Nicotine & Tobacco Research, 2019, 1556–1564
doi:10.1093/ntr/ntx271
Original investigation
Received June 12, 2017; Editorial Decision December 5, 2017; Accepted December 30, 2017

Original investigation

Psychometric Evaluation of the E-cigarette Dependence Scale

Meghan E. Morean PhD[1,2], Suchitra Krishnan-Sarin PhD[2], Steve Sussman PhD[3], Jonathan Foulds PhD[4], Howard Fishbein PhD[5], Rachel Grana PhD[6], Stephanie S. O'Malley PhD[2]

[1]Department of Psychology, Oberlin College, 120 W Lorain St. Oberlin, OH 44074; [2]Department of Psychiatry, Yale School of Medicine, 34 Park Street, New Haven, CT 06519; [3]Institute for Health Promotion & Disease Prevention Research, University of Southern California, 2001 N Soto Street, MC 9239, Los Angeles, CA 90032; [4]Penn State Tobacco Center of Regulatory Science, Penn State University, College of Medicine, 500 University Drive, P.O. Box 850 Hershey, PA 17033; [5]Health Sector, Westat, 1450 Research Boulevard, TC3030, Rockville, MD 20850; [6]Tobacco Control Research Branch, Behavioral Research Program, Division of Cancer Control and Population Sciences, National Cancer Institute, 9609 Medical Center Drive, Rockville, MD 20850

Corresponding Author: Meghan Morean, PhD, Department of Psychology, Oberlin College, 120 W Lorain St. Oberlin, OH 44074; Department of Psychiatry, Yale School of Medicine, 34 Park Street, New Haven, CT 06519. Telephone: 440-775-8257; Fax: 440-775-8356; E-mail: Meghan.Morean@oberlin.edu

Abstract

Introduction: Psychometrically sound measures of e-cigarette dependence are lacking.
Methods: We modified the PROMIS Item Bank v1.0—Smoking: Nicotine Dependence for All Smokers for use with e-cigarettes and evaluated the psychometrics of the 22-, 8-, and 4-item adapted versions, referred to as The E-cigarette dependence scale (EDS). Adults (1009) who reported using e-cigarettes at least weekly completed an anonymous survey in summer 2016 (50.2% male, 77.1% White, mean age 35.81 [10.71], 66.4% daily e-cigarette users, 72.6% current cigarette smokers). Psychometric analyses included confirmatory factor analysis, internal consistency, measurement invariance, examination of mean-level differences, convergent validity, and test-criterion relationships with e-cigarette use outcomes.
Results: All EDS versions had confirmable, internally consistent latent structures that were scalar invariant by sex, race, e-cigarette use (nondaily/daily), e-liquid nicotine content (no/yes), and current cigarette smoking status (no/yes). Daily e-cigarette users, nicotine e-liquid users, and cigarette smokers reported being more dependent on e-cigarettes than their counterparts. All EDS versions correlated strongly with one another, evidenced convergent validity with the Penn State E-cigarette Dependence Index and time to first e-cigarette use in the morning, and evidenced test-criterion relationships with vaping frequency, e-liquid nicotine concentration, and e-cigarette quit attempts. Similar results were observed when analyses were conducted within subsamples of exclusive e-cigarette users and duals-users of cigarettes and e-cigarettes.
Conclusions: Each EDS version evidenced strong psychometric properties for assessing e-cigarette dependence in adults who either use e-cigarette exclusively or who are dual-users of cigarettes and e-cigarettes. However, results indicated little benefit of the longer versions over the 4-item EDS, which provides an efficient assessment of e-cigarette dependence.
Implications: The availability of the novel, psychometrically sound EDS can further research on a wide range of questions related to e-cigarette use and dependence. In addition, the overlap

between the EDS and the original PROMIS that was developed for assessing nicotine dependence to cigarettes provides consistency within the field.

Introduction

The landscape of tobacco products is evolving, with the introduction and escalation of electronic cigarette use being one of the most notable examples.[1,2] While combustible cigarettes remain the most commonly used tobacco product among American adults, 3.3% of all adults use e-cigarettes, with higher prevalence rates observed among young adults (18–24 years; 5.5%).[3]

With the exception of nicotine-free e-cigarette liquid, e-cigarette use can result in peak nicotine levels similar to combustible cigarettes and, therefore, could produce nicotine dependence over time.[4] Ultimately, many factors likely influence e-cigarette nicotine dependence including policies that promote or limit e-cigarette availability, device characteristics influencing nicotine delivery, e-liquid nicotine concentration, and individual differences in dependence risk factors. The development of a psychometrically sound measure of dependence to e-cigarettes would facilitate efforts to understand how these factors contribute to dependence.

To date, several e-cigarette dependence measures have been developed by modifying extant nicotine/cigarette dependence items or measures.[5–7] For example, the Penn State E-cigarette Dependence Index (PSECDI)[7] comprises ten modified items that were selected based on their predictive utility in studies of smokers.[8–13] Furthermore, national data from the PATH study recently were used to develop and validate a measure of tobacco dependence from an initial list of 24 items that were adapted from 4 cigarette dependence measures. A strength, the final 16-item dependence index was shown to be comparable across several different products including e-cigarettes (eg, cigarettes, e-cigarettes, cigars, hookah, and smokeless tobacco) in a sample of current product users.[6] Although these adaptions of existing measures of cigarette dependence to assess e-cigarette dependence have utility, each has some limitations. For example, the psychometric properties of the PSECDI have not been established, and the measure includes items adapted from original cigarette dependence measures with questionable psychometrics (eg, the Fagerstrom Test for Nicotine Dependence[8]). Although the PATH measure produced important findings about dependence across different tobacco products in a sample of current tobacco product users, its individual items have limitations for assessing dependence. For example, several items previously have been shown to reflect constructs that are related to, yet distinct from, nicotine dependence raising concerns that the measure may reflect a construct that is broader than dependence (ie, "Using [product] would really help me feel better if I've been feeling down" has been shown to reflect coping expectancies for cigarette smoking, whereas "Using [product] helps me think better" has been shown to reflect emotional and sensory expectancies or cognitive enhancement related to cigarette smoking).[14] Also, the time frame for rating the items is inconsistent; some items ask about experiences during the past 12 months while others have a more present focus (eg, "In the past 12 months, did you find it difficult to keep from using (product) in places where it was prohibited" vs. "I frequently crave (product)"). Finally, while most items refer to using a specific product, one item broadly refers to tobacco use, which may be confusing for users of products like e-cigarettes (ie, "Tobacco products control me").

