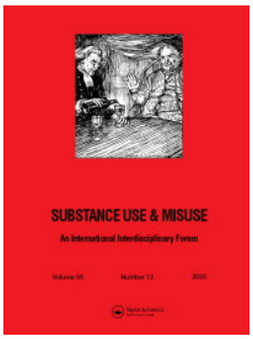

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ORIGINAL ARTICLE

Association Between E-Cigarettes, Cognition and Mood in Adolescents

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ABSTRACT

Objective: Research has indicated potentially neutral or even positive cognitive effects of e-cigarette usage in adults, but whether these findings extend to adolescents remains uncertain. This study aimed to examine the interplay between e-cigarette use, mind wandering and self-efficacy, and mood.

Method: The responses of 432 adolescents aged 11-18 years from an online survey were analyzed. Among them, 88 adolescents had used e-cigarettes.

Results: Adolescents who have used e-cigarettes reported poorer academic self-efficacy, t (430) = 3.26, 95% CI [1.12, 4.51], $p < 0.001$; greater mind-wandering tendencies $t(430) = -3.38$, 95% CI [-4.14, −1.10], $p < 0.001$; and greater severity of depression, $t(430) = -3.38$, $p < 0.001$, anxiety $t(430) = -2.67$, $p = 0.01$, and stress $t(430) = -3.32$, $p < .001$. Increased frequency of e-cigarette use was also associated with attitudes toward e-cigarette use, r (86) = 0.31, $p = 0.003$ and lower academic self-efficacy, r (86) = −0.27, p = .010. However, there was no significant correlation between frequency of use and mind-wandering. Further network analysis suggested negative relationships between frequency of e-cigarette use, academic self-efficacy and mind-wandering.

Conclusion: Our findings suggest a potential adverse impact of e-cigarette use on mind-wandering and academic confidence among adolescents. However, the direct or indirect relationship between e-cigarette use and these effects could not be definitively determined due to the cross-sectional survey design employed in our study. Nonetheless, our findings underscore the importance of considering developmental differences and the unique vulnerabilities of adolescents when assessing the impact of e-cigarette use.

KEYWORDS
e-cigarettes; cognition; mood; adolescents; perceptions

Introduction

The use of e-cigarettes has rapidly increased over the past decade, particularly among adolescents and young adults. In Australia, 34% of adolescents aged 14-17 years report having used e-cigarettes, with 14% report being current e-cigarette users (Watts et al., 2022), representing a nearly 3-fold increase in usage since 2019 (Heris et al., 2022). Evidence is mounting to show the harmful impact of e-cigarettes including cardiorespiratory and gastrointestinal complications, unintentional injury from burns and poisonings, mental health concerns, and the potential for e-cigarettes to act as a gateway to other substance use (Lechner et al., 2017; Yoon et al., 2023). However, there is a paucity of empirical literature investigating the cognitive effects of e-cigarettes, with even less evidence focused on adolescents.

Original, first-generation devices of E-cigarettes resemble cigarettes, are disposable, and contain a fixed composition of chemicals in the e-cigarette vaping liquid (Krishnan-Sarin et al., 2019). Newer, pod-based generations allow users to modify temperature and voltage, nicotine concentrations, and flavor combinations while also being more discrete, producing less vapor and being USB-rechargeable (Krishnan-Sarin et al., 2019; Pepper et al., 2019). Animal studies showed that e-cigarette aerosol exposure impaired learning and both short- and long-term memory in rats, even in the absence of nicotine (Alzoubi et al., 2021; Chen et al., 2021; Golli et al., 2016). Much of the empirical research of e-cigarettes focuses on cigarette smokers, with few studies isolate the actual effect of e-cigarettes from nicotine, either as a nicotine replacement device or in the absence of nicotine. Recent review on e-cigarettes suggest that the acute cognitive effect of e-cigarettes on regular cigarette smokers appears minimal, but long-term cognitive effect and their effects on never-smokers are unclear (Novak & Wang, 2024).

Evidence shows a link between inhalation exposure to e-cigarette flavoring chemicals and oxidative stress (Muthumalage et al., 2017; Tobore, 2019). Oxidative stress from e-vapor provokes an alteration of DNA repair systems and induces inflammation, contributing to the development and physiological processes of impaired neurocognitive conditions (Anderson et al., 2016; Tobore, 2019). Furthermore, oxidative stress generates excessive reactive oxygen species

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resulting in further inflammation, memory impairment and cognitive decline, particularly amongst adolescents (Anderson et al., 2016; Tobore, 2019). Evidence derived from preclinical studies show that e-cigarette aerosol exposure impaired learning and both short- and long-term memory, even in the absence of nicotine (Alzoubi et al., 2021; Chen et al., 2021).

