

Research on Influencing Factors and Intervention Strategies of Adolescent E-cigarette Use Behaviors

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Abstract

Peer interaction, online media exposure and adequate parental and school supervision are the basis of adolescent e-cigarette diffusion that has become a public health issue. Although there is increasing research on the behaviour of young people's vaping, most studies use traditional questionnaire analysis and lack a dynamic simulation of the spreading process and quantification of a hierarchical influence of multi-source risk. In addition, the interactions between various intervention strategies on the size and timing of the peak of the epidemic have not been sufficiently studied. This study is designed to discover the behavioral mechanism of the transmission of e-cigarette use among adolescents and to examine the efficacy of multi-dimensional intervention measures. The method used was a mixed-method by using a questionnaire to investigate 50 senior high school students and a SIR-ABM hybrid simulation model. Descriptive statistical analysis was applied to the adolescent risk cognition, behavioral gaps and vaping willingness. Parameter sensitivity analysis and multi-scenario simulations were also carried out to determine the key factors and to analyze the differences of intervention results. Results show that there is a knowledge-action gap among adolescents which means that a high level of hazard knowledge does not necessarily translate into action. Sensitivity analysis reveals that peer exposure is the most important driver of e-cigarette diffusion, family and school factors have a modest protective effect; single intervention strategies have a modest effect on reducing infection peaks and lengthening the time for the epidemic peak, but can lead to a delay in the peak and an increase in the duration of transmission; standalone media intervention can delay the epidemic peak and increase the duration of transmission.

Keywords

Adolescent e-cigarette use; SIR-ABM simulation model; intervention strategy.

1. Introduction

Over the past decade, electronic cigarette (e-cigarette) use has grown into a severe global public health crisis, with adolescents becoming the most vulnerable high-risk group. National and international cross-sectional surveillance data consistently document the rapid surge of youth vaping: in the United States, according to the CDC National Youth Tobacco Survey, e-cigarette have remained the most commonly used nicotine product among middle and high school students since 2014, in 2024, approximately 1.63 million US adolescents reported current e-cigarettes use, accounting for 5.9% of all middle and high school students while cross-country meta-analysis show that nearly one-sixth of global adolescents have tried e-cigarettes at least once in their youth.

In China, since the implementation of China's Regulations on Electronic Cigarettes, risks of adolescents accessing e-cigarettes through formal market channels have been effectively curbed. Nevertheless, unlicensed counterfeit and disguised fruit-flavoured e-cigarettes have

shifted to underground private circulation channels. Domestic epidemiological surveys reveal that the lifetime e-cigarettes experimentation rate among Chinese middle school students remains at around 8.2%, while the past-30-day usage rate reaches 2.6%. The spread of e-cigarettes among adolescents no longer mainly relies on offline retail, but depends heavily on interpersonal communication within campus social circles.

As a result, the overall adolescent e-cigarette experimentation rate remains high, and hidden vaping behavior within campus social groups has become increasingly prevalent.

From a health perspective, adolescent brain, respiratory and cardiovascular systems are still in development stages; nicotine contained in e-cigarette generates irreversible neurotoxicity, impairs attention and cognitive ability, and greatly raises the risk of subsequent combustible cigarette addiction and chronic respiratory diseases.

Two core social driving mechanism jointly fuel the spread of adolescent e-cigarette uptake, which have been repeatedly verified by longitudinal cohort studies and network simulation research.

First, massive youth-targeted e-cigarette marketing spreads widely on mainstream social media platforms; repeated exposure to online advertisements weakens teenagers' risk perception of nicotine products and lowers their vigilance against vaping behaviors. These advertising materials focus on popular flavors and social appeal, while intentionally glossing over the harmful effects of nicotine and long-term health effects. This can lead to desensitisation of teenagers to advertisements, as they are exposed to them so often and for so long. They gradually regard e-cigarette use as a commonplace, fashionable activity instead of a hazardous habit. Adolescents do not have the critical thinking to understand that covert marketing is not normal peer sharing, but instead a commercial. This misjudgment of risk and decreased vigilance ultimately reduces the psychological barrier to try e-cigarettes.

Secondly, adolescent peer friendship networks provide the foundation for the main diffusion pathway of vaping behaviors. Descriptive norms and injunctive norms are both significant positive factors that contribute towards the willingness of adolescents to try e-cigarettes.

Descriptive norms are the belief that vaping is common among peers, and injunctive norms are the perceived social approval of peers' vaping. Adolescents may be more likely to try e-cigarettes when people they know are vaping, as this normalizes e-cigarette use. Parental attitudes towards e-cigarettes also play a significant protective role; negative attitudes significantly decrease the adolescents' intention to use e-cigarettes.

