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# The association between e-cigarette use characteristics and combustible cigarette consumption and dependence symptoms: Results from a national longitudinal study

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## HIGHLIGHTS

- Exclusive smokers who start using e-cigarettes decrease cigarette consumption.
- E-cigarette use may help reduce smoking related dependence symptoms.
- Higher frequency of e-cigarette use is associated with better cigarette outcomes.
- E-cigarette use with flavoring is associated with lower quantity of cigarette use.
- Hispanics may be less likely to substitute cigarette use with e-cigarette use.

## ARTICLE INFO

*Keywords:*
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## ABSTRACT

*Background:* Existing longitudinal surveys focused on the association between ever use of e-cigarettes and combustible cigarette consumption, making it difficult to infer what characteristics of e-cigarette use could potentially change combustible cigarette use behavior, which may have long-term health consequences. Although e-cigarettes' efficacy of alleviating dependence symptoms was supported by studies conducted in laboratory settings, whether the results can be translated into symptom reduction in the real world and over time is an open question.

*Methods:* This study conducted secondary analysis on the Waves 1-2 data of the Population Assessment of Tobacco and Health (PATH) Study to examine the association between e-cigarette use characteristics (frequency, flavoring, and voltage adjustment) and combustible cigarette use outcomes (frequency, quantity, and symptoms), using the Heckman 2-step selection procedure with the selection bias controlled. The inclusion criteria ensured that we followed an adult cohort of exclusive combustible cigarette users at Wave 1.

*Results:* The result shows that higher frequency of e-cigarette use was associated with lower combustible cigarette consumption and dependence symptoms, controlling for the corresponding baseline cigarette use variable and other confounders. Given the frequency of e-cigarette use, the feature of voltage adjustment was not significantly associated with any of the cigarette use outcomes. Flavoring, on the other hand, was associated with lower quantity of cigarette use.

*Conclusions:* Exclusive smokers who start using e-cigarettes do indeed change the frequency and quantity with which they smoke cigarettes. E-cigarette use may also help reduce dependence symptoms.

## 1. Introduction

E-cigarettes have been hypothesized to be a potential harm reduction device, like nicotine patches, in that if smokers can substitute vaping for some or all of their consumption of combustible cigarettes, they will absorb a smaller amount of toxins into their systems. Yet, some longitudinal studies following smokers for about a year did not find a significant association between e-cigarette use and reduction in combustible cigarette consumption (Grana, Popova, & Ling, 2014; Wills et al., 2017). A six-wave longitudinal survey of college students from

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the fall of freshman year to the fall of senior year, however, showed that among those who reported current cigarette smoking but no history of e-cigarette use at Wave 1, trying e-cigarettes during Waves 2–5 was a significant predictor of persistence of cigarette smoking at Wave 6 (Sutfin et al., 2015). A common limitation of these studies is that they defined e-cigarette use as ever use (even once), making it difficult to infer what levels of e-cigarette consumption could potentially influence combustible cigarette use. In fact, some longitudinal studies involving e-cigarette consumption levels in the analysis were able to establish the hypothesized association. Brose, Hitchman, Brown, West, and McNeill (2015) conducted a web-based survey on a general population sample of adult smokers in Great Britain and followed them up a year later. They found that compared with non-use, daily e-cigarette use at baseline was associated with increased cessation attempts, but not with cessation at follow-up; non-daily use was not associated with cessation attempts or cessation. Further, Biener and Hargraves (2015) conducted telephone interviews with a population-based sample of adult smokers in two US metropolitan areas at baseline and a two-year follow-up, showing that intensive users (used daily for at least 1 month) of e-cigarettes were more likely than non-users to report smoking cessation (abstinence for at least 1 month); no such relationship was found for intermittent users (more than once or twice but not daily for a month or more).

E-cigarettes are novel products that allow users to customize them in a variety of ways (e.g., adding flavorings and adjusting voltage), so traditional quantity/frequency measures may not be sufficient to characterize e-cigarette consumption. A unique characteristic of e-cigarettes is the great flexibility to add a variety of flavorings which may be safe for ingestion but could have adverse respiratory toxic effects (Barrington-Trimis, Samet, & McConnell, 2014; Lerner et al., 2015). Litt, Duffy, and Oncken (2016) found that flavoring had significant effects on the smoking behavior of cigarette smokers asked to adopt e-cigarettes for 6 weeks: the largest drop in cigarette smoking occurred among those assigned menthol e-cigarettes. Research also showed that tobacco or menthol flavors produced very strong feeling for sensation fulfillment (i.e., throat hit) that is very similar to the effect of smoking (Li, Zhan, Wang, Leischow, & Zeng, 2016). Another study indicated that adolescents and young adults who mixed together multiple flavors were more likely to use e-cigarettes to quit smoking (Camenga, Kong, Cavallo, & Krishnan-Sarin, 2017). Furthermore, ex-smoking e-cigarette users who used more advanced e-cigarette devices allowing them to control the voltage were found to have higher levels of dependence symptomatology (Foulds, Veldheer, Yingst, et al., 2015). Thus, flavoring and voltage adjustment are both important characteristics of e-cigarette consumption that could be potentially associated with combustible cigarette consumption and dependence symptoms.

