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# Bidirectional associations of e-cigarette, conventional cigarette and waterpipe experimentation among adolescents: A cross-lagged model

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## HIGHLIGHTS

- Trying e-cigarettes increases the risk of trying conventional cigarettes and waterpipe.
- Trying multiple products is more frequent than trying a single product.
- Conventional smoking prevention program did not prevent experimentation of other tobacco products.
- Tailored programs are needed to prevent the use of e-cigarette and waterpipe among adolescents.

## ARTICLE INFO

*Keywords:*
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## ABSTRACT

*Purpose:* With an increasingly diverse tobacco product market, it is imperative to understand the trajectories of product experimentation in order to design effective prevention programs. This study aims to explore the bidirectional associations of conventional cigarette, e-cigarette and waterpipe experimentation in a large adolescent sample.
*Methods:* Longitudinal assessment of conventional cigarette, e-cigarette and waterpipe use initiation was conducted in a school-based cohort of 1369 9th graders (mean age = 14.88 SD = 0.48 at baseline) during fall 2014 and reassessed 6-months later using online self-reported questionnaires. Autoregressive cross-lagged analysis within structural equation modeling framework was performed to simultaneously estimate the initiation of these products over a six-month period, controlling for age, gender, and participation in an intervention program to reduce conventional cigarette initiation.
*Results:* Tobacco product lifetime use was prevalent at baseline in the sample: conventional cigarettes (48.4%), e-cigarettes (35.8%), and waterpipe (20.8%). At six-month follow-up, trying conventional cigarettes predicted trying e-cigarette (adjusted odds ratio (AOR) = 3.78, CI95%: 2.66–5.37) and trying waterpipe (AOR = 2.82, CI95%: 2.00–3.97). Trying e-cigarette predicted trying conventional cigarette (AOR = 3.57, CI95%: 1.96–6.49) and trying waterpipe (AOR = 1.51, CI95%: 1.07–2.14). Although trying waterpipe predicted trying e-cigarette at follow-up (AOR = 2.10, CI95%: 1.30–3.40), its use did not predict trying conventional cigarette (AOR = 0.55, CI95%: 0.24–1.30).
*Conclusions:* The high rates of poly-tobacco use and the bidirectionality of tobacco product experimentation demands comprehensive tobacco control and prevention programs that address the increasingly diverse tobacco product market targeting adolescents.

## 1. Introduction

Considerable efforts have been taken to prevent smoking among adolescents, but products like electronic cigarettes (e-cigarettes) and waterpipe have created new challenges for tobacco control. E-cigarettes and waterpipe are popular among adolescents all over the world

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(Kristjansson et al., 2017; Maziak et al., 2015; U.S. DHHS, 2016), and multi-product use is increasingly common (Chaffee, Couch, & Gansky, 2017). The rising epidemic of e-cigarette and waterpipe use might be explained by the sensory properties of these products, the perceived lower harm, the context of consumption, the decreasing attractiveness of conventional cigarettes, and the lack of prevention programs targeting the public image of e-cigarettes and waterpipe (Kong & Krishnan-Sarin, 2017; Lopez, Eissenberg, Jaafar, & Afifi, 2017).

The availability of new tobacco products raises questions regarding their potential role as gateway products to conventional smoking. Despite an emerging literature on the increasing use of e-cigarettes and waterpipe and dual use of these products with conventional cigarettes, we lack data on the directionality of use, whereby limiting causal inference on their role as starter products. The main question is: How each tobacco product influences the use of other products? – without a priori assumptions that one inherently precedes the other. Only a few longitudinal studies tested whether e-cigarette experimentation predicts conventional cigarette initiation or vice versa. The vast majority of these studies focused only on adolescents living in the US (Barrington-Trimis et al., 2016; Leventhal et al., 2015; Miech, Patrick, O'Malley, & Johnston, 2017; Primack, Soneji, Stoolmiller, Fine, & Sargent, 2015; Wills et al., 2017) and one study on UK adolescents (Conner et al., 2017), hindering the generalizability of these findings to other populations. These studies demonstrated consistently that e-cigarette experimentation predicts initiation of conventional cigarette smoking and other tobacco product use among American and UK adolescents (Barrington-Trimis et al., 2016; Leventhal et al., 2015; Miech et al., 2017; Primack et al., 2015; Thomas A Wills et al., 2017; Conner et al., 2017). The effect sizes (adjusted odds ratio) of the association between e-cigarette use and later conventional cigarette smoking initiation varied between 1.75 (Leventhal et al., 2015) and 8.3 (Primack et al., 2015) in the U.S., and the only estimation that is available currently from Europe was 4.06 for UK adolescents (Conner et al., 2017).