Internationally, abundant research has explored factors driving adolescent e-cigarette uptake. Existing evidence verifies that peer social networks, parent-adolescent communication and repeated exposure to pro-vaping content on youth social media severe as critical predictors of youth vaping behaviors. Lozano et al.[1] adopted a cross-sectional questionnaire survey with generalized estimating equation models based on 4,471 Mexican middle school students who had never used tobacco products. They concluded that peer and family tobacco use, favourable societal perceptions of e-cigarettes, misperceptions that e-cigarettes carry lower health risks, exposure to online e-cigarettes ads, high sensation-seeking tendencies and alcohol consumption collectively to e-cigarettes, with peer vaping exerting a stronger product-specific effect than family use and no mediating role of general societal acceptance of e-cigarettes being validated.

On the basis of the cross-sectional findings mentioned above, Trucco et al.[2] further conducted a 15-month longitudinal study among US Latinx teenagers, comparing the long-term impacts of parental attitudes and peer norms on adolescents' subsequent actual e-cigarettes use. The study verified that parents' belief that e-cigarettes are harmful significantly reduces teenagers' likelihood of vaping later, while peer norms only generate adolescents' positive expectations of e-cigarettes and cannot directly lead to real vaping behavior.

To further unpack the psychological mechanism linking external environmental stimuli and vaping intention, [3] revealed the serial mediating pathway of online ad exposure and reduced risk perception to explain how social media drives adolescent e-cigarette use.

Building upon the mediating mechanism framework proposed by Zheng et al.[3], Lee et al.[4] carried out two-wave longitudinal data from the US PATH Study and applied multinomial and binomial logistic regression models to examine the longitudinal associations between adolescents' frequency of social media use and their subsequent e-cigarettes susceptibility, initiation and continued vaping. The study demonstrates that the frequency of social media use is a significant predictor of increases in e-cigarettes susceptibility and e-cigarettes initiation among adolescents who do not use e-cigarettes at baseline, but that social media exposure is not significantly associated with continued e-cigarettes use by youth who had already initiated e-cigarettes at baseline.

In particular, Lee et al. [4] propose a direct correlation between the social media use and susceptibility to youth vaping, but do not explain how. Previous research has found a number of common conclusions [5]. Pro-vaping posts on social media are an important risk factor for initiation of e-cigarette use among adolescents and misperceptions about e-cigarette risks are an important cognitive mediator. Furthermore, peer and familial contexts are verified to be pivotal social determinants [6].

Nevertheless, notable divergences remain. Scholars hold different views on whether peer norms can directly trigger actual vaping conduct. However, conventional statistical approaches including regression, SAOM and mediation models are retrospective analytical tools that merely interpret correlational associations derived from historical survey data, with no capacity to forecast future trends of adolescent vaping. In contrast, the SIR dynamic simulation model addresses this gap in two key ways [7]. First, it categorizes the population into: susceptible individuals(S), infectious vapers(I), and recovered ex-users(R) to simulate the full vaping cycle, and forecasts long-term vaping spread speed and peak prevalence.

Adolescent e-cigarette use is strongly contagious within peer social networks. Most existing intervention strategies are universal rather than targeted. Few schemes are precisely designed to cut off transmission pathways based on the social spread characteristics of adolescents e-cigarettes use. Without targeted and effective intervention, vaping behaviors will continuously spread among teenagers and expand the high-risk youth group. Therefore, exploring the spreading rules of adolescent e-cigarette use and verifying the effectiveness of different intervention strategies is of great practical significance. It can provide scientific evidence and systematic guidance for school prevention management and social tobacco control policy formulation [8].

