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ORIGINAL ARTICLE

Main and Interactive Effects of e-Cigarette Use Health Literacy and Anxiety Sensitivity in Terms of e-Cigarette Perceptions and Dependence

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Abstract
Although e-cigarette use is on the rise, there is little understanding of cognitive-based individual difference factors that maintain maladaptive e-cigarette beliefs and dependence. The present investigation sought to test a theoretically-driven interactive model of e-cigarette health literacy and anxiety sensitivity (AS; fear of the consequences of anxiety) among 537 e-cigarette users (50.7% female, $M_{age} = 35.2$ years, $SD = 10.1$) in terms of perceived benefits and risks of e-cigarette use as well as dependence. Results indicated a significant interaction between e-cigarette health literacy and AS. The significant interaction effect for each dependent variable was evident over and above the main effects as well as the covariates of sex, income, education, and dual cigarette use (e-cigarette dependence was also controlled for the models of perceived benefits and risks). The form of this interaction indicated that greater e-cigarette health literacy was more strongly related to greater perceived benefits and risks of e-cigarette use as well as dependence among those with higher, relative to lower, AS. Overall, the current data suggest that individual differences in e-cigarette health literacy and AS may represent two important factors to consider in e-cigarette beliefs and dependence. This study provides the first empirical evidence of the potential role of two cognitive factors in relation to e-cigarette use beliefs and behavior. These data suggest future clinical research may benefit by understanding the potential therapeutic role of e-cigarette health literacy and AS for e-cigarette use behavior.

Keywords Anxiety sensitivity · e-Cigarettes · Health literacy · Tobacco · Addiction · Cognition

Electronic cigarettes (e-cigarettes) use is prevalent in the United States and in other regions of the world, particularly among adolescents (Cummins et al. 2014; Delnevo et al. 2015; Rubinstein et al. 2018). e-Cigarettes are used to inhale aerosol, nicotine, and related chemicals (Trtchounian et al. 2010). Many persons use e-cigarettes to help quit or reduce combustible cigarette use, presumably because they believe e-cigarettes are a safer alternative (Dawkins et al. 2012). Consistent with this assumption, some data suggest e-cigarette use may be a safer alternative to cigarette smoking when one completely switches from combustible cigarettes to e-cigarettes (National Academies of Sciences and Medicine 2018). Unfortunately, the majority of e-cigarette users are dual users (Leventhal et al. 2016), and little is known about the combined risk of dual use (Gilreath et al. 2016). Despite the potential to reduce harm exposure under certain circumstances, e-cigarettes use is still characterized by exposure to nicotine and an array of toxins (Bitzer et al. 2018; Callahan-Lyon 2014; Dinakar and O'Connor 2016) that may contribute to poor health outcomes.

Some initial research also suggests e-cigarette use is higher among persons with mental health problems, including anxiety (Cummins et al. 2014; King et al. 2018). It is possible that persons with anxiety-related and other mental health problems are more apt to use e-cigarettes because these persons often struggle to quit cigarette smoking (Prochaska and Grana 2014), and therefore, they may perceive greater potential utility in e-cigarettes as an alternative form of substance use. Although limited, such data suggest

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anxiety-related problems may be important in understanding the nature of e-cigarette use, as has been evident for cigarette smoking (Leventhal and Zvolensky 2015). Despite the potential relation of anxiety to e-cigarette use, there is limited knowledge of how anxiety-related factors are associated with cognitive processes of e-cigarettes.

At a broad-based level, perceived benefits of e-cigarette use, perceived risk of e-cigarette use, and e-cigarette dependence represent three clinically important e-cigarette facets that may be related to mental health. Yet, little is understood about these factors. Indeed, research on these constructs has thus far focused exclusively on sociodemographic characteristics (e.g., sex, ethnicity, education) and patterns of use (e.g., duration of use, apparatus models) as they relate to perceived benefits and risks of e-cigarette use and e-cigarette dependence (Copeland et al. 2017; Foulds et al. 2015). The available data, Albeit Limited, indicate that being White, being more educated, and having a history of smoking cigarettes is associated with greater perceived benefits of e-cigarettes and fewer perceived risks (Choi and Forster 2013; Pearson et al. 2012). Additionally, being female, White, having a lower education level, having used e-cigarettes for longer, and having tried more e-cigarette models are related to a higher level of e-cigarette dependence (Foulds et al. 2015). This initial work has neglected to evaluate cognitive-based individual difference factors that may maintain beliefs about e-cigarette use and dependence. Considering the clinically notable association between perceived benefits and risk of e-cigarettes and e-cigarette dependence with use and quit difficulty (Etter and Bullen 2011; Wackowski and Delnevo 2016), there is a need to evaluate additional cognitive-based factors related to these constructs. Anxiety-related constructs may be particularly viable explanatory targets in this domain given their long-standing association with health concerns, substance dependence, and relapse (Zvolensky and Smits 2007).