The few longitudinal studies testing if conventional cigarette use predicts e-cigarette experimentation yielded mixed results. One US-based study reported a significant correlation between conventional cigarette ever use and later e-cigarette experimentation (Leventhal et al., 2015), while a German and a Swiss study reported no significant associations (Hanewinkel & Isensee, 2015; Surís, Berchtold, & Akre, 2015). Only one study investigated the bidirectional impact of e-cigarette and conventional cigarette experimentation, but this study did not simultaneously address the directionality in a single model (Leventhal et al., 2015).

Considerably less prospective research has focused on the connection between waterpipe and conventional cigarette use. Waterpipe smoking led to the initiation of conventional cigarette smoking among Jordanian adolescents with a dose-dependent effect (Jaber et al., 2015). Several reports from Middle Eastern adolescent cohorts yielded the same conclusion regarding the impact of waterpipe use on susceptibility or initiation of conventional cigarette use (Kheirallah, Alzyoud, & Ward, 2015; Veeranki, Alzyoud, Kheirallah, & Pbert, 2015). In a Danish study, occasional waterpipe use predicted the transition to regular cigarette smoking, but only among boys (Jensen, Cortes, Engholm, Kremers, & Gislum, 2010). Two prospective studies tested and found that cigarette smoking also predicts waterpipe initiation (Fakhari, Mohammadpoorasl, Nedjat, Sharif Hosseini, & Fotouhi, 2015; McKelvey et al., 2014) and another longitudinal study explored the bidirectional relationship between waterpipe and cigarette smoking onset (Mzayek et al., 2012). Waterpipe experimentation may be an underestimated risk factor for later conventional cigarette use, but more studies are needed to explore this association in different cultural contexts where waterpipe is less common.

The causal relationship between e-cigarette and waterpipe use is relatively neglected. We identified two relevant longitudinal studies. Leventhal et al. (2015) found that e-cigarette ever users at baseline were more likely to use waterpipe one year later. Barrington-Trimis et al. (2016) reported that among adolescent who had never used any combustible tobacco product at baseline, e-cigarette users were almost three times more likely to initiate waterpipe use. To date, we could not identify any prospective study investigating the impact of waterpipe use on future e-cigarette experimentation.

The complex association of the experimentation of various tobacco products is less studied in the European context, especially in Central and Eastern European countries in the region. The main aim of this study was to explore the bidirectional associations of conventional cigarette, e-cigarette and waterpipe experimentation in a large adolescent sample.

## 2. Methods

### 2.1. Design and participants

The present study is the secondary analysis of the data collected in a school-based, cluster randomized controlled trial designed to test a web-based multimedia program to prevent the initiation of smoking among adolescents. Detailed description of the original study design is provided elsewhere (Nădășan et al., 2017).

The study was launched in November 2014 in Tirgu Mures, Romania, with a population of 145,000. The sampling frame included all 9th grade students in the 16 high schools of the city. Because three classes from one school declined participation, the initial sample comprised 79 classes from 16 schools, including 2002 students. Due to the refusal of the participation in the follow-up or being absent on the days of questionnaire administration, the responses of 1369 students (68.4%) were included in the present report. The study was approved by the Institutional Review Board of University of Medicine and Pharmacy of Tirgu Mures. Confidentiality of the responses was ensured by assigning an eight-digit unique identification code to each student who completed the questionnaires. Individual data were linked over time using this code. The file containing the students' names and the matching identification code was accessible only to the project director and maintained separately from the data. Parents were informed about the purpose, benefits and risks of the study and all parents (100%) provided active written consent.