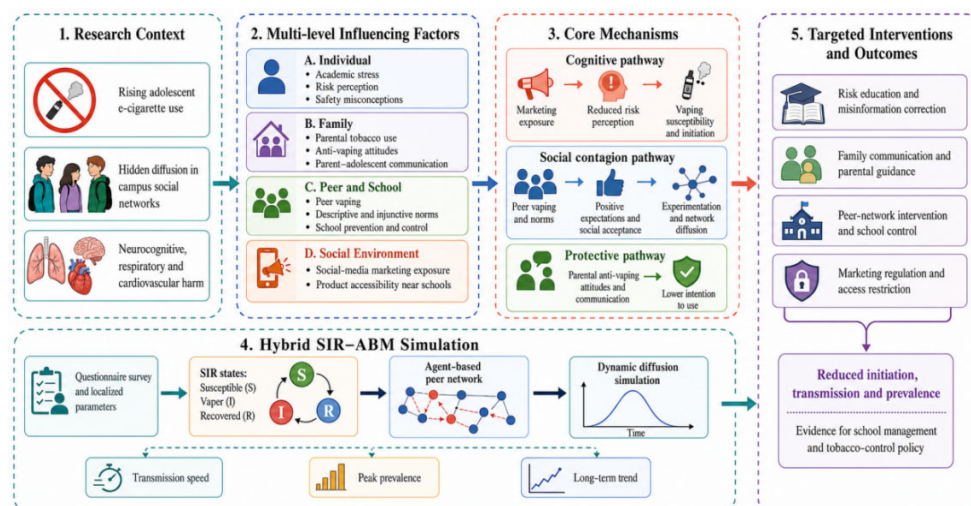


Figure 1. Research framework

Against such a research backdrop, this study integrates the SIR epidemic model and agent-based modelling (ABM) to construct a hybrid simulation framework, taking social contagion as the core perspective, this paper simulates the transmission process of adolescent e-cigarette use and further evaluates the practical effects of multiple intervention strategies.

2. Methodology

2.1. Overall research design

The design of this study is a sequential explanatory type of mixed methods. At the first phase, a questionnaire survey is carried out on the adolescents. It examines multi-dimensional influencing factors of adolescent e-cigarette use behavior on one hand and collects empirical data such as population structure, social interaction characteristics and behavioural probability on the other hand, and provides the parameters for the next stage of modeling according to the local situation. In the second phase, a hybrid model of SIR-ABM is built. Questionnaire results are used to import parameters into the simulation system that simulate the hidden peer-to-peer diffusion process of e-cigarettes in adolescent social networks. Various intervention scenarios are modeled and contrasted to investigate targeted interventions to interrupt transmission.

2.2. Questionnaire survey

Table 1. Questionnaire Questions

No.	Dimension	Item stem	Response options (coded)	Variable role
Q1	Demographics	Current grade	1 = Grade 10; 2 = Grade 11; 3 = Grade 12	Control
Q2	Demographics	Sex	1 = Male; 2 = Female	Control
Q3	Demographics	On-campus accommodation	1 = Day attendance; 2 = Boarding	Control
Q4	Individual	Level of academic pressure in daily life	1 = Very low; 2 = Moderate; 3 = Very high	Risk (r)
Q5	Individual	Awareness that e-cigarettes contain nicotine and can cause irreversible lung damage	1 = Completely unfamiliar; 2 = Slightly aware; 3 = Completely clear	Protection (p)
Q6	Individual	Agreement that e-cigarettes are harmless and healthier than cigarettes	1 = Disagree; 2 = Not sure; 3 = Strongly agree	Risk (r)
Q7	Family	Tobacco or e-cigarette use by co-resident parents or relatives	1 = Neither; 2 = Cigarettes only; 3 = E-cigarettes only; 4 = Both	Risk (r)
Q8	Family	Parents explain the dangers of e-cigarettes and prohibit contact	1 = Never mentioned; 2 = Mentioned briefly; 3 = Systematic guidance with strict rules	Protection (p, f)
Q9	Family	[TO SUPPLY: parent-child communication item, reported in the analysis but absent from the original table]	[TO SUPPLY]	Protection (p, f)
Q10	School	Lectures or themed activities on e-cigarette hazards per semester	1 = Never held; 2 = Once or less; 3 = Twice or more	Protection (p, s)
Q11	School	Strict on-campus inspection with clear penalty rules	1 = No management; 2 = Occasional inspections; 3 = Strict inspections with enforced penalties	Protection (p, s)
Q12	External	Number of close friends and classmates who use e-cigarettes	1 = Nobody; 2 = 1-3 people; 3 = Many	Risk (r, e)
Q13	External	Frequency of seeing e-cigarette promotion on short-video or social media platforms	1 = Never seen; 2 = Occasionally; 3 = Frequently	Risk (r, m)
Q14	External	Ease of buying e-cigarettes at shops near the school	1 = Cannot buy at all; 2 = Only secretly; 3 = Can buy casually	Risk (r)
Q15	Behaviour	Ever tried e-cigarettes	1 = Never tried; 2 = Tried once or twice; 3 = Frequent long-term use	Outcome (I)
Q16	Behaviour	Ever taken action to resist e-cigarettes and curb their spread	1 = No; 2 = Occasionally remind others; 3 = Regularly call on others	Outcome (R); p
Q17	Behaviour	Irritability and craving after a long period without use	1 = Not at all; 2 = Slight craving; 3 = Strong urge	Dependent indicator (u)

2.3. Statistical analysis and composite indices

The questionnaire platform reported 63 valid responses for aggregate frequency and percentage summaries. The individual-level workbook available for respondent-level analysis contained 50 complete records. Accordingly, aggregate descriptive statements use $n=63$, whereas group comparisons, correlations, regression, index construction and agent heterogeneity use $n=50$. These denominators were analysed separately and were not pooled.