One anxiety-related cognitive-based factor that has received attention in the context of smoking and related addictive behaviors is anxiety sensitivity (AS). AS reflects a relatively stable individual difference factor that predisposes individuals to the development of anxiety/depressive problems (Taylor 1999) by amplifying negative mood states(e.g., anxiety; Reiss 1991; Zinbarg et al. 1997). Thus, AS is an 'amplifying factor,' enhancing the aversiveness and need to escape/avoid negative affective or somatic experiences. A large body of work documents the role of AS in smoking maintenance and relapse processes (Leventhal and Zvolensky 2015). However, no work has yet explored AS in relation to e-cigarette use, including beliefs about use or dependence. Given the prominence and clinical utility of the AS construct in relation to tobacco use (Zvolensky et al. 2018), there is strong support to explore its potential as an explanatory factor in terms of e-cigarettes. Indeed, greater levels of AS would be expected to relate to higher levels of perceived benefits and risks of e-cigarette use, because high AS persons may tend to be hypervigilant to and worried about health risks. Thus, e-cigarette users higher in AS may be more apt to believe e-cigarettes are a safe alternative to smoking cigarettes, but still relatively more likely to worry about the risks related to e-cigarette use in general. Further, because high AS e-cigarette users may be more likely to use to cope with aversive mood and bodily states, as has been found in the tobacco literature (Leventhal and Zvolensky 2015), they may have more addictive potential and thereby be at greater risk for more severe e-cigarette dependence.

Another heretofore unexplored cognitive factor that may be relevant to e-cigarette use and processes, is e-cigarette health literacy. In general, health literacy is the ability to obtain, understand, and use health information to make important decisions regarding health and medical care (Kutner et al. 2006). Health literacy is frequently related to anxiety-related concerns in the form of health-seeking information and it can maintain adaptive (e.g., problem solving) and maladaptive functions (e.g., reassurance seeking; Ishikawa et al. 2016; Jorm 2000). Past work has found that limited health literacy is associated with higher health care costs, greater use of health care services, higher rates of hospitalization, and poorer response to treatment (Kutner et al. 2006). These data suggest health literacy may be related to several health-related factors. Indeed, persons with inadequate health literacy often have poorer recollection and comprehension of advice and instructions and health beliefs that interfere with care (Berkman et al. 2011). Among smokers, available data suggest that lower health literacy is associated with higher nicotine dependence, more positive and less negative smoking outcome expectancies for smoking, less knowledge about smoking health risks (Stewart et al. 2013), and lower smoking risk perceptions (Hoover et al. 2018).

Although past data suggest that smokers with lower health literacy may lack the knowledge/skills to access high-quality health information (e.g., skills to correctly use evidence-based cessation products and services), no study has evaluated general health literacy or specific e-cigarette health literacy in the context of e-cigarette use or processes. Yet, some research suggests e-cigarette users are particularly 'health conscious' (Caponnetto et al. 2011). That is, they may be more focused on educational material related to smoking and tools that could theoretically help them quit, such as e-cigarettes (Cahn and Siegel 2011; Dawkins et al. 2012). Thus, greater e-cigarette health literacy among e-cigarette users may be related to greater perceived benefits of e-cigarette use and less perceived risk of e-cigarette use. At the same time, greater health literacy may be related to more severe e-cigarette dependence because this group may be more apt to believe e-cigarettes are a healthier alternative to smoking, and therefore, they may be more apt to learn to

use e-cigarettes in an addictive fashion (e.g., increased puff frequency, greater degree of use).

Consistentwith theoretical models that posit AS is an amplifying risk factor for poor smoking outcomes (Leventhal and Zvolensky 2015), it is possible that AS may influence the association between e-cigarette health literacy and e-cigarette beliefs and dependence severity. Specifically, AS and e-cigarette health literacy may operate with one another to confer greater vulnerability across e-cigarette outcomes such that e-cigarette health literacy may be more strongly related to greater perceived benefits and risks of e-cigarette use as well as dependence among e-cigarette users with higher relative to lower AS. Therefore, these processes may theoretically function synergistically in relation to clinically significant e-cigarette use characteristics. To illustrate, an e-cigarette user higher in e-cigarette health literacy who is also higher in AS, may be at an increased risk of endorsing more perceived benefits as well as risks associated with use and more likely to experience higher levels of dependence. That is, the combination of greater knowledge about e-cigarettes and higher AS (an affect amplifier) may fuel specific types of beliefs and use patterns; in this case, greater expectancies of benefits and risks, as well as dependence. From this perspective, a formative next research step is to further explore the potential interplay of e-cigarette health literacy and AS as an integrative explanatory process for e-cigarette perceived risk and benefits and severity of dependence.