Students in treatment (intervention) and control conditions completed the baseline questionnaire in November 2014 (one week before intervention) and the follow-up questionnaire in May 2015 (six months after baseline, five months from the completion of the intervention, one week after the booster session). The web-based questionnaire was completed in the computer lab during one teaching hour under the supervision of trained field assistants unknown to the participants. Neither teachers nor school staff was present in the classrooms during the evaluations. Students in the intervention group received five sessions of web-based, multimedia smoking prevention education while students in the control group received no educational intervention.

### 2.2. Measures

Experimentation with cigarette smoking was measured with one question "Have you ever tried smoking (even one or two puffs)?" (yes/no). Experimentation with alternative tobacco products were assessed by: "Which of the following products have you ever tried?" Response options included "Yes" or "No" for e-cigarettes, waterpipe, cigar, pipe, chewing tobacco, snus (or other oral tobacco products), and snuff (or other nasal tobacco products). In the current analyses we focused on e-cigarette and waterpipe experimentation because other tobacco product ever use was negligible among nonsmokers in this sample (Nădăşan et al., 2016) and the use of emerging tobacco products like e-cigarettes and waterpipe are increasing among adolescents (Singh et al., 2016). Intervention/control condition, gender, and age were included in the analyses in order to control for confounding variables.

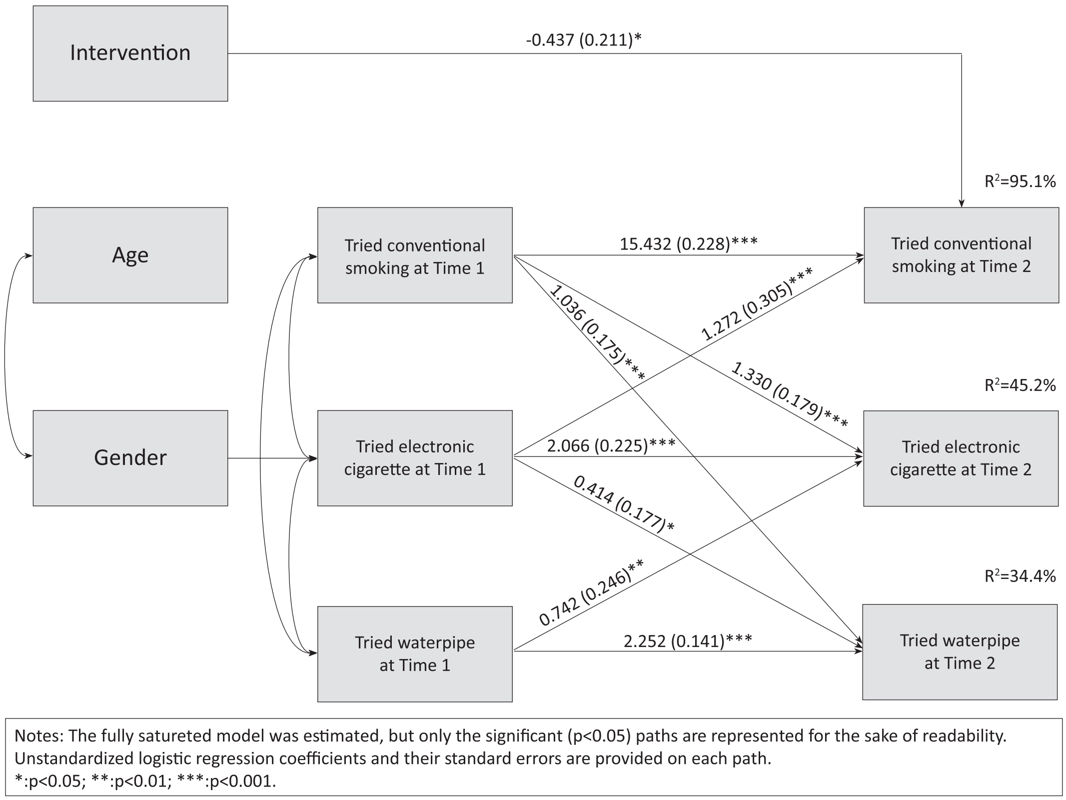


**Fig. 1.** Autoregressive cross-lagged model including conventional cigarette smoking, e-cigarette and waterpipe.

### 2.3. *Statistical analysis*

Before the main analysis, we performed descriptive statistics and univariate logistic regression analyses to estimate the unadjusted odds ratios of trying conventional cigarette, e-cigarette and waterpipe.

In order to infer how the variables measured at baseline predict variables measured at follow-up, we applied causal modeling which included cross-lagged and autoregressive components. Cross-lagged components are the focus of this analysis, while autoregressive components reflect the stability of the responses. This type of analysis makes it possible to test the reciprocal relations simultaneously (Biesanz, 2012). The autoregressive cross-lagged analysis was performed within a structural equation modeling framework using maximum likelihood estimation with robust standard errors (MLR) in the Mplus 8.0 software program. MLR is appropriate for categorical outcome variables (Muthén & Muthén, 1998). However, when used with categorical dependent variables, traditional indices of model fit (such as $\chi^2$, RMSEA, CFI, TLI, WRMR) are not available. We controlled for the design effect due to the cluster sampling and used schools as cluster units.

