to quit and each measure, there was no significant difference between the correlation coefficients of each measure for intention to quit. Concurrent, bivariate relationships were observed between all three measures and vaping frequency (both daily and monthly) and nicotine e-cigarette use and concentration. The PS-ECDI measure was found to have a significantly lower correlation coefficient for daily e-cigarette use frequency, compared with both the EDS and the self-perceived measure, when the vaping frequency question from the measure was omitted. In the univariate GLM regressions, all measures were found to be significantly associated with the outcomes of interest, vaping frequency and nicotine concentration when adjusting for demographic variables and cigarette smoking status. This is consistent with results from Buu et al., who observed a significant association between the PS-ECDI score and daily vaping frequency.[10] Camara-Medeiros et al. also reported a correlation between the self-perceived dependence measure and nicotine concentration, aligning with the results of this study, however their study found no correlation between the self-perceived measure and daily vaping frequency, unlike this study.[15] The PS-ECDI and the self-perceived measured were equally superior in predicting monthly vaping compared with the EDS and time from waking, while all three measures were superior to the PS-ECDI in predicting daily vaping frequency. This is somewhat consistent to the results of Morean et al.,[9]

who reported that the EDS consistently predicted frequency of vaping above and beyond the PS-ECDI. Age and sex were both found to be significant predictors of vaping behaviors, with some variation between measures. Males were found to have an increased daily vaping frequency, while younger males were more likely to use higher concentrations of nicotine.

This study exhibited convergent and concurrent validity of the self-perceived vaping dependence measure against the PS-ECDI, EDS, and time from waking for use specifically in adolescents and young adults. This single-item measure can be of benefit when incorporated into surveys where respondent fatigue or time might be a concern, as it decreases the number of questions to answer, while still providing an accurate assessment of e-cigarette dependence, and also decreases the need to remember specific values, which is necessary in the other measures, decreasing recall bias.

Limitations

Due to the online, convenience-sampled nature of the study, it is difficult to ensure reliability or generalizability of the responses. However, the anonymity of the survey and the attention checks throughout to limit random answers are expected to mitigate excess response bias. Recall bias also impacted the accuracy of certain data points, in particular nicotine concentration last used among nicotine e-cigarette users. Of 1109 participants that reported have previously used nicotine when vaping, 47 could not recall the concentration of nicotine they had most recently used. While Morean et al.[9] adjusted for this by instead using a binary variable of nicotine e-cigarette use, this study was interested specifically in how nicotine concentrations impact dependence measures, and thus this was not a valid option. The study sample was stratified by age during recruitment to ensure a relatively even dispersal of age, in that approximately half of the sample was 18 or under. However, it does not include younger teenagers or children, as the youngest age was 16, limiting generalizability to youth.

Conclusion

While the PS-ECDI is a stronger predictor of monthly vaping frequency when controlling for demographic variables, the self-perceived dependence measure displayed convergent and concurrent validity against the PS-ECDI, EDS, time from waking, and vaping behaviors of interest, along with superiority in predicting certain properties of dependence. Thus, the use of the self-perceived measure would be appropriate to assess e-cigarette dependence in youth, especially in situations that would benefit from a smaller number of questions. Longitudinal data that assesses vaping behaviors and self-perceived dependence over time will be of use to further observe the natural history and progression of e-cigarette dependence in youth.

Supplementary Material

A Contributorship Form detailing each author's specific involvement with this content, as well as any supplementary data, are available online at https://academic.oup.com/ntr.

Funding

This study was supported by CIHR.

Declaration of Interests

None declared.

Data Availability

Deidentified data are available to researchers by contacting the authors with approval from academic institutional review boards.

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