Together, the present investigation sought to test the main and interactive effects of e-cigarette health literacy and AS among adult e-cigarette users. It was predicted that e-cigarette health literacy would more strongly relate to greater perceived benefits and risks of e-cigarette use as well as dependence, among e-cigarette users with higher relative to lower AS. Additionally, it was predicted that for both e-cigarette health literacy and AS, there would be significant main effects for the studied criterion variables.

Method

Measures

Demographics Questionnaire

Participants provided data regarding sex (1 = Male, 2 = Female), race, age, educational level (1 = Grade 6 or less to 8 = Graduate or professional degree), annual income (1 = $0–$4,999 to 8 = $75,000 or higher), and, when applicable, information about their cigarette use (i.e., age of onset, smoking rate). Demographic information was used to characterize the sample. Sex, income, education, and dual use were entered as covariates.

Penn State Electronic Cigarette Dependence Index

The Penn State Electronic Cigarette Dependence Index is a 10-item self-report questionnaire used to asses e-cigarette dependence (Foulds et al. 2015). Participants are asked to provide information on the strength of urges to use (e.g., how strong have the urges to smoke/use an electronic cigarette been?), waking and night use (e.g., Do you sometimes awaken at night to use your electronic cigarette?), number of times that an individual uses an e-cigarette (e.g., How many times per day do you usually use your electronic cigarette?), difficulty quitting (e.g., Did you feel more irritable because you couldn't use an electronic cigarette?), and experience of craving and withdrawal symptoms (e.g., Did you feel more irritable because you couldn't use an electronic cigarette?) are measured. Previous work supports the total score as a valid and reliable index of e-cigarette dependence (Foulds et al. 2015).

Electronic Cigarette Smoking History Questionnaire

The Electronic Cigarette Smoking History Questionnaire (EC-SHQ) is a 28-item self-report measure developed by the current research team and utilized in previous work (Zvolensky et al. 2018). The measure includes modified items borrowed from the Smoking History Questionnaire (Brown et al. 2002) and select items from a large national study on e-cigarette use (Wilson et al. 2015). The EC-SHQ was developed to assess electronic smoking history and includes items pertaining to frequency of use (e.g., Since you started regular daily e-cig use, how many TIMES per DAY do you usually use your electronic cigarette?), age at onset of use (e.g., How old were you when you first smoked an electronic cigarette?), and dual tobacco use (e.g., Do you currently use cigarettes? [1 = Yes, 2 = No]). The EC-SHQ was used to characterize the sample and report of dual use.

Risks and Benefits of e-Cigarettes

The Risks and Benefits of e-cigarettes (RABE; Copeland et al. 2017) is a 30-item self-report measure that assess the perceived risks (e.g., Nicotine is addictive, regardless of whether ingested through e-cigarettes or regular cigarettes.) and benefits (e.g., e-cigarettes are a good way to "beat" smoking bans) of e-cigarettes use. Each item is assessed on a 7-point Likert-type scale ranging from 1 (Totally Disagree) to 7 (Totally Agree). The questionnaire contains two subscales: risks (16 items) and benefits (14 items). The RABE has demonstrated sound psychometric properties and reliability (Copeland et al. 2017). Both the mean risks and benefits subscales were utilized in the present study and demonstrated excellent internal consistency (Risks: $\alpha = 0.93$; Benefits: $\alpha = 0.94$).