## 3. Results

### 3.1. *Experimentation with cigarette, e-cigarette and waterpipe: descriptive statistics*

The sample included 1369 students in the ninth grade, of which 662 (48.4%) had ever tried smoking conventional cigarettes, 490 (35.8%) had ever tried e-cigarettes and 285 (20.8%) had ever tried waterpipe at baseline. 187 (13.7%) students reported the experimentation of all three products, 246 (18.0%) reported that they have tried both conventional and e-cigarettes, and 36 (2.6%) tried only e-cigarettes at baseline. Gender was significantly associated with e-cigarette use at baseline ($\chi^2_{(1)} = 16.9$, $p < 0.001$), with boys more likely than girls to try e-cigarettes (OR = 1.59, 95%CI: 1.27–1.99). In a supplementary table, the baseline and follow-up distributions of all combination of experimentation are provided for interested readers. Of these results, we would highlight that the largest change in experimentation from Time 1 to Time 2 occurred in the group that have tried all three products.

Among 707 students who did not try conventional cigarettes at baseline, 119 (16.8%) students tried conventional cigarettes between baseline and follow-up. From 879 students who did not try e-cigarettes at baseline, 189 (21.5%) students tried them between baseline and follow-up. Out of 1084 (79.2%) students who did not experiment with waterpipe, 172 (15.9%) tried waterpipe between baseline and follow-up. From 614 students who did not try any of these three products at baseline, 93 (15.1%) tried one, 47 (7.7%) tried two, and 12 (2.0%) tried all three products at follow-up.

Experimenting with conventional cigarettes at baseline increased the likelihood of trying both e-cigarettes ($OR_{unadjusted} = 5.36$, 95%CI: 3.80–7.57) and waterpipe ($OR_{unadjusted} = 3.87$, 95%CI: 2.74–5.47) at follow-up. Trying e-cigarettes at baseline increased the odds of experimenting with both conventional cigarettes ($OR_{unadjusted} = 2.75$, 95%CI: 1.52–4.96) and waterpipe ($OR_{unadjusted} = 3.34$, 95%CI: 2.38–4.68). Trying waterpipe at baseline increased the odds of experimenting with e-cigarettes ($OR_{unadjusted} = 3.11$, 95%CI: 1.91–5.04), but was unrelated to conventional cigarette experimentation ($OR_{unadjusted} = 0.92$, 95%CI: 0.44–1.93).