In our effort to develop a psychometrically sound measure of e-cigarette dependence, we focused our attention on the PROMIS Item Bank v1.0—Smoking: Nicotine Dependence for All Smokers,[14–16] which was developed through an exceptionally comprehensive and systematic process that was completed after the PATH study was launched in 2013. The development of the PROMIS included a qualitative phase (ie, comprehensive review of the literature from 1970–2010 to identify items, measures, and scales to be included in the initial pool of 1334 items; binning and winnowing these items by researchers, focus groups and cognitive interviews) and quantitative analyses (eg, exploratory/confirmatory factor analysis, internal consistency, differential item functioning) in large, national samples.[14–16] The total item bank comprises 22 items that are relevant for both daily and nondaily smokers. Two psychometrically sound short forms (8 and 4 items)—the PROMIS Short Form v1.0—Smoking Nicotine Dependence for All Smokers 8a and the PROMIS Short Form v1.0—Smoking Nicotine Dependence for All Smokers 4a—also were identified.[14–16]

In the current study, we examined whether the 22-item PROMIS, as well as the 8- and 4-item banks, could be adapted to assess e-cigarette dependence. Although several characteristics of e-cigarettes and their use differ from cigarette smoking, nicotine plays a central role in the development of dependence to all tobacco products that contain it. Consequently, we hypothesized that the three E-cigarette dependence scale (EDS) versions (22-item, 8-item, 4-item), like the original PROMIS nicotine dependence items, would represent psychometrically sound measures of dependence on e-cigarettes. We anticipated that each would evidence a confirmable, single-factor latent structure, internal consistency, and scalar measurement invariance for subgroups of interest (eg, sex, smoking status). Based on prior research,[14,16] we anticipated that the EDS versions would evidence convergent validity with existing indices of e-cigarette dependence and modest to moderate test-criterion relationships with e-cigarette use outcomes.

Methods

Participants

Adults (1009) who self-reported currently using e-cigarettes at least weekly completed an anonymous, 25-min, online survey (50.2% male, 77.1% White, mean age 35.81 [10.71] years, 66.4% daily e-cigarette users, 72.6% smokers [22.7% occasional smokers; 49.9% daily smokers]).

Procedures

The current study was approved by the Yale School of Medicine Institutional Review Board. Participants were recruited online via Qualtrics Online Sample, a secure market research service offered through Qualtrics, Inc. Individuals first volunteer to be market research "panelists" via the Qualtrics website and complete a "profiling survey" that assesses various demographic characteristics. Qualtrics utilizes profiling survey data to send targeted recruitment emails to panelists who are most likely to be eligible for a study. Interested panelists were directed to our study eligibility questions (see Measures) via an embedded email link. Eligible participants

completed an online consent form informing them of the voluntary and anonymous nature of the survey. Qualtrics compensated participants directly (up to $5).

Measures

Participants filled out the screener questions first, followed by demographics and basic e-cigarette and cigarette use questions. Participants completed the remaining questionnaires (including the EDS) in a randomly presented order to balance participant fatigue.

Screening Questions

Participants completed two screening questions to determine study eligibility (ie, past-week e-cigarette use; sex [to ensure equal participation by men and women]) and four filler questions that were designed to obscure the survey goals (ie, related to sleeping, eating vegetables, drinking alcohol, and smoking cigarettes). Eligible participants endorsed using an e-cigarette at least once in the past week on the screener and provided a consistent response on a subsequent question assessing the number of days of e-cigarette use in the past month (ie, at least 4).

Demographic Information

Participants reported their age, biological sex, and race.

E-cigarette Use

Participants reported how frequently they used e-cigarettes in the past month (0–30 days) and how many minutes per day they typically use their e-cigarette (0, 1–10, 11–20, 21–30, 31–40, 41–50, 51–60, 61–90, 91–119, and ≥120 min).

E-liquid Nicotine Content and Concentration

Participants reported whether they typically use nicotine e-liquid (no/yes). Participants who endorsed using e-liquid containing nicotine then reported on the nicotine concentration they typically use (0, 3, 6, 12, 18, 24, ≥30 mg, or I do not know).

Number of E-cigarette Quit Attempts

Participants reported how many times they had stopped vaping at least 1 day because they were trying to quit (0, 1, 2–3, 4–5, 6–9, ≥10).

Cigarette Smoking Behavior

Participants reported on their current cigarette smoking status ("I have never been a cigarette smoker; I am a former smoker, meaning that I used to smoke cigarettes, but I successfully quit; I smoke cigarettes occasionally, meaning at least once a month; and I smoke cigarettes daily"). For the measurement invariance analyses (see Data Analytic Plan), occasional and daily smokers were categorized as "current smokers."