Anxiety Sensitivity Index-3

The Anxiety Sensitivity Index-3 (ASI-3; Taylor et al. 2007) is a 18-item measure, based in part upon the original Anxiety Sensitivity Index (Reiss et al. 1986), in which participants are asked to respond to which extent they feel concerned about the possible aversive effects of their anxiety relate symptoms. The responses are rated on a 5-point Likert scale from 0 (Very Little) to 4 (Very much). The ASI-3 has been validated among smokers (Farris et al. 2015). For the current study, the total score (ASI-3 Total) was used, and the scale demonstrated excellent internal consistency ($\alpha = 0.97$).

e-Cigarette Health Literacy Questionnaire

The e-cigarette Health Literacy Questionnaire is a 5-item self-report measure that assesses e-cigarette health literacy. The measure was developed by the present research team and informed by the All Aspects of Health Literacy Scale (Chin and McCarthy 2013). The e-cigarette Health Literacy Questionnaire measure includes items over a variety of health care related aspects of e-cigarette use. Specifically the questionnaire includes the following information: evaluating the degree to which a patient takes responsibility for understanding their health care information in regards to e-cigarettes (e.g., When you talk to a doctor or nurse, do you make sure they explain anything that you do not understand about e-cigarettes?), understanding chemicals in their e-cigarette liquid (e.g., When you talk to a retailer about e-cigarettes, do you make sure you understand all the chemicals contained in your e-cigarette liquid?), verification of such health care information (e.g., How often do you try to work out whether information about e-cigarettes can be trusted or is accurate?), what information is asked from retailers (e.g., When you talk to a retailer about e-cigarettes, do you make sure you understand all the chemicals contained in your e-liquid?), and lastly, how much information is sought out (Are you someone who likes to find out lots of different information about your e-cigarette?). Items were assessed via a 4-point Likert scale from 0 (Never) to 3 (Often). For the current study, a mean score was calculated. The scale demonstrated good internal consistency in the present sample ($\alpha = 0.82$).

Procedure

Participants were recruited nationally through Qualtrics. This data management program would show participants advertisements for studies in which they may qualify for based upon the information they gave upon registering with Qualtrics. From there, if interested, participants were screened for eligibility and directed to the online, anonymous survey. Participants provided informed consent prior to completing the survey. The survey took approximately 30 min to complete, and participants were compensated with credit through their Qualtrics account for their participation at the rate of $8.50 for study completion. The study protocol was approved by the Institutional Review Board at the University of Houston.

Analytic Strategy

Analyses were conducted using SPSS version 24. First, sample descriptive statistics and zero-order correlations among study variables were examined. Second, to evaluate main and interactive effects of e-cigarette health literacy and AS, three separate hierarchical regression analyses were conducted among criterion variables: perceived benefits of e-cigarette use, perceived risk of e-cigarette use, and e-cigarette dependence. Covariates were entered in the first step of each model and included sex, income, education, and dual use; e-cigarette dependence was also controlled for the models of perceived benefits and risks. e-Cigarette health literacy and AS were then simultaneously entered in the second step of each model. Finally, the interaction of e-cigarette health literacy and AS was added in the third step. Planned post-hoc simple slope analyses were conducted using the PROCESS macro (Hayes 2013) to examine associations between e-cigarette health literacy and the three dependent variables at high and low values of AS (± 1 SD from the mean).

Results

Participants

The present study was comprised of 537 current e-cigarette users (50.7% female, $M_{age} = 35.2$ years, $SD = 10.1$). Participants were recruited via an online survey and were eligible if they were between the ages of 18 and 64 and a current e-cigarette user (defined as using at least once per day, on average, and use within the past month). Exclusion criteria included being younger than the age of 18, a non-English speaker (to ensure comprehension of the study questions), an inability to give informed, and voluntary, written consent to participant.

Most of the sample was White/Caucasian (75%), with 16.9% identifying as Black/African American, 4.3% Asian, 1.7% Native American/Alaska Native, 0.4% Hawaiian, and 1.6% other. In terms of education, about a quarter of the sample (25.3%) reported attaining a high school diploma, 20.9% percent reported "some college," and of the remaining sample 21.8% indicated completing a bachelor's degree. The median income bracket fell within the range of $50,000–$74,999. A medium level of e-cigarette dependence was observed in the sample ($M = 12.1$, $SD = 2.6$; Foulds

et al. 2015). e-Cigarette users reported an average of 2.8 ($SD = 3.1$) serious lifetime attempts to quit e-cigarettes, using e-cigarettes an average of 8.3 ($SD = 9.7$) used a day, and 18.9 ($SD = 20.1$) months of use. Among the e-cigarette users, the average age of onset was 28.3 ($SD = 12.3$). Approximately 77.5% of the sample reported dual users. Among those who reported dual use, participants reported smoking an average of 13 ($SD = 17.4$) cigarettes per day, 18.6 ($SD = 5.5$) years old when they started smoking cigarettes daily and being a daily cigarettes smoker for an average of 15.6 ($SD = 10.5$) years. Lastly, dual users also reported an average of 5.6 ($SD = 13.9$) number of previous combustible cigarette quit attempts.