Categorical distributions were summarized using counts and percentages. Differences in risk and protection profiles were examined across the three Q15 use categories. Direction and strength of monotonic associations were assessed using Spearman's rank correlation. Associations between categorical predictors and Q15 use status were summarized using bias-corrected Cramér's V with bootstrap 95% intervals. A simplified exploratory logistic model defined any e-cigarette use as $Q15>1$ and included the standardized exposure, education protection, harm-awareness and academic-pressure indices. Because only 50 complete individual records were available, coefficient estimates were interpreted as association measures rather than causal effects.

To place ordered questionnaire items on a common scale, response q_{ij} for respondent i and item j was rescale to x_{ij} in $[0, 1]$, where K_j denotes the number of response categories:

$$x_{ij} = \frac{q_{ij}-1}{K_j-1} \quad (1)$$

The risk index r_i combined academic pressure (Q4), belief in e-cigarette harmlessness (Q6), household tobacco exposure (Q7), peer exposure (Q12), media promotion exposure (Q13) and retail access (Q14):

$$r_i = \frac{x_{i4}+x_{i6}+x_{i7}+x_{i12}+x_{i13}+x_{i14}}{6} \quad (2)$$

The protection index combined harm awareness (Q5), parental education (Q8), parent-child communication (Q9), school education (Q10), school enforcement (Q11) and resistance behaviour (Q16):

$$p_i = \frac{x_{i5}+x_{i8}+x_{i9}+x_{i10}+x_{i11}+x_{i16}}{6} \quad (3)$$

The equal-weight construction was chosen to keep the small-sample model transparent and reproducible. Consequently, the indices represent study-specific summary scores rather than validated clinical scales.

2.4. Operational definition of the SIR behavioural states

The classical SIR labels were used as behavioural analogues rather than biomedical diagnoses. The susceptible state (S) comprised respondents who were not regular users and did not meet the resistance/protection rule. The use state (I) was assigned when Q15 indicated long-term regular use or Q17 indicated a strong craving. Among respondents not assigned to I, the resistant/recovered state (R) was assigned when Q16 indicated at least occasional resistance behaviour or when the protection index was at or above the sample median. All remaining respondents were assigned to S.

This operational classification separates current behavioural adoption from susceptibility and observable protection. R therefore denotes a comparatively resistant or recovered behavioural

condition; it does not imply permanent immunity. The cross-sectional state composition is descriptive and is not treated as an observed longitudinal transition history.

2.5. Survey-informed non-network heterogeneous SIR-ABM

The agent-based model represents each adolescent as an autonomous agent with a fixed profile sampled from the 50 complete records. Each profile contains the risk and protection indices together with normalized peer exposure e_i , media exposure m_i , family protection f_i , school protection s_i and craving u_i . For every simulation replicate, 500 agents were sampled with replacement, preserving the observed combination of individual characteristics while avoiding claims that the 50 respondents form a population-representative cohort.

All intervention scenarios used the same prospective initialisation. Five per cent of agents with the highest risk scores were assigned to I, five per cent of the remaining agents with the highest protection scores were assigned to R, and the other 90% were assigned to S. The model contains no adjacency matrix, network centrality or node-level transmission path. Instead, z_t , the population proportion in I at period t , provides a mean-field behavioural exposure term. Q12 remains an individual peer-exposure covariate and does not define a relationship edge.

2.6. State-transition mechanism

At each discrete period, the transition probability of an agent depends on its current state, its fixed questionnaire-derived profile and the current population share z_t in I. Background susceptibility and targetable exposure channels were combined into the adoption force A_i :

$$A_i = 0.30 + 0.22r_i + 0.18w_e e_i + 0.12w_m m_i + 0.16w_u u_i \quad (4)$$

Here w_e , w_m and w_u are scenario-specific multipliers for peer exposure, media exposure and craving. Protection that promotes movement out of the use state was represented by B_i :

$$B_i = 0.45 + 0.18p_i + 0.18w_f f_i + 0.18w_s s_i \quad (5)$$

where w_f and w_s modify family and school protection. Given these forces, the permitted state-transition probabilities were:

$$P_{S \rightarrow I, i, t} = \min\{0.92, \beta(0.22 + 1.75z_t)A_i\} \quad (6)$$

$$P_{I \rightarrow R, i, t} = \min\{0.92, \gamma B_i\} \quad (7)$$

$$P_{R \rightarrow S, i, t} = \min\{0.45, \rho(0.45 + 0.28r_i + 0.18w_u u_i)\} \quad (8)$$

Parameter β scales movement from S to I, γ scales movement from I to R, and ρ scales the loss of protection from R to S. The upper bounds prevent probabilities from exceeding plausible numerical ranges in one period. A Bernoulli draw determines whether the permitted transition occurs; otherwise the agent remains in its current state. The R→S channel makes the implementation an extended SIR-ABM and represents waning behavioural protection, not clinical relapse.