In Australia, it is now illegal to use e-cigarettes in places where smoking cigarettes is banned, such as in restaurants and in vehicles with children (Department of Health & Aged Care, 2023b). It is also illegal to sell e-cigarettes and related products to minors (i.e., individuals under the age of 18 years old), while some states (New South Wales, Queensland, Tasmania, South Australia, and Western Australia) have laws that enable the confiscation of e-cigarettes and cigarettes from minors (Youth Law Australia, 2019). On 21 December 2020, the Australian Government Therapeutic Goods Administration announced that consumers will need a medical prescription from an Australian doctor to be able to purchase e-cigarettes and related products that contain nicotine (including from any online or overseas supplier), making it illegal to purchase any e-cigarette products containing nicotine from 1 October 2021 (Department of Health & Aged Care, 2020). However, this new reform has not done much to quell the insidious rise in e-cigarette use and appears to have encouraged a thriving black market that provides e-cigarettes containing undisclosed nicotine (Mendelsohn et al., 2023). Globally, other countries that have restricted the sale of e-cigarettes have encountered similar problems. In 2020, when the United States Food and Drug Administration developed an enforcement policy against flavored e-cigarettes that were not tobacco or menthol flavored, 78.7% of e-cigarette users in the United States simply moved to using disposable devices that were exempt from the restrictions (Hammond et al., 2022). When Great Britain restricted e-cigarette flavors in 2020, they saw an 18-fold increase in the use of disposable e-cigarette devices, increasing from 1.2% in January 2021 to 22.2% in April 2022 (Tattan-Birch et al., 2023).

As adolescence is a particularly vulnerable stage of neurocognitive development, factors that affect neurocognitive development are likely to have long-term impacts. This study will contribute to the limited empirical evidence on the cognitive effects of e-cigarettes in adolescents from an Australian perspective. Specifically, this research aimed to investigate the relationship between e-cigarette use, mind wandering and self-efficacy in academic, social, and emotional domains, and mood. We hypothesized:

i. Adolescents who have used e-cigarettes would report lower academic performance and greater mind-wandering tendencies compared to those without history of e-cigarette use;
ii. Frequency of e-cigarette use would be negatively correlated with academic performance and attention.

Method

Participants

A convenience sample of 689 adolescents (age range 11 to 18 years) responded to the survey. Given that incomplete responses were considered withdrawal of consent to participate, any incomplete survey responses were excluded from analysis ($n = 257$; 37.3% total responses). The final sample consisted of 432 adolescents ($M = 14.72$, $SD = 1.64$). Participants were most commonly aged 15 (20.1%) or 16 years (20.1%). There was an even distribution of male (45.6%) and female genders (45.6%), with 38 participants indicating trans/non-binary gender or preferred not to disclose their gender (8.8%). Participants were grouped according to e-cigarette use status, with adolescents who reported having used e-cigarettes grouped as 'ever users' ($n = 88$), regardless of whether or not they used e-cigarettes over the past 30 days. Adolescents who reported no e-cigarette use were grouped as 'never users' ($n = 344$) (Table 1).

Table 1. Participant demographic characteristics.

	All Participants	
Characteristic	*n*	%
Total participants	432	100
Gender		
Male	197	45.6
Female	197	45.6
Trans/Non-binary/Prefer not to say	38	8.8
Age[a]		
11	2	0.5
12	40	9.3
13	76	17.6
14	68	15.7
15	87	20.1
16	87	20.1
17	52	12.0
18	13	3.0

[a]$M = 14.72$, $SD = 1.64$.