The E-cigarette Dependence Scale

Participants completed the 22 PROMIS nicotine dependence items.[14–16] We retained the original instructions ("Please respond to each question or statement by marking one box per row.") and 5-point rating scale (0 = never, 1 = rarely, 2 = sometimes, 3 = often, 4 = almost always). However, we modified each item to reflect e-cigarette use (i.e., the word "cigarette" was changed to "e-cigarette;" the words "smoking/smoke" were changed to "vaping/vape"). For the question, "I drop everything to go out and buy cigarettes," "e-cigarettes or e-juice" was substituted for "cigarettes."

For comparison, participants completed the Penn State E-Cigarette Dependence Index (PSECDI),[7] which comprises ten items that were adapted from cigarette dependence measures. Items cover frequency of use; time to first e-cigarette use of the day; waking at night to use; perceived difficulty quitting; and cravings, urges, and withdrawal symptoms. In a sample of exclusive e-cigarette users (n = 3609), PSECDI scores were related to e-cigarette characteristics known to determine nicotine delivery (ie, nicotine concentration, large battery, manual button).[7]

Time to First E-cigarette Use[17]

Participants reported on how long they typically wait after waking up to use their e-cigarette (i.e., "On days that you can use your electronic cigarette freely, how soon after you wake up do you use your e-cigarette for the first time?" Response options: 0–5, 6–15, 16–30, 31–60, 61–120, >120 min).

Data Analytic Plan

Descriptive Statistics

We ran descriptive statistics on all study variables to examine sample cell sizes (categorical data) and distributions (continuous data).

Confirmatory Factor Analysis

The E-cigarette Dependence Scale

We employed confirmatory factor analysis (CFA) to evaluate whether the 22-item, 8-item and 4-item EDS versions fit our data. Robust maximum-likelihood estimation was specified and full-information maximum-likelihood was employed to handle missing data. Bentler's Comparative Fit Index (CFI) ≥ .90,[18] Root Mean Square Error of Approximation (RMSEA) < .08,[19] and Standardized Root Mean Square Residual (SRMR) < .08[20] indicated acceptable model fit. Given that the chi-square statistic would be significant solely based on the large sample size, we excluded it as a fit index.[21]

Internal Consistency of the E-cigarette Dependence Scale

Cronbach's alpha was calculated for each EDS version.

Correlations between the E-cigarette Dependence Scale versions

Bivariate correlations were used to determine the shared variance among the EDS versions.

Measurement Invariance (MI) of the E-cigarette Dependence Scale

Using Mplus 7.0, we ran multigroup CFA models to evaluate whether the latent structures of the 22-item, 8-item, and/or 4-item EDS fit the data within the following groups: sex (female/male), race (nonWhite/White), e-liquid nicotine content (no/yes), e-cigarette use status (nondaily/daily), and current cigarette smoking status (nonsmokers/current smokers). Three levels of MI were evaluated: configural (ie, invariance of the number of latent factors and items per factor), metric (ie, invariance of the item factor loadings), and scalar (ie, invariance of the item factor loadings and intercepts). Configural invariance was established if the model fit the data as outlined above (ie, CFI > .90, RMSEA and SRMR < .08). If the model evaluating metric invariance did not produce a decrement in fit from the configurally invariant model exceeding CFI ≥ .01, RMSEA ≥ .015, or SRMR ≥ .030, metric invariance was established.[21] If the model

evaluating scalar invariance did not produce a decrement in fit from the model establishing metric invariance exceeding CFI ≥ .010, accompanied by either a change in RMSEA ≥ .015 or a change in SRMR ≥ .010, scalar invariance was established.[21] Of central importance, scalar invariance is required for mean-level comparisons of a construct across groups to be interpretable.

Group-Level Differences in E-cigarette Dependence Scale scores

For each group for which scalar MI was established, independent samples *t*-tests were run to examine the sensitivity of the EDS versions in assessing mean-level differences in e-cigarette dependence.

Test-Criterions Relationships Between the E-cigarette Dependence Scale and the PSECDI

Given that measures of e-cigarette dependence should share variance with one another, we examined bivariate correlations between the EDS versions and the PSECDI (despite the fact that the psychometric properties of the PSECDI are not well established). As additional evidence of convergent validity, we ran bivariate correlations between the EDS versions and a single item reflecting time to first e-cigarette use in the morning, which has been shown to be an index of dependence.[17]

Test-Criterions Relationships Between the E-cigarette Dependence Scale and Vaping Outcomes

To provide evidence of concurrent validity, we first ran simple bivariate correlations between the EDS versions and the following outcomes of interest: vaping frequency (days per month and minutes per day), e-liquid nicotine concentration, and number of e-cigarette quit attempts.

We then ran univariate general linear models (GLMs) in which e-cigarette dependence was examined as a "predictor" of vaping frequency and e-cigarette quit attempts after accounting for sex, age, race, e-liquid nicotine content, and smoking status. Univariate GLM was used because it provides effect sizes for each independent variable in the model. The binary variable for e-liquid nicotine content was included in the GLM model instead of e-liquid nicotine concentration to maximize statistical power; e-liquid nicotine content had no missing cases whereas 105 adults reported not knowing what nicotine concentration they use.

As evidence of incremental validity, the same GLM models were run with the PSECDI included as an additional covariate. The first PSECDI item assesses e-cigarette use frequency, so it was omitted from the total scale score when the PSECDI was included in models predicting e-cigarette use frequency. The full measure (i.e., 10-item) and the measure in which the first item was deleted were included as covariates in the models predicting quit attempts. We also examined the incremental validity of the 22-item EDS over the 4- and 8-item EDS versions as well as the 8-item EDS over the 4-item EDS to determine which version(s) evidenced the greatest utility.