3. Results

3.1. Sample characteristics and e-cigarette use status

The questionnaire platform returned 63 valid responses, which are used for all aggregate frequency and percentage summaries reported in Sections 3.1 and 3.2. The individual-level

workbook available for respondent-level analysis contained 50 complete records, which are used for the association analysis reported in Section 3.3. The two denominators were analysed separately and were not pooled, and the applicable denominator is stated with every reported statistic. Figure 2 summarises adolescent e-cigarette use status (Q15) together with sample demographic characteristics (n = 63). Of the respondents, 47.6% had never tried e-cigarettes, 22.2% reported one or two experimental attempts and 30.2% reported regular use. Respondents spanned Grades 10 to 12 (27.0%, 41.3% and 31.7% respectively), 57.1% were male and 76.2% were day students. Most students reported moderate academic pressure (69.8%), while 14.3% reported low and 15.9% high pressure. Two-thirds (66.7%) reported no craving to use e-cigarettes, 17.5% reported a mild craving and 15.9% a strong craving.

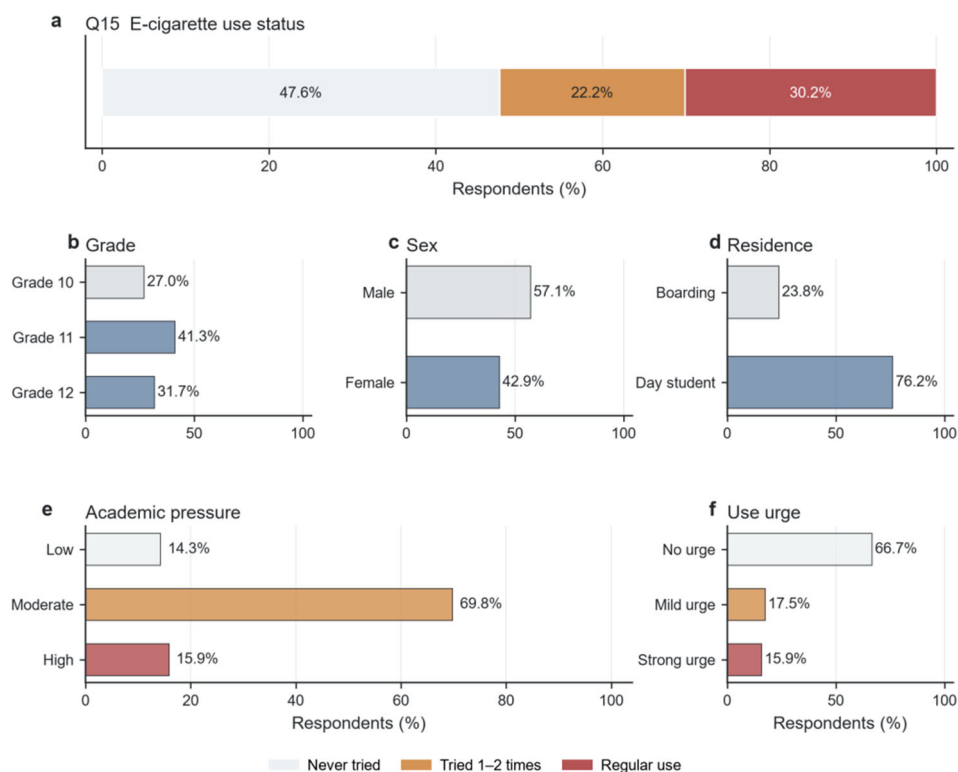


Figure 2. E-cigarette use status and sample characteristics

3.2. The gap between risk awareness and protective behaviour

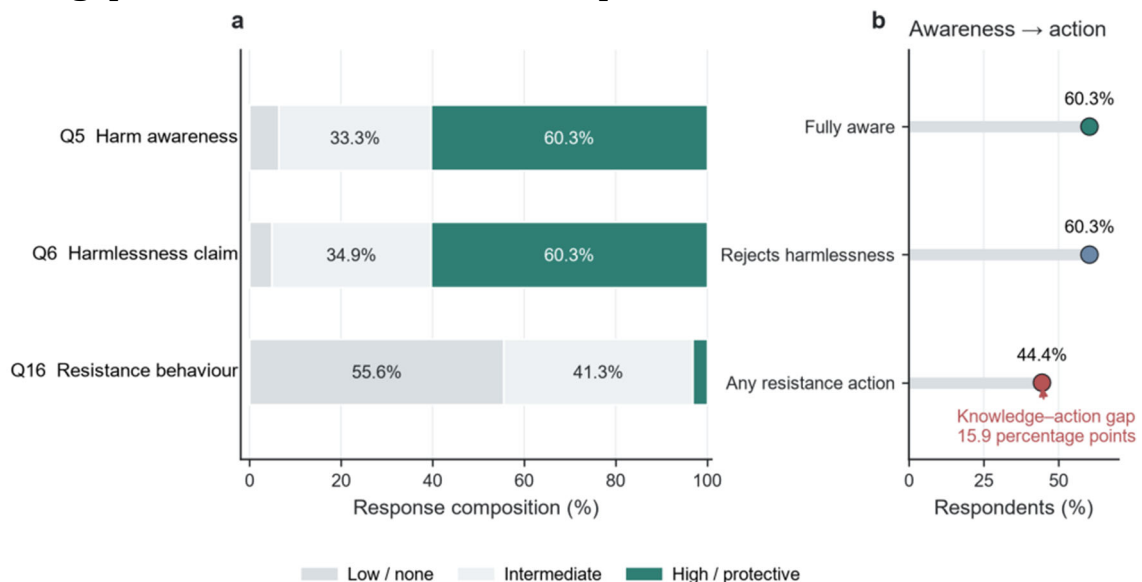


Figure 3. Risk awareness, attitude towards the harmlessness claim and resistance behaviour

Figure 3 presents participants' e-cigarette risk awareness, their judgement of the claim that e-cigarettes are harmless, and their resistance behaviour (n = 63). For Q5 (harm awareness) and Q6 (judgement on the harmlessness claim), 60.3% of respondents reached the high protective category in each item. Resistance behaviour (Q16) showed a markedly