Measures

The survey collected sociodemographic information, such as age and gender, as well as single question items related to perceptions of peer and parental approval of e-cigarette use, (e.g., "What level of approval do you hold of a person your age using e-cigarettes?", measured on a 3-point scale from *No disapproval*, somewhat approval, or *Strong disapproval*), and history of cigarette and e-cigarette use for self and family members (e.g., "Are there any people in your home who use e-cigarettes, cigarettes or waterpipes?", measured as either *No*, *Yes*, or *I don't know*). If participants indicated that they had personal experience with cigarette or e-cigarette use (i.e., by responding *Yes* to these questions), additional questions about their frequency of use were asked. Frequency of own substance use (e.g., "How frequently have you smoked e-cigarettes in the past 30 days") was measured on a 5-point scale from *Never* to *Every day).*

The Electronic Cigarette Attitudes Survey (ECAS): measures attitudes toward e-cigarette use and identifies factors that may contribute to the increasing use of e-cigarettes amongst adolescents (Diez et al., 2019). Items in the ECAS were derived from previous studies on the potential contributing factors, such as health risks, characteristics of e-cigarette products (e.g., taste, design, price, and accessibility) and social norms (Diez et al., 2019). For this study, the ECAS was used to identify attitudes and motivations of adolescents

toward e-cigarettes use; Cronbach's alpha (α = 0.89) represented good internal consistency.

Mind-Wandering Questionnaire (MWQ): measures the frequency of mind-wandering, defined as the interruption of task-focus by task-unrelated thoughts, regardless of whether the mind-wandering is deliberate or spontaneous (Mrazek et al., 2013). Mind-wandering is related to an individual's ability to control their cognitive resources when attempting to complete tasks, particularly when faced with distractions (Randall et al., 2014). The MWQ is a 5-item self-report questionnaire. Participants are asked to identify the frequency in which they experience each statement. Sample items include "I do things without paying full attention" and "I mind-wander during lectures or presentations". Each item is ranked on a Likert scale ranging from 1 (*almost never*) to 6 (*almost always*). Total scores range from 5 to 30, with higher scores indicating greater mind-wandering tendencies. The MWQ demonstrated sound psychometric properties, with good internal consistency and inter-item correlations (Mrazek et al., 2013). For the current study, Cronbach's alpha (α = 0.90) represented excellent internal consistency.

Self-Efficacy Questionnaire for Children (SEQ-C): measures how well children perceive their ability to carry out a desired behavior (Muris, 2001). It consists of three 8-item subscales which measure emotional self-efficacy, alongside academic and social self-efficacy respectively (Muris, 2001).

Social self-efficacy (SEQ-S) is the perceived ability to initiate and maintain peer relationships, express opinions, and assert oneself during conflict. Academic self-efficacy (SEQ-A) is the perceived ability to manage one's own learning behavior and fulfill academic expectations. Emotional self-efficacy (SEQ-E) is the perceived ability to prevent or manage negative emotions, such as feelings of worry, nervousness, or fear (Muris, 2001). Each item is ranked on a Likert scale ranging from 1 (*not at all*) to 5 (*very well*). For the current study, Cronbach's alpha scores represented good to excellent internal consistency: total SEQ-C α = 0.94, the SEQ-A α = 0.90, the SEQ-S α = 0.89, and the SEQ-E α = 0.91.

Depression, Anxiety and Stress Scale –21 (DASS21): measures symptoms of depression, anxiety, and stress in both clinical and non-clinical contexts (Lovibond & Lovibond, 1995). The DASS21 demonstrated sound psychometric properties, with Cronbach's alpha scores ≥ 0.89 for total and subscale scores (Brown et al., 1997). For the current study, Cronbach's alpha scores for each subscale represented excellent internal consistency, DASS-D α = 0.93, DASS-A α = 0.93, and DASS-S α = 0.93.

Procedure

Approval for this project was granted by the authors' institute Human Research Ethics Committee (HREC; H22REA213). Initial recruitment of participants occurred within the first author's (student researcher) own school workplace. After participation approval was granted by the school principal, parents and caregivers were provided a copy of the Project Information Statement (PIS) and researchers' contact information *via* email prior to inviting students to participate. All high school students were then invited to participate in the survey during a pastoral lesson in mid-April 2023. An email with the PIS and survey link was sent to teachers and students the morning of the pastoral lesson. Teachers read out the PIS to students and provided them time in the pastoral lesson to review the PIS themselves and complete the survey. Participants were informed that participation was voluntary, that they were able to opt out of completing the survey by closing the survey window, and that clicking 'Submit' at the conclusion of the survey indicated voluntary and informed consent to participate in the survey. The survey took approximately 15–20 min to complete. Further recruitment occurred with additional two high schools being contacted and invited to participate in the survey, with one high school accepting the invitation. This high school administered the survey to their students in mid-June 2023 in a similar manner described above.