Descriptive Statistics

Bivariate correlations are presented in Table 1. e-Cigarette health literacy and AS were significantly and positively related ($r = .33$ $p < .001$). e-Cigarette health literacy correlated significantly and positively with all three criterion variables (r's from .28 to .39; all p's $< .001$). AS also was significantly and positively associated with the criterion variables (r's from .32 to .40; p's $< .001$). Perceived benefits of e-cigarette use significantly and positively related to perceived risk of e-cigarette use ($r = .59$; $p < .001$) and e-cigarette dependence ($r = .38$; $p < .001$). Perceived risk of e-cigarette use and e-cigarette dependence also were significantly correlated ($r = .29$; $p < .001$).

Primary Analyses

In predicting perceived benefits of e-cigarette use, covariates entered in the first step accounted for a significant amount of variance (F [5, 531] = 30.60, $p < .001$, $R^2 = .22$; see Table 2). Income ($b = .07$, $SE = .03$, $t = 2.22$, $p = .03$), years of education ($b = .14$, $SE = .03$, $t = 4.27$, $p < .001$), and e-cigarette dependence ($b = .12$, $SE = .01$, $t = 8.76$, $p < .001$) were significant predictors. Step two accounted for significantly more variance in perceived benefits of e-cigarette use ($\Delta R^2 = .09$, $p < .001$). A significant main effect emerged for e-cigarette health literacy ($b = .33$, $SE = .07$, $t = 4.70$, $p < .001$) and AS ($b = .01$, $SE = .003$, $t = 5.42$, $p < .001$). As expected, there was a significant interaction of e-cigarette health literacy and AS ($\Delta R^2 = .03$, $p < .001$; $b = .01$, $SE = .003$, $t = 4.48$, $p < .001$). e-Cigarette health literacy was related to greater perceived benefits of e-cigarette use among e-cigarette use with higher AS ($b = .71$, $SE = .12$, $t = 6.51$, $p < .001$); the association was non-significant for those with lower AS ($b = .10$, $SE = .09$, $t = 1.14$, $p = .25$; See Fig. 1a).

For perceived risks of e-cigarette use, covariates entered in the first step accounted for a significant amount of variance (F [5, 531] = 14.69, $p < .001$, $R^2 = .12$; see Table 2). Income ($b = .06$, $SE = .03$, $t = 2.21$, $p = .03$), years of education ($b = .07$, $SE = .03$, $t = 2.39$, $p = .02$), and e-cigarette dependence ($b = .08$, $SE = .01$, $t = 6.12$, $p < .001$) emerged as significant predictors. Step two accounted for significantly more variance in perceived risks of e-cigarette use ($\Delta R^2 = .06$, $p < .001$). A significant main effect was evident for both e-cigarette health literacy ($b = .20$, $SE = .07$, $t = 3.03$, $p = .003$) and AS ($b = .01$, $SE = .002$, $t = 4.84$, $p < .001$). As hypothesized, the interactive effect of e-cigarette health literacy and AS was significant ($b = .02$, $SE = .003$, $t = 5.47$, $p < .001$). e-Cigarette health literacy was related to greater perceived risks of e-cigarette use among e-cigarette use with higher AS ($b = .63$, $SE = .11$, $t = 6.20$, $p < .001$); the association was non-significant for those with lower AS ($b = -.07$, $SE = .08$, $t = -.79$, $p = .43$; See Fig. 1b).

In predicting e-cigarette dependence, covariates entered in the first step accounted for a significant amount of variance (F [4, 531] = 9.18, $p < .001$, $R^2 = .07$; see Table 2). Dual use ($b = -1.98$, $SE = .39$, $t = -5.15$, $p < .001$) was a significant predictor. Step two accounted for significantly

Table 1 Bivariate correlations

	1.	2.	3.	4.	5.	6.	7.	8.	Mean (SD) or n [%]
1. Sex	–								272 [50.7% female]
2. Income	−.18***	–							6.07 (1.99)
3. Education level	−.20***	.53***	–						5.05 (1.80)
4. Dual use	.08	−.05	−.07	–					416 [77.5% Users]
5. e-Cigarette HL	−.12**	.20***	.26***	−.12**	–				2.00 (0.75)
6. ASI-3	−.08	.14**	.29***	−.08	.33***	–			31.40 (21.16)
7. Perceived benefits	−.13**	.25***	.30***	−.10*	.39***	.40***	–		4.74 (1.31)
8. Perceived risks	−.01	.19***	.20***	−.11*	.28***	.33***	.59***	–	5.03 (1.14)
9. ECD	−.05	.10*	.13**	−.23***	.31***	.32***	.38***	.29***	9.35 (3.82)