Psychometrics of the E-cigarette Dependence Scale in Exclusive E-cigarette Users and in Dual-Users of Cigarettes and E-cigarettes

All analyses first were run within the full sample, as it represented the full range of e-cigarette use (ie, both exclusive e-cigarette users and dual-users of cigarettes and e-cigarettes). Assuming the establishment of scalar measurement invariance by smoking status, we planned to examine the psychometric properties of the EDS versions with the subsamples of exclusive e-cigarette users and dual-users. We evaluated evidence for internal consistency and test-criterion validity for exclusive e-cigarette users to ensure that e-cigarette dependence within the total sample was not driven solely by tobacco cigarette dependence. Conversely, we repeated these psychometric analyses for dual-users to ensure that significant findings within the total sample were not driven by the experiences of exclusive e-cigarette users.

Results

Descriptive Statistics

For categorical variables, each cell contained a sufficient number of cases. For continuous variables, the data approximated normality.

Confirmatory Factor Analysis: The E-cigarette Dependence Scale

The single-factor, 22-item, 8-item, and 4-item EDS versions fit the data (22-item version: RMSEA = 0.071, CFI = 0.935, SRMR = 0.035; 8-item version: RMSEA = 0.078, CFI = 0.971, SRMR = 0.026; 4-item version: RMSEA = 0.044, CFI = 0.997, SRMR = 0.010). See Table 1 for items and factor loadings.

Internal Consistency of the E-cigarette Dependence Scale

Each EDS version evidenced excellent internal consistency (22-item version: $\alpha = 0.98$; 8-item version: $\alpha = 0.93$; 4-item version: $\alpha = 0.86$).

Correlations between the E-cigarette Dependence Scale Versions

Correlations among the EDS versions indicated that each shared significant variance with one another in accounting for e-cigarette dependence (r [22-item with 8-item] = 0.98; r [22-item with 4-item] = 0.94; r [8-item with 4-item] = 0.97).

Measurement Invariance (MI) of the E-cigarette Dependence Scale

Scalar invariance was established for sex, race, e-cigarette use status, nicotine e-liquid status, and cigarette smoking status (Supplementary Table 1). Thus, mean-level differences in e-cigarette dependence within these groups could be interpreted meaningfully.

Group-Level Differences in E-cigarette Dependence Scale Scores

Independent samples *t*-tests indicated no statistically significant differences in e-cigarette dependence based on sex or race. However, daily e-cigarette use, nicotine e-liquid use, and cigarette smoking were associated with greater e-cigarette dependence ($p < .01$; Supplementary Table 2).

Test-Criterions Relationships Between the E-cigarette Dependence Scale and the PSECDI

Bivariate correlations between the EDS versions, the PSECDI (10-item and 9-item), and time to first e-cigarette use provided evidence of convergent validity (Table 2).

Table 1. EDS Items and Associated Factor Loadings

	EDS Version		
Items	22-Item	8-Item	4-Item
I find myself reaching for my e-cigarette without thinking about it.	0.75	0.77	0.76
I drop everything to go out and buy e-cigarettes or e-juice.	0.73	0.73	0.77
I vape more before going into a situation where vaping is not allowed.	0.73	0.74	0.71
When I haven't been able to vape for a few hours, the craving gets intolerable.	0.88	0.88	0.89
When I'm really craving an e-cigarette, it feels like I'm in the grip of some unknown force that I cannot control.	0.77	0.76	
I crave vaping at certain times of day.	0.76	0.77	
My urges to vape keep getting stronger if I don't vape.	0.90	0.90	
After not vaping for a while, I need to vape in order to avoid feeling any discomfort.	0.88	0.87	
My desire to vape seems overpowering.	0.83		
Cravings for an e-cigarette make it difficult for me to quit.	0.87		
It is hard to ignore urges to vape.	0.91		
When I go without vaping for a few hours, I experience craving.	0.88		
I frequently crave e-cigarettes/vaping.	0.87		
The idea of not vaping causes me stress.	0.84		
When I run out of e-cigarettes or e-juice, I find it almost unbearable.	0.84		
I get a real gnawing hunger for an e-cigarette when l haven't vaped in a while.	0.87		
I vape even when I am so ill that I am in bed most of the day.	0.63		
When I go too long without vaping I feel impatient.	0.87		
It is hard for me to go without vaping for a whole day.	0.77		
When I go too long without vaping, I get strong urges that are hard to get rid of.	0.89		
Vaping is a large part of my daily life.	0.61		
I am tempted to vape when I realize I haven't vaped for a while.	0.83		

Test-Criterions Relationships Between the E-cigarette Dependence Scale and Vaping Outcomes

Bivariate correlations provided evidence of concurrent relationships between the EDS versions and vaping frequency, e-liquid nicotine concentration, and e-cigarette quit attempts (Table 2).

Univariate GLM provided evidence of the concurrent validity of the EDS versions after accounting for demographic covariates (Table 3). Each version accounted for significant variance in frequency of past 30-day e-cigarette use (22-item: $\eta_p^2 = 0.06$, 8-item: $\eta_p^2 = 0.04$; 4-item: $\eta_p^2 = 0.05$, $p < .001$), total number of minutes spent using an e-cigarette per day (22-item: $\eta_p^2 = 0.03$, 8-item: $\eta_p^2 = 0.03$; 4-item: $\eta_p^2 = 0.02$, $p < .001$), and number of e-cigarette quit attempts (22-item: $\eta_p^2 = 0.04$, 8-item: $\eta_p^2 = 0.05$; 4-item: $\eta_p^2 = 0.04$, $p < .001$). As an aside, current smokers and nicotine e-liquid users were more likely to report increased vaping frequency. Males, smokers, and nicotine e-liquid users were more likely to report more e-cigarette quit attempts.