Power analysis

A priori analyses were conducted using G*Power version 3.1.9.7 to determine appropriate sample sizes for hypothesis testing. To predict a medium effect size (f^2 = 0.15) with α = 0.05 and power (1—β = 0.80), a sample size of 144 is needed to compare group means using parametric inferential tests. This suggested sample size is large enough to also conduct correlation (suggested sample size $n = 82$) and linear regression (suggested sample size $n = 55$) analyses. A medium to large effect size aligns with previous research investigating the association between e-cigarette use and difficulties in concentrating, remembering, and making decisions in adolescents (Xie et al., 2020). This current study has sufficient power to test hypotheses based on the final sample size of 432 participants.

Data analysis

Data were analyzed using IBM SPSS statistics (Version 29) for the descriptive and inferential tests and JASP software (Version 17.3) for the network analysis. Differences between adolescent e-cigarette 'ever users' and 'never users' were examined using independent samples *t*-tests for continuous variables and Pearson chi-square (χ^2) tests for binary variables. To condense the analysis, the 12 items of attitudes toward e-cigarettes (i.e., ECAS scale) were categorized into groups that shared common properties and characteristics using the JASP network analysis. In line with groups reported in previous research (Evans-Polce et al., 2018; Harlow et al., 2022), the network analysis revealed three categories of attitudes related to convenience (ECAS items 8, 9, 10, and 12), health (items 1, 4, and 6) and personal (items 2, 3, 5, 7, and 11) motivations.

Pearson correlations were conducted between frequency of e-cigarette use, attitude of use and academic, social, and emotional self-efficacy; mind-wandering; and mood. Linear regressions were conducted to assess the predictability of frequency and attitude of use on measures of cognition and

Table 2. Independent samples t-tests comparing user status groups on sociodemographic characteristics and outcome measures.

	Never Users ($n = 344$)		Ever Users ($n = 88$)				95% CI		
Variable	*M*	*SD*	*M*	*SD*	*t*	*p*	*LL*	*UL*	Hedges's *g*
Age (in years)	14.55	1.62	15.45	1.53	**−4.58**	**< .001**	−1.29	−0.51	0.60
What level of approval do you hold for a person of your age using e-cigarettes?	1.51	0.80	2.16	0.74	**−7.09**	**< .001**	−0.83	−0.47	0.85
What level of approval do you believe that your parents or caregivers would hold of children's e-cigarette use?	1.35	0.72	1.60	0.81	**−2.71**	**.008**	−0.44	−0.07	0.35
ECAS Convenience	10.89	3.90	14.82	3.76	**−8.50**	**< .001**	−4.84	−3.02	1.01
ECAS Health	7.67	2.55	8.88	2.58	**−3.95**	**< .001**	−1.80	−0.61	0.47
ECAS Personal	11.71	4.37	15.87	4.28	**−8.02**	**< .001**	−5.19	−3.14	0.96
Academic Self-Efficacy (SEQ-A)	27.42	6.93	24.60	8.28	**3.26**	**< .001**	1.12	4.51	0.39
Social Self-Efficacy (SEQ-S)	26.93	6.59	26.60	8.36	0.34	.69	−1.31	1.97	0.05
Emotional Self-Efficacy (SEQ-E)	23.50	7.61	22.70	8.88	.847	.40	−1.05	2.65	0.10
Mind-Wandering (MWQ)	17.80	6.37	20.42	6.92	**−3.38**	**< .001**	−4.14	−1.10	0.40

Note. CI = confidence interval. *LL* = lower limit. *UL* = upper limit. ECAS = Electronic Cigarette Attitudes Survey. SEQ-A = Self-Efficacy Survey (Academic). SEQ-E = Self-Efficacy Survey (Emotional). SEQ-S = Self-Efficacy Survey (Social). MWQ = Mind-Wandering Questionnaire. Bold values indicate significant results.

mood. Additional network analyses were also conducted to visualize the dynamic interactions between frequency of e-cigarette use, attitudes, and outcome measures of cognition and mood. The Extended Bayesian Information Criterion (EBIC) was adopted as the chosen network analysis method as EBIC enhances the accuracy and interpretability of the networks (Hevey, 2018). The analysis was not pre-registered and that the results should be considered exploratory.