### 3.2. *Cross-lagged analysis of change in experimentation with conventional cigarettes, e-cigarettes and waterpipe*

We applied the cross-lagged analysis within structural equation modeling framework to test the reciprocal relations among conventional cigarette, e-cigarette and waterpipe experimentation simultaneously. The fully saturated model was estimated, and the model including only the significant paths is depicted in Fig. 1. The correlation

**Table 1**
Correlation matrix of study variables.

| | Gender | Age | Tried conventional smoking at Time 1 | Tried conventional smoking at Time 2 | Tried electronic cigarette at Time 1 | Tried electronic cigarette at Time 2 | Tried waterpipe at Time 1 | Tried waterpipe at Time 2 |
|---|---|---|---|---|---|---|---|---|
| Age | − 0.08** | | | | | | | |
| Tried conventional smoking at Time 1 | 0.02 | 0.05 | | | | | | |
| Tried conventional smoking at Time 2 | 0.03 | 0.04 | 0.84** | | | | | |
| Tried electronic cigarette at Time 1 | − 0.11** | 0.04 | 0.60** | 0.53** | | | | |
| Tried electronic cigarette at Time 2 | − 0.06* | 0.03 | 0.53** | 0.57** | 0.60** | | | |
| Tried waterpipe at Time 1 | − 0.04 | 0.01 | 0.33** | 0.27** | 0.40** | 0.34** | | |
| Tried waterpipe at Time 2 | − 0.04 | − 0.02 | 0.35** | 0.35** | 0.35** | 0.41** | 0.52** | |
| Intervention | − 0.11** | − 0.02 | − 0.08** | − 0.10** | − 0.04 | − 0.07* | − 0.05 | − 0.01 |

* $p < 0.05$.
** $p < 0.01$.

matrix of the variables included in the model is presented in Table 1. Trying conventional cigarette at baseline predicted trying e-cigarettes (adjusted OR (AOR) = 3.78, 95%CI: 2.66–5.37) and trying waterpipe (AOR = 2.82 95%CI: 2.00–3.97) at follow-up. Trying e-cigarettes at baseline predicted trying conventional cigarettes (AOR = 3.57, 95%CI: 1.96–6.49) and trying waterpipe (AOR = 1.51, 95%CI: 1.07–2.14) at follow-up. Finally, trying waterpipe predicted trying e-cigarettes (AOR = 2.10, 95%CI: 1.30–3.40), but did not predict trying conventional cigarettes (AOR = 0.55, 95%CI: 0.24–1.30) at follow-up.

The smoking prevention intervention had an impact only on conventional cigarette smoking (AOR = 0.65, 95%CI: 0.43–0.98) as it was reported previously (Nădășan et al., 2017), but had no significant effect on either trying e-cigarettes (AOR = 0.81, 95%CI: 0.60–1.11) or trying waterpipe (AOR = 1.17, 95%CI: 0.65–2.11). Gender was associated with e-cigarette experimentation only at baseline. Age was not associated with trying any of the three products neither at baseline nor at follow-up.

### 3.3. Differential attrition analysis

To determine if there was differential attrition in the sample, we conducted an assessment of baseline characteristics of participants who completed versus those who did not complete the study. We observed differences between the two groups on academic achievement, peer smoking, ever smoking, and current smoking. Dropouts were more likely to have low grades (36.9% vs. 28.0%), to report having more friends who smoke (37.6% vs. 30.7%), to be ever smokers (63.7% vs. 48.4%), and to be current smokers (32.2% vs. 21.4%) compared to those who completed the study. There were no significant differences between the two groups regarding age, gender, ethnicity, depressive symptoms, sensation seeking, and intention to try smoking during the next year. For additional information on attrition see Nădășan et al., 2017.