N = 551; ***p < .001, **p < .01, *p < .05. Sex: 1 = male, 2 = female; annual income: 1 = $0–$4,999 to 8 = $75,000 or higher; education level: 1 = grade 6 or less to 8 = graduate or professional degree; dual use = dual combustible tobacco use (Brown et al. 2002; Zvolensky et al. 2018). *e-Cigarette HL* e-Cigarette Health Literacy (Zvolensky et al. 2018); *ASI-3* Anxiety Sensitivity Index (Taylor et al. 2007); perceived benefits = risks and benefits of e-cigarettes (Copeland et al. 2017); *ECD* e-cigarette dependence (Foulds et al. 2015)

Table 2 Regression models

	Model 1: perceived benefits of e-cigarette use					
	b	*SE*	*t*	*p*	sr^2	R^2 change
Step 1						
Income	0.07	0.03	2.22	.03	0.18	
Sex	−0.14	0.10	−1.36	.18	0.00	
Education	0.14	0.03	4.27	< .001	0.03	
Dual use	−0.01	0.12	−0.08	.94	0.00	.22***
e-Cigarette dependence	0.12	0.01	8.76	< .001	0.12	
Step 2						
ASI-3	0.01	0.03	5.42	< .001	0.04	
e-Cigarette health literacy	0.33	0.07	4.70	< .001	0.03	.09***
Step 3						
ASI-3 × e-cigarette health literacy	0.01	0.003	4.48	< .001	0.03	.03***
	Model 2: perceived risks of e-cigarette use					
	b	*SE*	*t*	*p*	sr^2	R^2 change
Step 1						
Sex	0.11	0.10	1.14	.25	0.00	
Income	0.06	0.03	2.21	.03	0.00	
Education	0.07	0.03	2.39	.02	0.01	
Dual use	−0.12	0.11	−1.01	.31	0.00	
e-Cigarette dependence	0.08	0.01	6.12	< .001	0.05	.12***
Step 2						
ASI-3	0.01	0.002	4.84	< .001	0.04	
e-Cigarette health literacy	0.20	0.07	3.03	< .001	0.01	.06***
Step 3				< .001		
ASI-3 × e-cigarette health literacy	0.02	0.003	5.47	< .001	0.04	.04***
	Model 3: e-cigarette dependence					
	b	*SE*	*t*	*p*	sr^2	R^2 change
Step 1						
Sex	−0.08	0.33	−0.25	.80	0.00	
Income	0.08	0.10	0.87	.39	0.00	
Education	0.18	0.11	1.72	.09	0.00	
Dual use	−1.98	0.39	−5.15	< .001	0.05	.07***
Step 2						
ASI-3	0.04	0.01	5.45	< .001	0.04	
e-Cigarette health literacy	1.10	0.22	5.02	< .001	0.04	.12***
Step 3						
ASI-3 × e-cigarette health literacy	0.03	0.01	2.45	.01	0.01	.01*

N = 537; ***p < .001, **p < .01, *p < .05. Sex: 1 = male, 2 = female; annual income: 1 = $0–$4999 to 8 = $75,000 or higher; education level: 1 = grade 6 or less to 8 = graduate or professional degree; dual use = dual combustible tobacco use (Brown et al. 2002); *ASI-3* Anxiety Sensitivity Index (Taylor et al. 2007); e-cigarette Health Literacy = (Zvolensky et al. 2018); e-cigarette dependence = (Foulds et al. 2015)

more variance in e-cigarette dependence ($\Delta R^2 = .12$, $p < .001$). Additionally, significant main effects emerged for both e-cigarette health literacy ($b = 1.10$, $SE = .22$, $t = 5.02$, $p < .001$) and AS ($b = .04$, $SE = .01$, $t = 5.45$, $p < .001$). Step three accounted for significantly more variance ($\Delta R^2 = .01$, $p = .01$). As expected, there was a significant interaction of e-cigarette health literacy and AS ($b = .03$, $SE = .01$, $t = 2.45$, $p = .01$). e-Cigarette health literacy was more strongly related to greater e-cigarette dependence among e-cigarette use with higher AS ($b = 1.74$, $SE = .34$, $t = 5.11$, $p < .001$) relative to those with lower AS ($b = .68$, $SE = .28$, $t = 2.45$, $p = .01$; See Fig. 1c).