Results

Sociodemographic Characteristics of E-cigarette ever users and never users

'Ever users' were significantly older ($M = 15.45$ years, $SD = 1.53$) than 'never users' ($M = 14.55$ years, $SD = 1.62$), $t(430) = -4.58$, $p < 0.001$, but there was no significant difference on gender between them, $\chi^2(1, N = 432) = 2.68$, $p = 0.102$ (Table 2). Compared to 'never users', 'ever users' reported significantly greater approval of peer use of e-cigarettes, $t(430) = -7.09$, 95% CI [−0.83, −0.47], $p < 0.001$, Hedge's $g = 0.85$, and perceived parental approval to use e-cigarettes, $t(124.88) = -2.71$, 95% CI [-0.44, −0.07], $p = 0.008$, Hedge's $g = 0.35$.

Group differences on E-Cigarette Attitudes, academic performance, cognition and mood

Group comparison of attitude categories showed that 'ever users' held significantly greater positive attitudes toward e-cigarettes across all three attitude categories compared to 'never users': Convenience, $t(430) = -8.50$, 95% CI [-4.84, −3.02], $p < 0.001$, Hedge's $g = 1.01$; Health, $t(430) = -3.95$, 95% CI [-1.80, −0.61], $p < 0.001$, Hedge's $g = 0.47$; and Personal, $t(430) = -8.02$, 95% CI [-5.19, −3.14], $p < 0.001$, Hedge's $g = 0.96$.

Furthermore, e-cigarette 'ever users' reported significantly poorer academic self-efficacy, $t(430) = 3.26$, 95% CI [1.12, 4.51], $p = < 0.001$, Hedge's $g = 0.39$; and greater mind-wandering tendencies, $t(430) = -3.38$, 95% CI [-4.14, −1.10], $p = < 0.001$, Hedge's $g = 0.40$. There were no significant group differences for social or emotional self-efficacy (Table 2).

Association between frequency of E-cigarette use and attitudes toward E-cigarette use, academic performance, and cognition

Frequency of e-cigarette use was positively correlated with the personal category of attitudes toward e-cigarette use, $r(86) = 0.31$, $p = 0.003$; and negatively correlated with academic self-efficacy, $r(86) = -0.27$, $p = 0.010$ (Table 3). However, the correlations between frequency of e-cigarette use and other variables, including attitude categories of health and convenience, social and emotional self-efficacy, and mood, was not significant. More frequent e-cigarette use amongst adolescents was also significantly predictive of lower academic self-efficacy scores, $b = -1.36$, $t(88) = -2.67$, $p = 0.01$, $F(1, 86) = 6.85$, $p = 0.01$, accounting for 7.4% of the variability in academic self-efficacy scores.

The network visualization of frequency of e-cigarette use, categories of attitudes toward e-cigarettes, and outcome measures (i.e., mind-wandering; academic, social, and emotional self-efficacy; and mood) are shown in Figure 1. From the frequency of e-cigarette use node (i.e., FREQ), there were six edges illustrating the network of relationships between the FREQ node and six other variables (i.e., SEQ-A, SEQ-E, MWQ, ANX, STRESS, and PERS). There are negative relationships between frequency of e-cigarette use and academic self-efficacy (i.e., SEQ-A) and mind-wandering (i.e., MWQ), and a positive relationship between frequency of e-cigarette use and the personal attitudes category (i.e., PERS).

Discussion

Adolescents who have ever used e-cigarettes reported poorer self-beliefs in their academic capabilities and greater mind-wandering tendencies than those never users. Furthermore, increased frequency of use was associated with lower self-efficacy in academic performance. However, it should be note that although e-cigarette users reported greater mind-wandering tendencies, when other factors are taken into consideration, as in the case with the network analysis, the relationship between frequency of use and attention is more complex than a simple linear relationship.

Our network analysis showed that an increase in frequency of e-cigarette use was associated with a decrease in both mind-wandering tendencies and academic self-efficacy. This would add a great uncertainty to the interpretation of the present findings, e.g., how the direction of e-cigarette use, cognition and academic self-efficacy should be interpreted. Perhaps adolescents with low academic self-efficacy use e-cigarettes more frequently to manage the negative mental states associated with academic challenges (McLeod et al., 2012; Wyatt et al., 2017). Or the high frequency of e-cigarette use is to blame for adolescents not feeling capable of managing their own academic performance. Furthermore, as the cognitive construct of attention is so complex and multi-faceted, it is also likely that the mind-wandering questionnaire alone did not fully capture all aspects of attention in adolescents.