The EDS versions evidenced incremental validity above and beyond the PSECDI when predicting frequency of past 30-day e-cigarette use (22-item: $\eta_p^2 = 0.02$, 8-item: $\eta_p^2 = 0.01$; 4-item: $\eta_p^2 = 0.01$, $p < .01$) and number of minutes spent using an e-cigarette per day (22-item: $\eta_p^2 = 0.01$, 4-item: $\eta_p^2 = 0.01$, $p < .05$) with the exception of the 8-item version predicting minutes of e-cigarette use per day (Table 4). Of note, the PSECDI was not associated significantly with either outcome assessing e-cigarette use frequency. When accounting for quit attempts, the EDS versions evidenced incremental validity above the 9-item PSECDI only.

Comparisons of the incremental utility of using longer versus shorter versions of the EDS (Supplementary Table 3) found that the 8-item version added only modest variance to the 4-item version when predicting vaping frequency conceptualized in minutes per day. The 22-item version added only modest variance in predicting number of days of e-cigarette use in the past month and minutes spent vaping per day above and beyond the 4-item and 8-item versions).

Psychometrics of the E-cigarette Dependence Scale in Exclusive E-cigarette Users and Dual-Users of Cigarettes and E-cigarettes

Scalar invariance was established for smoking status, indicating that the latent structures of the EDS versions fit the data and that scores were comparable for exclusive e-cigarette users and dual-users. As such, the psychometric properties of the EDS could be examined within the subsamples of exclusive e-cigarettes users and dual-users. Findings generally mirrored those observed within the total sample.

The EDS evidenced excellent internal consistency in both samples (Exclusive E-cigarette Users/Dual-Users: 22-item version: $\alpha = 0.97/0.98$; 8-item version: $\alpha = 0.91/0.94$; 4-item version: $\alpha = 0.81/0.88$). Further, EDS versions were strongly correlated with one another (Exclusive E-cigarette Users/Dual-Users: r [22-item with 8-item] = 0.98/0.98, r [22-item with 4-item] = 0.94/0.94, r [8-item with 4-item] = 0.96/0.97).

Within the sample of exclusive e-cigarette users, daily e-cigarette users and nicotine e-liquid users reported higher levels of e-cigarette dependence than their counterparts. Among dual-users, only daily e-cigarette users reported stronger e-cigarette dependence relative to nondaily users (Supplementary Table 4). Within both subsamples, bivariate correlations between the EDS versions, the PSECDI, time to first e-cigarette use, and e-cigarette use outcomes provided evidence of convergent and concurrent validity, except for a nonsignificant relationship between the 8-item EDS and time spent vaping per day in dual-users. However, the magnitudes of the correlations between the EDS versions, time spent vaping each day, and nicotine concentration were significantly smaller for dual-users relative to exclusive e-cigarette users (Supplementary Table 5). Finally, GLM models indicated that each EDS version accounted for significant variance in each e-cigarette outcome above and beyond demographic covariates (Supplementary Table 6) and accounted for significant variance in the past 30-day e-cigarette use and the number of e-cigarette quit attempts above and beyond the PSECDI (Supplementary Table 7).

Table 2. Bivariate Correlations Providing Evidence of the Convergent and Concurrent Validity of the EDS

	Penn State (10-Item)	Penn State (9-Item)	Vaping Frequency (Past 30 days)	Vaping Frequency (Minutes per Day)	Nicotine Concentration	Quit Attempts
EDS (22-Item)	.70***	.78***	.24***	.15***	.28***	.20***
EDS (8-Item)	.66***	.75***	.20***	.12***	.27***	.22***
EDS (4-Item)	.66***	.74***	.21***	.14***	.28***	.22***

N = 1009 for all outcomes except for the E-liquid Nicotine Concentration (n = 904);
*** $p < .001$

Table 3. Univariate General Linear Models Providing Evidence of the Concurrent Validity of the EDS

	Vaping frequency (past 30 days)					
	EDS (22-Item)		EDS (8-Item)		EDS (4-Item)	
	F (6, 985)	η_p^2	F (6, 985)	η_p^2	F (6, 985)	η_p^2
	Adj R^2 = .08		Adj R^2 = .07		Adj R^2 = .07	
Sex	3.58	0.00	3.31	0.00	3.45	0.00
Race	0.22	0.00	0.22	0.00	0.23	0.00
Age	3.99	0.00	4.21	0.00	4.67	0.01
Smoking status	20.84	0.02***	20.12	0.02***	20.48	0.02***
Nicotine content	9.45	0.01**	10.36	0.01**	9.81	0.01**
EDS	60.79	0.06***	43.31	0.04***	48.28	0.05***
	Vaping frequency (minutes per day)					
	Adj R^2 = .06		Adj R^2 = .05		Adj R^2 = .06	
Sex	0.05	0.00	0.08	0.00	0.53	0.00
Race	2.36	0.00	2.29	0.00	2.42	0.00
Age	0.47	0.00	0.53	0.00	0.64	0.00
Smoking status	26.95	0.03***	26.28	0.03***	27.00	0.03***
Nicotine content	16.17	0.02***	17.11	0.02***	16.26	0.02***
EDS	24.11	0.03***	15.62	0.03***	21.79	0.02***
	E-cigarette quit attempts					
	Adj R^2 = .09		Adj R^2 = .10		Adj R^2 = .10	
Sex	10.46	0.01**	10.70	0.01**	10.78	0.01**
Race	2.10	0.00	1.82	0.00	1.88	0.00
Age	1.05	0.00	1.15	0.00	1.38	0.00
Smoking status	43.32	0.04***	42.57	0.04***	42.56	0.04***
Nicotine content	1.83	0.00	1.94	0.00	2.05	0.00
EDS	38.62	0.04***	46.64	0.05***	45.52	0.04***

** $p < .01$; *** $p < .001$.

Discussion

The current study provides novel psychometric evidence that the EDS, a modified version of the PROMIS measure of nicotine dependence, which originally was developed to assess cigarette dependence, can be used to assess e-cigarette dependence. Mirroring the original PROMIS, single factor latent structures were confirmed for the 22-item, 8-item, and 4-item EDS measures, each version evidenced excellent internal consistency, and each version was scalar measurement invariant by sex, race, daily e-cigarette use status, nicotine e-liquid content, and cigarette smoking status.