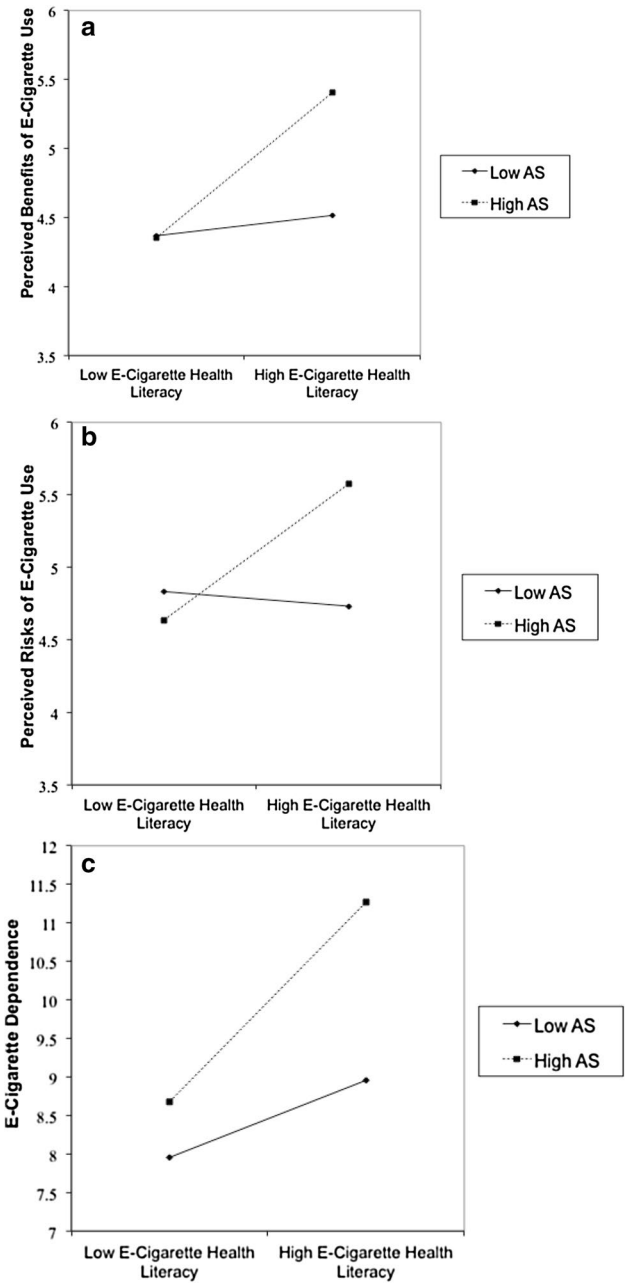

Fig. 1 Interaction effects among variables

Discussion

The present investigation sought to test the main and interactive effects of two anxiety-related cognitive-based factors, e-cigarette health literacy and AS, in relation to beliefs about e-cigarettes and e-cigarette dependence among adult e-cigarette users. Consistent with prediction, the interaction between e-cigarette health literacy and AS was significantly related to greater perceived benefits of e-cigarette use, greater perceived risk of e-cigarette use, and greater e-cigarette dependence. The significant interaction effect for each criterion variable was seen over and above the main effects as well as the theoretically-relevant covariates sex, income, education, and dual use (and, e-cigarette dependence for the models of perceived benefits and risks). The form of the interaction indicated that e-cigarette users with greater e-cigarette health literacy were more likely to endorse greater perceived benefits and risks of e-cigarette use as well as dependence among those with higher relative to lower AS.

Theoretically, e-cigarette users with greater health literacy who are more likely to worry about the negative consequences of health-related symptoms (i.e., AS) may be a heretofore unrecognized at-risk group. It is possible that e-cigarette users higher in health literacy may be seeking out information related to e-cigarettes because they are worried about the adverse health effects of smoking cigarettes and desire to quit, as has been found in the cigarette smoking literature (McLeish et al. 2016; Zvolensky et al. 2007). Regardless of the actual safety of e-cigarettes, however, these 'health literate' e-cigarette users with higher AS appear to be more prone to experiencing specific beliefs and e-cigarette use patterns. Indeed, these novel data suggest that e-cigarette health literacy is an important cognitive factor that, when coupled with greater AS, is associated with e-cigarette beliefs (both positive and negative) and more severe e-cigarette dependence.

