

Cannabis vape product sales in California following CDC's initial advisory about lung injuries

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Abstract:	<p>Introduction: The 2019 outbreak of e-cigarette or vaping product use-associated lung injury (EVALI) is believed to have been caused by vitamin E acetate, an additive used in some cannabis vaporizer products. Previous studies have primarily focused on changes in sales of electronic nicotine delivery systems (ENDS) following the initial advisory issued by the Centers for Disease Control (CDC) on August 17, 2019. The present study is intended to examine variation by age groups in sales of regulated cannabis vape products in the state of California before, during and after the outbreak.</p> <p>Methods: Weekly sales revenue of cannabis vape products (1/1/2018-12/31/2020) were obtained from a sample of licensed California adult-use cannabis retailers. An interrupted time series analysis, using ARIMA methods, was employed to estimate changes in the sales and market share of cannabis vape products in the weeks following the CDC advisory.</p> <p>Results: The total volume of regulated cannabis vape product sales increased substantially over the three-year study period (2018-2020). However, the market share of cannabis vape products declined in both younger adults (23-25 years) and older adults (>25 years) immediately following the advisory, rebounding to pre-EVALI levels only for younger adults. For older adults, a 20% decline in market share of cannabis vape products was observed over the twelve weeks following the EVALI advisory.</p> <p>Conclusions: The differential age effect on sales may reflect concerns regarding health effects of cannabis vaping products and greater awareness of the outbreak amongst older adults. Findings highlight the importance of informing consumers about health risks associated with using cannabis vape products acquired from regulated versus illicit</p>

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1 EVALI and cannabis vape sales
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3 **Cannabis vape product sales in California following CDC's initial advisory**
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2
3 **Abstract**

4
5 **Introduction:** The 2019 outbreak of e-cigarette or vaping product use-associated lung injury
6 (EVALI) is believed to have been caused by vitamin E acetate, an additive used in some
7
8 cannabis vaporizer products. Previous studies have primarily focused on changes in sales of
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10 electronic nicotine delivery systems (ENDS) following the initial advisory issued by the Centers
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12 for Disease Control (CDC) on August 17, 2019. The present study is intended to examine
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14 variation by age groups in sales of regulated cannabis vape products in the state of California
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16 before, during and after the outbreak. **Methods:** Weekly sales revenue of cannabis vape products
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18 (1/1/2018-12/31/2020) were obtained from a sample of licensed California adult-use cannabis
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20 retailers. An interrupted time series analysis, using ARIMA methods, was employed to estimate
21
22 changes in the sales and market share of cannabis vape products in the weeks following the CDC
23
24 advisory. **Results:** The total volume of regulated cannabis vape product sales increased
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26 substantially over the three-year study period (2018-2020). However, the market share of
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28 cannabis vape products declined in both younger adults (23-25 years) and older adults (>25
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30 years) immediately following the advisory, rebounding to pre-EVALI levels only for younger
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32 adults. For older adults, a 20% decline in market share of cannabis vape products was observed
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34 over the twelve weeks following the EVALI advisory. **Conclusions:** The differential age effect
35
36 on sales may reflect concerns regarding health effects of cannabis vaping products and greater
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38 awareness of the outbreak amongst older adults. Findings highlight the importance of informing
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40 consumers about health risks associated with using cannabis vape products acquired from
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42 regulated versus illicit sources.
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54 **Keywords:** ENDS; lung injuries (EVALI); cannabis vape; sales; time series analysis
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3 **Introduction**
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5 The outbreak of e-cigarette or vaping product use-associated lung injury (EVALI), which
6 peaked in September 2019 (1), was the first major health crisis that had the potential for
7 drastically altering public perceptions, sales and use of cannabinoid-containing vaporizer
8 products and electronic nicotine delivery systems (ENDS). The first advisory about EVALI was
9 issued by the Centers for Disease Control (CDC) on August 17, 2019 (2, 3). By January 14,
10 2020, the CDC reported that among the 2,022 EVALI cases with substance use data,
11 82% used a tetrahydrocannabinol (THC)-containing vaporizer product and 57% used a nicotine-
12 containing vaporizer product (4). Among the cases that reported product source, most (78%)
13 acquired products from informal sources such as a dealer or friend. While vitamin E acetate was
14 strongly associated with the EVALI outbreak (5), other vape product additives may have
15 contributed to the acute lung injuries (6).
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31 The CDC's initial recommendation to abstain from using any e-cigarette or vaping
32 device, along with media coverage of the outbreak (7, 8, 9), may have contributed to
33 misperceptions about EVALI (10) and ENDS health risks (11). East et al. (2022) reported that
34 the peak in the upward trend in U.S. youths' exposure to negative news stories about ENDS
35 (64.6%) coincided with the nadir in perceiving a lower risk of ENDS (vs. cigarettes) (34.0%)
36 immediately following the EVALI outbreak (February-March 2020). The conflation of risks of
37 lung injury associated with vaping nicotine and vaping cannabis raised concern that cigarette
38 smokers might be reluctant to use ENDS for harm reduction purposes (10, 12).
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49 The decline in nationwide sales of ENDS during the EVALI outbreak (13) may reflect
50 either greater awareness among youth of harm associated with vaping or declining perception of
51 potential harm reduction benefits by current or former smokers. Tobacco control policies enacted
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1 EVALI and cannabis vape sales