Consistent with research on the original PROMIS, strong correlations were observed among the EDS versions (Range of correlations PROMIS [0.90–0.96]; EDS [0.89–0.98]).[15]

When group-level differences were examined, no significant differences in e-cigarette dependence were noted by sex or race within the total sample or the subsamples of exclusive e-cigarette users or dual-users. Within the total sample, daily e-cigarette users, nicotine e-liquid users, and current smokers reported stronger e-cigarette dependence, indicating the sensitivity of the measures to detect group-level differences. Within the subsamples of exclusive e-cigarette users and dual-users, daily e-cigarette users also reported stronger dependence than nondaily users. Of note, while exclusive e-cigarette users who used nicotine e-liquid reported higher levels of e-cigarette dependence than those who did not use nicotine e-liquid, no significant difference in e-cigarette dependence was observed based on nicotine e-liquid content for dual-users. For exclusive e-cigarette users who

Table 4. Univariate General Linear Models Providing Evidence of the Incremental Validity of the EDS

	Vaping Frequency (Past 30 days)					
	EDS (22-Item)		EDS (8-Item)		EDS (4-Item)	
	F (7, 984)	η_p^2	F (7, 984)	η_p^2	F (7, 984)	η_p^2
	Adj R^2 = .08		Adj R^2 = .07		Adj R^2 = .08	
Sex	3.57	0.00	3.33	0.00	3.46	0.00
Race	0.22	0.00	0.19	0.00	0.21	0.00
Age	4.00	0.00	4.32	0.00	4.64	0.01***
Smoking Status	20.79	0.02***	21.31	0.02***	21.51	0.02***
Nicotine Content	9.41	0.01***	9.88	0.01***	9.45	0.01***
Penn State	0.02	0.00	3.49	0.00	2.77	0.00
EDS	20.37	0.02***	7.06	0.01***	11.12	0.01**
	Vaping Frequency (Minutes per Day)					
	Adj R^2 = .06		Adj R^2 = .05		Adj R^2 = .06	
Sex	0.05	0.00	0.07	0.00	0.53	0.00
Race	2.34	0.00	2.18	0.00	2.37	0.00
Age	0.48	0.00	0.57	0.00	0.63	0.00
Smoking Status	27.11	0.03***	27.54	0.03***	27.65	0.03***
Nicotine Content	16.03	0.02***	16.53	0.02***	15.94	0.02***
Penn State	0.18	0.00	3.12	0.00	1.10	0.00
EDS	6.63	0.01**	1.19	0.00	5.24	0.01*
	E-cigarette Quit Attempts					
	Adj R^2 = .11		Adj R^2 = .11		Adj R^2 = .11	
Sex	10.63	0.01**	10.87	0.01**	10.95	0.01**
Race	2.28	0.00	2.50	0.00	2.05	0.00
Age	1.29	0.00	1.26	0.00	1.35	0.00
Smoking Status	39.31	0.04***	39.53	0.04***	39.45	0.04***
Nicotine Content	2.24	0.00	2.38	0.00	2.47	0.00
Penn State	17.85	0.02***	12.37	0.01***	13.89	0.01***
EDS	0.11	0.00	2.39	0.00	2.81	0.00
	E-cigarette Quit Attempts					
	Adj R^2 = .10		Adj R^2 = .10		Adj R^2 = .10	
Sex	10.20	0.01**	10.52	0.01**	10.57	0.01**
Race	2.69	0.00	2.27	0.00	2.35	0.00
Age	1.05	0.00	1.10	0.00	1.25	0.00
Smoking Status	41.43	0.04***	41.20	0.04***	41.10	0.04***
Nicotine Content	2.70	0.00	2.66	0.00	2.81	0.00
Penn State (9-item)	6.50	0.01*	4.12	0.01*	4.90	0.01*
EDS	3.86	0.01*	9.20	0.01**	8.90	0.01**

Note. * $p < .05$ ** $p < .01$ *** $p < .001$

did not use nicotine e-liquid, mean dependence scores were very low, but not 0 (n = 43, EDS-22 [M = 0.70(0.82)]; EDS-8 [M = 0.65(0.83)]; EDS-4 [M = 0.60(0.83)]), suggesting that the scale may also capture behavioral aspects of dependence.

The three EDS versions also evidenced convergent validity with the PSECDI and time to first e-cigarette use in the total sample and within the subsamples of exclusive e-cigarette users and dual-users. Correlations of similar magnitude were observed between the original PROMIS and extant measures of cigarette dependence (eg, the original PROMIS-22 and the Wisconsin Inventory of Smoking Dependence Motives, r = 0.76;[16] the EDS versions and the PSEDI range r = 0.66 to 0.69) as well as with time to first cigarette in the morning (the original PROMIS range r = –0.32 to –0.51;[15,16] the EDS versions range r = –0.40 to –0.49).