## 4. Discussion

Adolescents from Central and Eastern European countries have a lifetime smoking prevalence ranging from 39.2% (the Republic of Moldova) to 58.8% (Bulgaria) according to the Global Youth Tobacco Survey (Hipple, Lando, Klein, & Winickoff, 2011). Moreover, data from the 2011 European School Survey Project on Alcohol and Other Drugs indicates that both lifetime and past 30 days smoking prevalence among youth could be even higher than estimated in the Global Youth Tobacco Survey (Hibell, Guttormsson, Ahlström, et al., 2012). Our results support the claim that e-cigarette use may facilitate experimentation of other tobacco products including conventional cigarettes. Only a few previous longitudinal studies in the United States and United Kingdom tested and demonstrated that trying e-cigarettes increases the risk of future conventional cigarette smoking (Barrington-Trimis et al., 2016; Conner et al., 2017; Leventhal et al., 2015; Miech et al., 2017; Primack et al., 2015; Wills et al., 2017). In a meta-analysis of nine studies that evaluated the use of e-cigarettes and cigarette smoking initiation of adolescents and young adults, Soneji et al. (2017) reported that e-cigarette ever use was strongly associated with a higher pooled odds of subsequent cigarette smoking initiation (pooled OR 3.62, 95%CI, 2.42–5.41). We are not aware of any study in Central Europe reporting similar results. We also found that trying e-cigarettes significantly increased the odds of trying waterpipe. Similar results were reported in two previous studies from the US (Barrington-Trimis et al., 2016; Leventhal et al., 2015) reinforcing the generalizability of this findings. While this study suggests that e-cigarette experimentation facilitates conventional cigarette and waterpipe trial, we cannot address whether and how e-cigarettes serve as a gateway to regular use, which is a critical importance to public health. Moreover, a large proportion of students tried at least two different products, rather than a single product. Thus, a larger sample with multiple observations is needed in order to understand simultaneous poly-tobacco use.

The explanation of these associations can be multiplex. Among nonsmoker adolescents, students who experiment with e-cigarettes may be more novelty and sensation seekers (Hanewinkel & Isensee, 2015; Primack et al., 2015; Wills, Knight, Williams, Pagano, & Sargent, 2015) that fuels their interest in trying other products, such as conventional cigarettes and waterpipe. However, some studies found that individuals who only use e-cigarettes have conventional values and are less prone to problem behavior compared to persons who experiment with conventional cigarettes and other tobacco products (Kristjansson et al., 2017; Primack et al., 2015; Wills et al., 2015). Consequently, youth who only use e-cigarettes are generally at lower or intermediate risk of susceptibility to substance use. Once they became e-cigarette lifetime user, however, their willingness to smoke conventional cigarettes increases dramatically (Barrington-Trimis et al., 2016; Bunnell et al., 2015; Leventhal et al., 2015; Park, Seo, & Lin, 2016; Primack et al., 2015; Wills et al., 2015). Our results suggest that a similar process might also occur in waterpipe experimentation.

One possible explanation of increased susceptibility to novel and conventional tobacco use is that trying e-cigarettes may change the risk perceptions regarding the harmful effects of these products. Recent studies consistently found that nonsmokers who used e-cigarettes perceived these products to be less harmful to health (Amrock, Zakhar, Zhou, & Weitzman, 2015; Cooper, Harrell, Pérez, Delk, & Perry, 2016; Gorukanti, Delucchi, Ling, Fisher-Travis, & Halpern-Felsher, 2017; Wills et al., 2015) and downgrade the health risks of conventional cigarette smoking compared to their counterparts who never tried e-cigarettes (Miech et al., 2017). Positive sensory experiences of vaping, including the pleasant taste and attractive device designs, might initiate a desensitization process towards perceived reduced health risks of e-cigarettes and other tobacco products (Kong, Morean, Cavallo, Camenga, & Krishnan-Sarin, 2015; Miech et al., 2017; Patrick et al., 2016; Pepper, Ribisl, & Brewer, 2016). Many adolescents perceive waterpipe use as less harmful than other tobacco products (Akl et al., 2015), therefore it is plausible to regard waterpipe as the second step in the desensitization process. Waterpipe and e-cigarettes share appealing perceptual components such as tempting flavors and smells, sight of the voluminous exhaled smoke or vapor, and the visual and tactile sensations of the device (Lopez et al., 2017; Patrick et al., 2016; Soule, Rosas, & Nasim, 2016) which may explain our findings that both e-cigarette and waterpipe use can serve as interchangeable initiator product for future alternative and/or conventional cigarette use.