While few studies of adolescents show that e-cigarette use is associated with an increased risk of self-reported difficulties in concentration, remembering, decision-making, mood, and poorer academic performance, the majority of existing evidence suggests either positive or minimal cognitive effects of e-cigarette use, particularly among those with previous history of cigarette use (Dawkins et al., 2013; Dawkins et al., 2012; Wade et al., 2022). For example, a study examining the cognitive effects of vaping e-cigarettes (containing 16 mg/ml nicotine) on current cigarette smokers following overnight cessation reported that participants performed more poorly in memory task following e-cigarette use compared to using their regular brand cigarette (Kim et al., 2022). It was argued that regular cigarette smokers could not fully satiated by vaping e-cigarettes, negatively affecting individual performance (Kim et al., 2022). Combining with our present findings, this may implicate that either age, previous exposure to nicotine, or both, could modulate the actual effect of e-cigarettes on cognition. In fact, research shows that there are age-dependent behavioral responses induced by nicotine, with adolescents being more sensitive to nicotine's reward effects (Yuan et al., 2015). At present, most adolescent e-cigarette users typically are not cigarette smokers or ex-smokers (i.e., are not using e-cigarettes as a means to cut back on cigarette smoking); therefore, it is likely that they are more vulnerable to the side effects of nicotine and would be affected by e-cigarettes if harmful cognitive effects existed. More recently, animal studies have found that extended exposure to e-cigarette vapor impaired learning (as measured by short- and long-term memory) and resulted in brain chemistry changes that were consistent with reduced cognitive function and increased inflammation from oxidative stress (Alzoubi et al., 2021), independent of nicotine exposure (Chen et al., 2021). This suggests a link between the inflammatory nature of e-cigarettes and cognitive impairments that are beyond our previous understanding of nicotine (Tobore, 2019).

Furthermore, we found that young people who were primarily in favor of e-cigarettes for personal reasons tended to report more frequent use. This finding was consistent with previous research showing personal reasons (e.g., customizable attributes of e-cigarette devices and an appealing range of flavors) resulted in more frequent e-cigarette use compared to health reasons (e.g., to cut back or quit smoking cigarettes), or for the convenience of e-cigarettes over cigarettes (e.g., being able to use e-cigarettes more discreetly than smoking cigarettes; (Harlow et al., 2022). Research on substance use amongst adolescents shows that cognitions, such as more positive attitudes and social norms, were found

Table 3. Pearson correlations between e-cigarette use frequency, attitude categories and outcome measures.

Variable	*M*	*SD*	Frequency of E-Cigarette Use
Frequency of E-cigarette use	1.68	1.65	
ECAS Convenience	11.92	4.04	.15
ECAS Health	7.48	2.66	.02
ECAS Personal	11.61	4.72	.31**
Academic Self-Efficacy (SEQ-A)	24.60	8.28	−0.27*
Social Self-Efficacy (SEQ-S)	26.60	8.36	−0.17
Emotional Self-Efficacy (SEQ-E)	22.70	8.88	−0.06
Mind-Wandering (MWQ)	20.42	6.92	−0.15
Mood (DASS - total)	54.55	33.79	.19

*$p < .05$. **$p < 0.01$.