Concurrent, bivariate relationships also were observed with the number of e-cigarette quit attempts and with vaping frequency in the

total sample and within the subsamples of exclusive e-cigarette users and dual-users. While correlations were modest, their magnitudes generally were in line with those observed in prior studies examining relationships between the original PROMIS and cigarette smoking behavior.[14–16] However, it is worth noting that the correlations between e-cigarette dependence and both time spent vaping per day and e-liquid nicotine concentration were significantly larger for exclusive e-cigarette users relative to dual-users. These findings likely are linked to the fact that exclusive e-cigarette users are using only one product. As such, the amount of time they spend vaping each day and the concentration of nicotine they use are likely to be more strongly linked to dependence on the sole product that they use. Conversely, dual-users necessarily also smoke cigarettes and, therefore, are exposed to nicotine via smoking, which could attenuate the relationship between e-cigarettes and e-cigarette dependence. Future research is needed to directly compare dual-users' cigarette and e-cigarette dependence and to evaluate the extent to which cigarette dependence contributes to ratings of e-cigarette dependence and visa-versa.

In cross-sectional "prediction" models, each EDS version was associated significantly with each e-cigarette use outcome after accounting for demographic covariates within the total sample and among the subsamples of exclusive e-cigarette users and dual-users. Finally, within the total sample, each version of the EDS evidenced incremental validity over the PSECDI when accounting for vaping frequency but not when accounting for the number of e-cigarette quit attempts (unless the first item assessing e-cigarette use frequency was omitted from the PSECDI). The same pattern was observed among the subsamples of exclusive e-cigarette users and dual-users with one exception; the EDS versions only predicted time spent vaping per day above and beyond the PSECDI for exclusive e-cigarette users.

Although each version of the EDS evidenced solid psychometric properties, the results suggested that there is little to no benefit of using the 22-item version over the much shorter 4-item version for assessing e-cigarette dependence. Analyses that examined the incremental utility of including the additional items found that the 4-item and 22-item versions accounted for similar variance in the outcomes assessed. Thus, researchers should consider using the shortest version given that it performs similarly to the 22-item version while reducing participant burden.

The study findings should be considered in light of several limitations. Data were collected online and were self-report. Although, data were limited by participants' ability and willingness to provide accurate responses, these concerns are mitigated by the anonymity of the survey and the lack of evidence that any participant provided random responses. Given the online nature of the study, it also was not possible to assess biomarkers of e-cigarette or cigarette use. Future research is needed to examine how biochemical indices of exposure relate to self-reported dependence and to other relevant constructs like use frequency and time to first use of each product. In addition, while using research market panel members may limit generalizability, market research panel members likely were motivated to provide high quality data because their reputations as panel members and continued inclusion in panels often depends on good performance. Our sample also was limited to American adults. Future research is needed to investigate the strengths and limitations of the EDS for use with individuals of other ages and nationalities. Regarding construct validity, the original version of the PROMIS was developed using Item Response Theory while we used a Classical Test Theory approach to validate the items for use with e-cigarettes. While the differences in approach may be viewed as a limitation by some, we view the fact that the psychometric properties were equally strong when a different statistical approach was employed as a strength that bolsters our confidence in the EDS.[22] Further, the measure of cigarette smoking used in the current study was crude and the sample of current smokers comprised occasional smokers and daily smokers. Although this approach is consistent with past research,[23] future research that uses more refined smoking measures is needed to evaluate how e-cigarette dependence is impacted by the quantity and frequency of cigarette smoking. Related, while we assessed e-cigarette dependence in exclusive e-cigarette users and in dual-users of cigarettes and e-cigarettes, we did not assess cigarette dependence in dual-users. As such, it was not possible to assess potential interacting effects of cigarette and e-cigarette dependence among dual-users within the current study. As suggested by Strong and colleagues,[6] the best way to capture nicotine dependence across multiple products remains to be determined, and additional research is needed to determine how individuals make attributions to being dependent on one product over another. Finally, the EDS versions were derived from an existing, psychometrically sound measure of cigarette dependence. However, e-cigarette dependence may have some unique characteristics that distinguish it from cigarette dependence and, therefore, were not assessed in the current study. The Tobacco Center for Regulatory Science (TCORS) Measurement Workgroup identified ten potential domains that may be of relevance to e-cigarette dependence.[24] The first domain, quantity and frequency of use, could be assessed as a separate but related measure. The remaining domains include: tolerance; perceived benefits; withdrawal symptoms; craving; use despite harm; impaired control; automaticity; preference over competing rewards; and sensory dependence. The 22-item version of the EDS assesses each of these domains with the exceptions of tolerance, perceived benefits, and sensory dependence. However, our study suggests the core construct of e-cigarette dependence can be evaluated with only a subset of these domains (eg, automaticity, craving). Also, the original PROMIS includes a separate item bank for emotional and sensory expectations,[25] suggesting that these are unique aspects of smoking that do not directly overlap with dependence. As such, these additional item banks could provide a starting point for the development of perceived e-cigarette benefits and sensory dependence measures. Future research is needed to determine whether these domains (or others) are important determinants of e-cigarette use and/or dependence.

Despite the study limitations, the EDS proved to be psychometrically sound for assessing e-cigarette dependence in adult e-cigarette users. Adapted from the most psychometrically sound measure of cigarette dependence, the brief, 4-item EDS represents an advantage over other longer measures of e-cigarette dependence. Like the goals of the PATH study,[6] the merit of modifying the PROMIS items to assess tobacco dependence that develops or is maintained via other sources (eg, cigars, hookah, smokeless tobacco) should be investigated. Future research also should evaluate whether the EDS has utility for assessing e-cigarette dependence in other samples (eg, adolescents) and whether additional domains like sensory dependence are important to assessing e-cigarette dependence.

Funding

This work was supported in part by grants from the National Institute on Drug Abuse and the Food and Drug Administration Center for Tobacco Products

(CTP; Yale TCORS P50DA036151; Penn State TCORS P50DA036107) and the National Institutes of Health and the Food and Drug Administration Center for Evaluation and Coordination of Training and Research in Tobacco Regulatory Science (CECTR) Coordinating Center Award (Westat U54CA189222). The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health or the Food and Drug Administration.