different distribution: 55.6% reported low or no resistance, 41.3% reported intermediate resistance and only 3.2% reported the highest level of protective action. Defining any resistance action as the intermediate and high categories combined gives 44.4%, against 60.3% who held protective risk perceptions. The difference of 15.9 percentage points is reported here as a knowledge-action gap. The difference between the two quantities is descriptive, meaning that it shows that the proportion of people who reported having enough hazard awareness did not correspond proportionately to the proportion of people who took concrete measures to prevent the hazard; it does not mean that those who reported having enough hazard awareness did not take concrete measures to prevent the hazard.

3.3. Bivariate associations with e-cigarette use

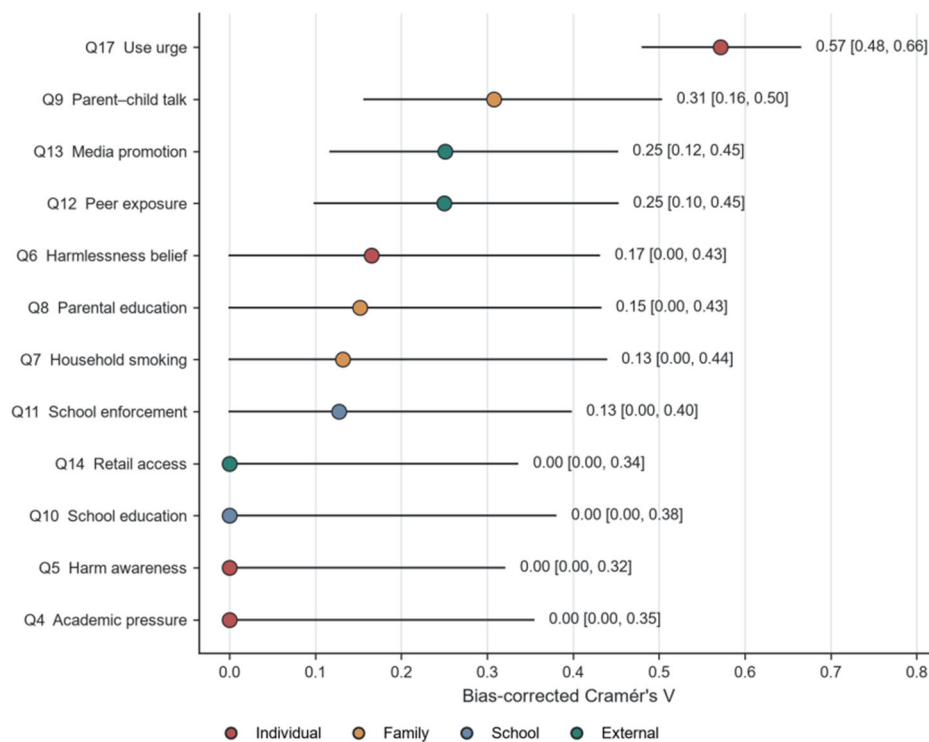


Figure 4. Bias-corrected Cramér's V with bootstrap 95% confidence intervals

Bias-corrected Cramér's V values, representing the magnitude of association between candidate influencing factors and adolescent e-cigarette use, are presented in Figure 4. The rank of the magnitude of correlation is as follows. Individual-level vaping urge (Q17, $V=0.57$ [0.48, 0.66]) showed the strongest correlation. The family factors that exerted the greatest influence were parent-child communication (Q9, $V=0.31$ [0.16, 0.50]). Media promotion exposure (Q13) and peer e-cigarette exposure (Q12, both $V=0.25$) were the strongest external environment predictors. Several other variables, such as academic pressures, awareness of harm, smoking in school, and tobacco retail availability, had Cramér's V values of 0.00, meaning there was no statistically significant relationship with the vaping behavior in this sample.