In terms of e-cigarette health literacy, the current findings indicate that greater literacy is related to more perceived benefits of use and more perceived risks as well as, greater dependence to e-cigarettes. This novel finding may be somewhat initially counter intuitive. However, e-cigarette users may be an especially health conscious group, and therefore, seek health-related information on both the benefits and risks of e-cigarettes. Further, greater e-cigarette literacy among this group may be related to positive expectancies for e-cigarette use and more addictive usage because they believe that they are 'better' than smoking cigarettes. These results highlight the complexity of information-seeking behavior and that it may be either potentially adaptive (i.e., corrective information gathering) or maladaptive (e.g., reassurance-seeking; Ishikawa et al. 2016). Among e-cigarette users, such behavior is especially complex because extant knowledge of e-cigarette safety is only emerging (Cahn and Siegel 2011).

The main effect of AS was significantly related to each criterion variable. These data, consistent with AS-specific models of substance use generally (Zvolensky et al. 2004), suggest that higher AS e-cigarette users maintain 'dual beliefs' about e-cigarette use. That is, they endorse the benefits of such use but also worry about the negative consequences of such use. Further, as has been found for other forms of substance use, higher AS persons may experience greater dependence (Guillot et al. 2016; Johnson et al. 2010; Svicher et al. 2017). Future research is needed to explore the

prospective relation between AS and e-cigarette use during actual quit attempts to better understand how this individual difference factor relates to other facets of use (e.g., withdrawal, craving, motivation to quit).

Clinically, our findings suggest that a subgroup of adult e-cigarette users are at greater risk for endorsing 'risky' beliefs about e-cigarette use and experiencing greater dependence based upon their e-cigarette health literacy and AS rates. There is utility in continuing to explore the potential interactive risk associated with e-cigarette health literacy and AS on other aspects of e-cigarette use. To that extent, the present findings extend past other facets of e-cigarette use, and targeted prevention and intervention efforts could be considered. Strategies to be implemented could include such therapeutic tactics as AS reduction methods that have shown promise in past work (Zvolensky et al. 2018) for smoking, providing personalized feedback and corrective information on safety and what others are doing compared to perceptions for e-cigarette use, and increasing awareness of coping skills in relation to where e-cigarette use occurs and individuals' underlying motives and self-regulatory techniques.

Limitations should be noted. First, the cross-sectional design limits the conclusions that can be drawn from a directionality perspective. Future laboratory and longitudinal research is needed to explicate the temporal relations between the studied variables. For example, longitudinal research could usefully explore whether e-cigarette health literacy and AS are increasing e-cigarette usage and whether it is possible to reduce these risk candidates to offset e-cigarette use. Second, the adult sample was self-selected and most appeared to be dedicated e-cigarette users. As a result, the findings may not generalize to all e-cigarette users, including 'experimenters.' Future research would be usefully oriented on younger e-cigarette users. Third, we expressly sampled e-cigarette users and 78% were also dual users. Future research may benefit by exploring whether the present model is equally applicable to e-cigarette users that engage in combined use of cigarettes and e-cigarette use. Fourth, we oriented our tests on e-cigarette health literacy, as this domain of health was the most directly relevant to the present research questions. However, it is possible the observed effects for e-cigarette health literacy are more broadly applicable to a global health literacy construct. Future research may therefore benefit from testing the domain specificity of health literacy in terms of e-cigarette use beliefs and behavior. Fifth, it may be useful understand other e-cigarette use processes related to interest in quitting. For example, future research could test the present model in relation to motivation to quit e-cigarettes or combustible cigarettes or both. Sixth, we conceptualized e-cigarette health literacy as a health-based construct that may tap features of stress and anxiety (e.g., greater knowledge about e-cigarettes may be associated with greater worry about health problems). Yet, there is presently highly limited work on e-cigarette health literacy and the best ways to conceptualize this construct. Future work could usefully explore the factors that underlie this construct, which could enhance theoretical models related to it. Finally, our tests were informed, in part, by past research on AS among combustible cigarette smokers. However, it is presently unclear how well this body work captures e-cigarette use processes. Future research is needed among AS and other transdiagnostic factors among e-cigarette users to better understand the generalized and distinct features of this group.

Overall, the current study findings suggest that individual differences in e-cigarette health literacy and AS may represent two important, yet thus far unrecognized, anxiety-related cognitive-based factors to consider in better understanding e-cigarette beliefs and dependence. Such cognitive-based factors represent potential therapeutic targets to assess and change in modify e-cigarette use.

Compliance with ethical standards

Conflict of Interest Michael J. Zvolensky, Nubia A. Mayorga, and Lorra Garey declare that they have no conflicts of interest.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent Informed consent was obtained from all individual participants included in the study.

Research Involving Animal Participants No animal studies were carried out by the authors for this article.

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