Malas et al. (2016) conducted a systematic review of 62 published studies and concluded that the evidence in support of e-cigarettes' effectiveness on smoking cessation was very low to low, and the evidence on smoking reduction was very low to moderate. The same review, however, found that e-cigarettes' efficacy of alleviating smoking withdrawal symptoms and cravings was supported by the majority of studies conducted in laboratory settings, which do not always translate into symptom and craving reduction in the real world and over time. In fact, a recent study (Jorenby, Smith, Fiore, & Baker, 2017) took a further step toward such translation. The study recruited 74 dual users (cigarettes + e-cigarettes) and 74 exclusive smokers and conducted 26-day ecological momentary assessment with two ad lib use intervals. Participants were asked to reduce their cigarette consumption by 75% for one week and later to abstain completely for three days. Dual users were allowed to vape as much as they wanted. The results showed that dual users quadrupled their use of e-cigarettes during smoking reduction periods and were significantly more likely to maintain 100% reduction. More importantly, e-cigarettes reduced withdrawal symptoms especially among women.

Taken together, the field needs more studies examining the association between e-cigarette use characteristics (e.g., consumption level, flavoring) and longitudinal changes in combustible cigarette consumption and dependence symptoms in real world settings. Furthermore, given most national surveys on e-cigarette and combustible cigarette use are cross-sectional, the recent release of the second wave data of the Population Assessment of Tobacco and Health (PATH) Study (USDHHS, 2017) provides a great opportunity to address this research question using longitudinal data from a representative sample of the general population. The present study conducted secondary analysis on the PATH data to fill in this knowledge gap. We followed an adult cohort of exclusive smokers at Wave 1, and examined the association between e-cigarette use characteristics and combustible cigarette consumption and dependence symptoms at Wave 2. We adopted the Heckman 2-step selection procedure (Heckman, 1979) to deal with the potential selection bias that may contribute to the difference between smokers who used e-cigarettes and those who did not at Wave 2.

## 2. Material and methods

### 2.1. Data and study sample

The PATH study is an annual longitudinal survey conducted by the NIH and FDA on a national sample of 45,971 tobacco users and non-users (Wave 1: 2013–2014; Wave 2: 2014–2015). It has the most comprehensive collection of tobacco and e-cigarette related questions among all the existing national surveys. The present study used the Waves 1–2 data from the adult cohort. This secondary analysis included 2727 exclusive smokers who (1) had smoked cigarettes in past 12 months at Wave 1; (2) had smoked at least 100 or more cigarettes in their lifetime at Wave 1; (3) did not use any other tobacco products or e-cigarettes in past 12 months at Wave 1; and (4) did not use other tobacco products except combustible or e-cigarettes in past 12 months at Wave 2. These inclusion criteria ensured that we could follow a cohort of exclusive combustible cigarette users at Wave 1 and examine the association between e-cigarette use characteristics and combustible cigarette consumption and dependence symptoms at Wave 2, controlling for the levels of cigarette consumption and dependence symptoms at Wave 1.

### 2.2. Measures

#### 2.2.1. Primary outcome variables

We examined three outcome measures for combustible cigarette use at Wave 2 that are likely to be associated with long-term health consequences: frequency, quantity, and dependence symptoms. They served as the outcome variables of the second step of the Heckman procedure. The frequency was measured by the item: “On how many of the past 30 days did you smoke cigarettes?”. The quantity was measured by the item: “On average, on those days you smoked, how many cigarettes did you usually smoke each day?”. In terms of dependence symptoms, we used 10 items in the PATH study with the same ordinal scale of 1(not true of me at all) to 5 (extremely true of me): eight of the items were adopted from the Wisconsin Inventory of Smoking Dependence Motives (e.g., I find myself reaching for cigarettes without thinking about it); the rest two items were adopted from the Nicotine Dependence Syndrome Scale (e.g., I would find it really hard to stop smoking). Interested readers may refer to Strong et al. (2017) for details about the items and associated psychometric information. We used the mean score of these 10 items as the severity score for cigarette use related dependence symptomatology. The Cronbach alpha for this measure was 0.94 with the bivariate correlations between items ranged 0.48–0.80.

#### 2.2.2. Use of E-cigarette at Wave 2

We defined the e-cigarette users at Wave 2 as those who used e-cigarettes some days or every day in the past 30 days. This variable was