3.4. Simulated intervention scenarios

Figure 5 and Figure 6 should be viewed together to present the outputs of SIR-ABM simulations for two different intervention scenarios, which show the double impact of interventions on the

two key indicators: the maximum proportion of I-state adolescents and the time at which interventions peak. The peak magnitude and the time at which the peak occurs, for each of the strategies, are summarized in figure 4, and the continuous temporal trajectory of the I-state share during the simulation cycle is shown in figure 5. The highest proportion in the I-state is actually in the baseline scenario, which does not involve any intervention. Each of the single interventions, to families and schools, reduces the peak number of infected adolescents, with peaks at time 8, as in the baseline scenario. Independent media intervention, by contrast, decreases the peak of the infection moderately, but pushes the peak time to time 10 which suggests the e-cigarette transmission would last longer.

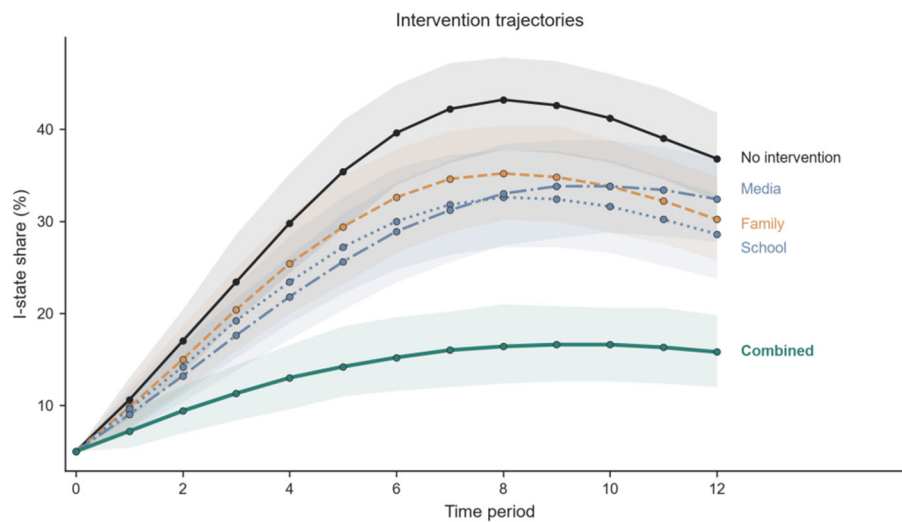


Figure 5. Simulated trajectory of the I-state share over 12 periods under each scenario

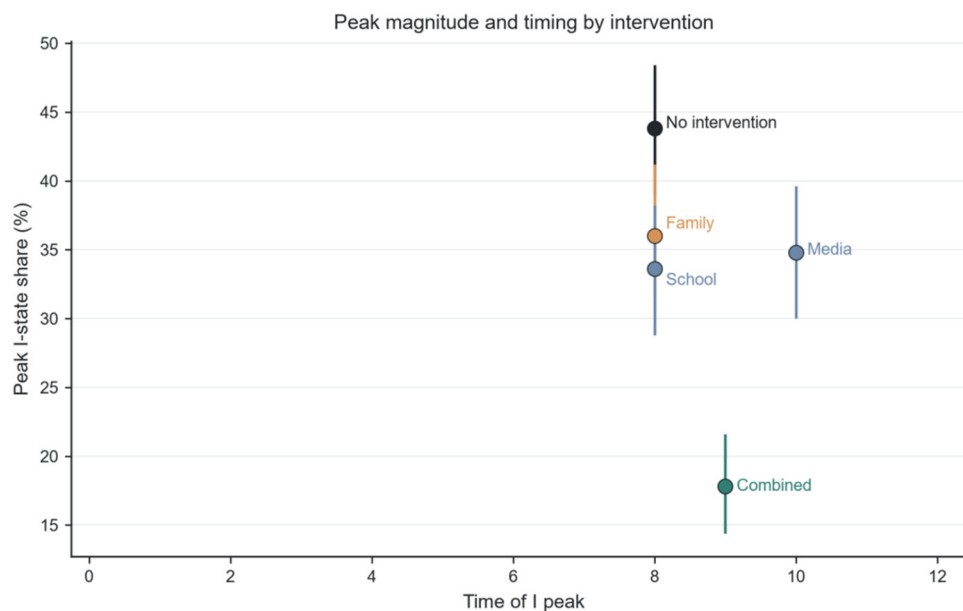


Figure 6. Peak I-state share and the period at which the peak occurs

3.5. Sensitivity analysis

The sensitivity analysis for the SIR-ABM model is shown in figure 7. The baseline parameter point in panel (a) is an I-state peak of ~43.5%. The two multipliers, peer exposure and family protection, have positive interactions: the higher they are, the higher the peak number of I-state