We have also revealed that trying waterpipe increased the likelihood of trying e-cigarettes, but did not facilitate conventional cigarette experimentation directly. Surprisingly, research on e-cigarette and waterpipe use has developed relatively in isolation from each other. A rapidly accelerating growth curve is observed for published work about e-cigarettes that is not matched by that for waterpipe (Pepper & Eissenberg, 2014). However, our study implies that waterpipe use can direct adolescents to experiment with e-cigarettes and vice versa and therefore needs to be included in studies that consider tobacco use initiation and progression among adolescent populations.

Although previous cross-sectional studies have reported that waterpipe use is associated with higher susceptibility to smoking conventional cigarettes (Jiang, Ho, Wang, Leung, & Lam, 2017; Salloum et al., 2016), and a few prospective studies have demonstrated that waterpipe use can increase the risk of susceptibility to and the rate of initiation of cigarette smoking (Jaber et al., 2015; Jensen et al., 2010; Kheirallah et al., 2015; Mzayek et al., 2012; Veeranki et al., 2015), our prospective study did not support the impact of waterpipe use on smoking initiation. However we cannot exclude an indirect route from waterpipe use to conventional cigarette smoking through e-cigarette experimentation, although in order to test this mechanism a longer follow-up study with more measurement time points are needed.

We also observed that the intervention targeting conventional cigarette smoking did not influence either e-cigarette or waterpipe experimentation. This finding highlights the importance of developing tailored programs to prevent their use on the increasingly diverse tobacco market. Evidence-based interventions to prevent youth tobacco smoking should pay more attention to waterpipe use prevention and start incorporating e-cigarette and vaporizer use prevention (Lopez et al., 2017; U.S. DHHS, 2016). School-based tobacco interventions should be expanded with messages targeting e-cigarette and waterpipe prevention, specifically educating youth about the adverse health effects of vaping substances from e-cigarettes including nicotine as an addictive substance, flavoring chemicals and other toxicants (Gorukanti et al., 2017; Miech et al., 2017; Pepper et al., 2016).

The major strength of our study is its longitudinal design. The study design allowed our team to demonstrate the complexity of tobacco use experimentations in an increasingly diverse tobacco market, but further research is needed to explain these findings. Our study is unique in that we focused on three different tobacco products simultaneously, which yielded a more nuanced perspective in the developmental trajectory of tobacco use. The present study, however, is not without limitations. First, the present sample is limited to urban adolescents and, therefore, its generalizability to rural and minority adolescents is restricted. The accessibility to e-cigarettes and waterpipe might be different in urban and rural settings which would have an impact on the strength of the associations. Second, this study is based only on self-reported tobacco use, which might be prone to memory and response biases. Third, due to the small number of participants who reported e-cigarette-only experimentation at baseline, the observed bidirectional association between e-cigarette and conventional cigarette experimentation should be interpreted with caution. Moreover, we analyzed only experimentation and did not focus on regular use and motives of use.

The replication and extension of these findings are required to explain the complex associations between the conventional cigarette smoking and the use of non-cigarette tobacco products. Further research should focus on mediation and moderator variables of these associations in order to design effective prevention programs. Furthermore, person-oriented statistical approach such as latent class and latent transition analyses of data from a longer prospective study is required to delineate the different patterns of use during the follow-up.

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## Contributors

Valentin Nădăşan, Kristie Foley, Robert Urbán and Zoltán Ábrám designed the study and wrote the protocol. Melinda Pénzes conducted literature searches and provided summaries of previous research studies. Robert Urbán and Valentin Nădăşan conducted the statistical analysis. Melinda Pénzes wrote the first draft of the manuscript and all authors contributed to and have approved the final manuscript.

## Conflict of interest

None.

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