Declaration of Interests

JF has done paid consulting for pharmaceutical companies involved in developing and marketing smoking cessation products (eg, Pfizer, GSK, J&J) and has received a research grant from Pfizer, all for work unrelated to the current paper. SO is a member of the American Society of Clinical Psychopharmacology work group supported by Alkermes, Amygdala, Arbor Pharma, Ethypharm, Indivior, Lundbeck, and Otsuka; has received donated study medications from AstraZeneca and Pfizer; and has been a consultant/advisory member to Alkermes, Amygdala, Cerecor, Mitsubishi Tanabe, and Opiant.

References

1. Gravely S, Fong GT, Cummings KM, et al. Awareness, trial, and current use of electronic cigarettes in 10 countries: findings from the ITC project. *Int J Environ Res Public Health*. 2014;11(11):11691–11704.
2. McMillen RC, Gottlieb MA, Shaefer RM, Winickoff JP, Klein JD. Trends in electronic cigarette use among U.S. adults: use is increasing in both smokers and nonsmokers. *Nicotine Tob Res*. 2015;17(10):1195–1202.
3. Hu SS, Neff L, Agaku IT, et al. Tobacco product use among adults - United States, 2013-2014. *MMWR Morb Mortal Wkly Rep*. 2016;65(27):685–691.
4. Marsot A, Simon N. Nicotine and cotinine levels with electronic cigarette: a review. *Int J Toxicol*. 2016;35(2):179–185.
5. Etter JF, Eissenberg T. Dependence levels in users of electronic cigarettes, nicotine gums and tobacco cigarettes. *Drug Alcohol Depend*. 2015;147:68–75.
6. Strong DR, Pearson J, Ehlke S, et al. Indicators of dependence for different types of tobacco product users: descriptive findings from wave 1 (2013-2014) of the population assessment of tobacco and health (PATH) study. *Drug Alcohol Depend*. 2017;178:257–266.
7. Foulds J, Veldheer S, Yingst J, et al. Development of a questionnaire for assessing dependence on electronic cigarettes among a large sample of ex-smoking E-cigarette users. *Nicotine Tob Res*. 2015;17(2):186–192.
8. Heatherton TF, Kozlowski LT, Frecker RC, Fagerström KO. The fagerström test for nicotine dependence: a revision of the fagerström tolerance questionnaire. *Br J Addict*. 1991;86(9):1119–1127.
9. Shiffman S, Waters A, Hickcox M. The nicotine dependence syndrome scale: a multidimensional measure of nicotine dependence. *Nicotine Tob Res*. 2004;6(2):327–348.
10. Etter JF. Comparing the validity of the cigarette dependence scale and the fagerström test for nicotine dependence. *Drug Alcohol Depend*. 2008;95(1-2):152–159.
11. DiFranza JR, Savageau JA, Fletcher K, et al. Measuring the loss of autonomy over nicotine use in adolescents: the DANDY (Development and Assessment of Nicotine Dependence in Youths) study. *Arch Pediatr Adolesc Med*. 2002;156(4):397–403.
12. Bover MT, Foulds J, Steinberg MB, Richardson D, Marcella SW. Waking at night to smoke as a marker for tobacco dependence: patient characteristics and relationship to treatment outcome. *Int J Clin Pract*. 2008;62(2):182–190.
13. Fidler JA, Shahab L, West R. Strength of urges to smoke as a measure of severity of cigarette dependence: comparison with the fagerström test for nicotine dependence and its components. *Addiction*. 2011;106(3):631–638.
14. Edelen MO, Stucky BD, Hansen M, Tucker JS, Shadel WG, Cai L. The PROMIS smoking initiative: initial validity evidence for six new smoking item banks. *Nicotine Tob Res*. 2014;16(suppl 3):S250–S260.
15. Shadel WG, Edelen MO, Tucker JS, Stucky BD, Hansen M, Cai L. Development of the PROMIS nicotine dependence item banks. *Nicotine Tob Res*. 2014;16(suppl 3):S190–S201.
16. Edelen MO, Huang W, Stucky BD. Additional validity evidence for the PROMIS Smoking Assessment Toolkit. *Addict Behav*. 2016;58:80–84.
17. Baker T, Piper ME, McCarthy DE, Bolt DM, Smith S, Kim S, Toll B. Time to first cigarette in the morning as an index of ability to quit smoking: Implications for nicotine dependence. *Nicotine Tob Res*. 2007;9:S555–S570.
18. Bentler PM. Comparative fit indexes in structural models. *Psychol Bull*. 1990;107(2):238–246.
19. MacCallum RC, Browne MW, Sugawara HM. Power analysis and determination of sample size for covariance structure modeling. *Psychol Med*. 1996;1:130–141.
20. Hu LT, Bentler PM. Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Struct Equ Modeling*. 1999;6:1–55.
21. Chen FF. Sensitivity of goodness of t indexes to lack of measurement. *Struct Equ Modeling*. 2007;14:464–504.
22. Cappelleri JC, Jason Lundy J, Hays RD. Overview of classical test theory and item response theory for the quantitative assessment of items in developing patient-reported outcomes measures. *Clin Ther*. 2014;36(5):648–662.
23. QuickStats. Cigarette smoking status among current adult e-cigarette users, by age group—national health interview survey, United States. *MMWR Morb Mortal Wkly Rep*. 2016;65:1177.
24. Bold KW, Sussman S, O'Malley SS, et al. Measuring e-cigarette dependence: Initial guidance. *Addict Behav*. 2018; doi: 10.1016/j.addbeh.2017.11.015.
25. Tucker JS, Shadel WG, Edelen MO, et al. Development of the PROMIS positive emotional and sensory expectancies of smoking item banks. *Nicotine Tob Res*. 2014;16(suppl 3):S212–S222.