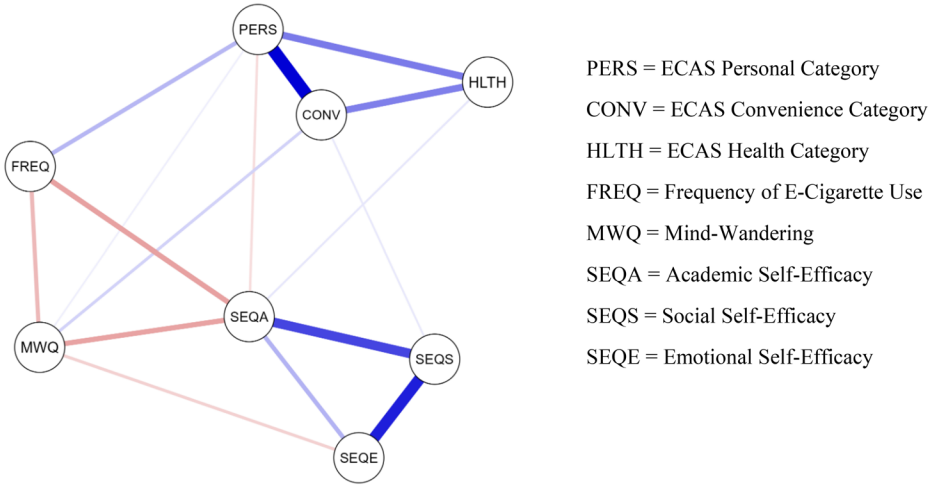

Figure 1. EBIC Network for Frequency of E-Cigarette Use, Categories of Attitudes, and Outcome Measures.
Note. Blue lines indicate positive relationships between items. Red lines indicate negative relationships between items. Thicker lines indicate stronger relationships between items. EBIC = Extended Bayesian Information Criterion method.

to be the most influential predictors of substance use related behaviors amongst adolescents (Mazloomy Mahmoodabad et al., 2019). Both peer and family members' e-cigarette use could influence the adolescents' choice to use e-cigarettes by shaping their attitudes toward them, such as whether e-cigarettes are desirable or not (Akers & Lee, 1996; Hoffmann, 2021; Rocheleau et al., 2020). While adults primarily use e-cigarettes for health reasons (e.g., to cut back on cigarette smoking), adolescents are attracted to the myriad of flavors and the experimentation and exploration of a new device (Evans-Polce et al., 2018; Khouja et al., 2020). Evidence shows that drug effects can be modulated by user expectancy (Oken et al., 2008). Perhaps, cognitive effect of e-cigarettes might also be related to purpose of use.

Conclusions from this study need to be draw while considering limitations. The network analysis only identified interactions between limited factors. Further analysis of the strength of edges between nodes within the network could uncover additional complexities within the connections. There were several incomplete participant responses, which resulted in data being excluded from analysis. Participants who did not complete the survey (i.e., those who withdrew consent to participate) might be the participants that need more attention. As such, although the current sample size had sufficient statistical power, it would be valuable to consider more personal research methods and recruitment strategies to maximize the response rate in future research (e.g., conducting a survey within social group or club settings, qualitative interviews, or experimental designs). Participants were primarily located in Queensland (94.0%), with only two schools participating in the project. The impact of geographic region and education setting was not assessed. Furthermore, we did not examine history of e-cigarette use (e.g., age of initiation or length of use) and other potential confounding variables (e.g., physical wellbeing, education level, or nicotine exposure levels), which would need to be controlled for when conducting a more thorough exploratory analysis of the cognitive effect of e-cigarettes amongst adolescents. For example, adolescents with adverse childhood experiences are more likely to use e-cigarettes (Melka et al., 2019) and also experience cognitive problems (Hawkins et al., 2021). As such, the population validity of this study may be reduced, and the representativeness of this sample needs to be taken into consideration when generalizing these conclusions to a broader adolescent population. Although some self-report measures of cognition are reported to be more likely to better capture cognitive impairments associated with daily functioning compared to lab-based neurocognitive measures (Albein-Urios et al., 2018; Cyders & Coskunpinar, 2011), they are not without their limitations. Self-report measures are open to response bias and social desirability bias, which may be more exaggerated in an adolescent population responding to potentially anti-social behaviors, such as substance use, particularly if they have concerns about being identified from their responses. Finally, this cross-sectional self-report survey study does not enable causative conclusions to be drawn between e-cigarette use and cognitive functions because a temporal sequence cannot be established, nor does it allow for long-term observations to be made.

Despite limitations, this study provides support for theoretical and practical implications that can guide future research. This study highlights the importance of social norms and individual perceptions of e-cigarette use and alerts us to the potential adverse effects of e-cigarettes on academic performance, attention, and mood. Substance use by parents and other family members, and peers may impact a child's social norm, expose them to secondhand smoke or vapor, increase substance use expectancies and susceptibility, and potentially increase their risk of initiation and progression to regular use of e-cigarettes. A collective effort is required by policy makers, parents, schools, and young people to create a public health model of limiting exposure, drawing awareness to health effects, and eliminating advertising and product packaging that is appealing to and marketed toward an adolescent demographic. It is therefore recommended that future research focus on longitudinal effects of e-cigarettes, particularly targeting adolescents during their vulnerable stage of brain development. Furthermore, a large-scale, nationally representative sample to include participants from all states and territories, and from varying sociocultural demographics would improve the generalizability of conclusions and capture data that better represents Australian adolescents.

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