individuals. For the tornado diagram in panel (b), a parameter perturbation of $\pm 20\%$ is used. Peer-exposure weight causes the greatest change in the value of the transmission peak: The higher this value, the greater the transmission peak, while the lower the value, the lower the transmission peak. An increase in the family weight, school weight and a decrease in the epidemic peak are more significant, while an increase in the media-exposure weight and use-urge weight are less significant. There is an obvious order of effectiveness of intervention in panel (c). The smallest reduction at the peak is that of the single family intervention. Media and school interventions are more effective when used in combination, and the combined intervention using all domains (medium-scale) results in significantly higher peak reduction compared to any of the separate intervention strategies.

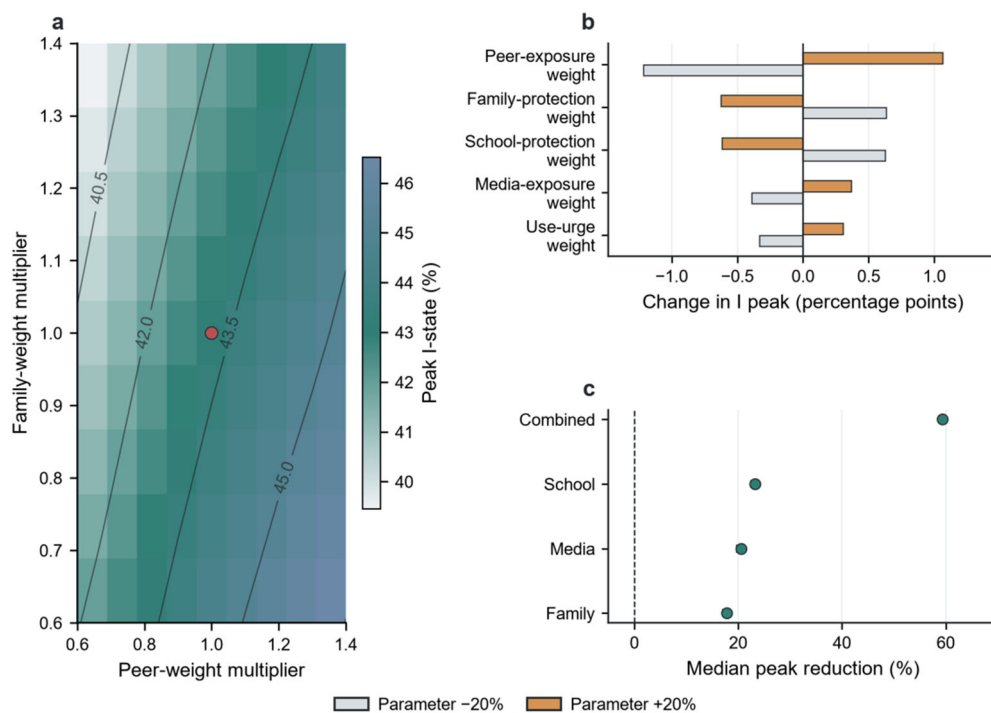


Figure 7. Sensitivity analysis of the SIR-ABM

4. Conclusion

In this study, questionnaires and the SIR-ABM model are used to dissect the transmission of e-cigarettes among adolescents. Hidden interpersonal diffusion occurs mostly through peers. There is a significant knowledge-action gap among adolescents, as knowledge of risks is not always reflected in actual preventive actions. Independent media intervention delays the prevalence peak and transmission while single intervention measures are ineffective. Integrated family-school-media intervention is the best control performance in contrast. The inspection of relevant regulatory departments should be periodic and joint to prevent underground e-cigarette sales in the vicinity of campuses. Schools need to be creative with anti-vaping education and to implement a peer advocacy programme to reduce the peer group contagion effect. Social media sites need to narrow the audit of their content and stop e-cigarette marketing information aimed at teens. Among the adolescents, they need to build a definite awareness of risks, refuse the persuasion of peers and actually discourage their surrounding behaviors of using e-cigarette, collectively curbing the e-cigarette epidemic among the adolescent population.

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