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3 in the wake of the outbreak could have affected the availability and sales of ENDS. Liber et al.
4
5 (2021) addressed this issue by developing first-differenced panel regression models to
6
7 differentiate effects of the outbreak from subsequent state-level policy changes. However, local
8
9 tobacco flavor bans and the federal government's announcement on September 11, 2019 to ban
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11 the sales of most flavored ENDS (14) may have impacted ENDS sales.
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15 The present study, by contrast, focuses exclusively on changes in sales of regulated
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17 cannabis vape products unaffected by recent tobacco-related policy changes. California legalized
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19 possession of non-medical cannabis in 2016 and adult-use retail sales began in January 2018,
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21 launching a four-year period of rapid expansion of legal commerce and sales of a growing array
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23 of cannabis products, including products intended for vaporization. Although California's
24
25 municipalities have the authority to regulate their local cannabis industry (15), only Contra Costa
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27 County and Pomona restricted sale of cannabis vape products or related accessories in 2019 (16),
28
29 making California an ideal setting for the present study. Changes in sales of cannabis vape
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31 products were examined separately in younger and older age groups given differential risk
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33 perceptions by age (17) and a young median age of EVALI patients (24 years) (1). Based on
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35 their higher risk perceptions, we hypothesize that older consumers were more likely to curtail
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37 their purchases of cannabis vape products following the CDC's initial advisory about lung
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39 injuries.
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44 **Materials and Methods**

45 *Data Source*

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49 Retail sales data originated from Headset, a company that tracks cannabis point-of-sale
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51 retail transactions in several US states and Canada (<https://www.headset.io/markets>). Weekly
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53 sales data and consumer demographics for this study were obtained from a custom Headset
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EVALI and cannabis vape sales

dataset of licensed cannabis retailers in California for the years 2018-2020 (156 weeks). Over the three-year period, Headset's market coverage of cannabis retailers in California averaged 20.63% (17.63% in 2018, 19.85% in 2019, and 24.34% in 2020). Headset's sales data were divided into nine product categories: concentrates; flower; pre-roll; edibles; beverages; tinctures and sublinguals; capsules; topicals; and vapor pens which encompass multiple cannabis vape products. Within the vapor pen category, Headset tracked sales of vaporizer cartridges (73.02% of category revenue); all-in-one disposable vaporizers (8.17% of revenue); all-in-one rechargeable vaporizers sold as cartridges with detachable batteries that can be reused with another cartridge (0.03% of revenue); refills/e-juice, cannabis products marketed for refilling depleted vaporizer cartridges (0.02% of revenue); and other or unknown (18.75% of revenue). We combined these subcategories in analyzing weekly sales revenue for cannabis vape products and vape market share (i.e., vape sales divided by total sales across all categories).

Age Groups and Control Variables

Analyses were conducted separately for two age groups defined by the year cannabis was purchased by the younger consumers (23 to 25-year-olds) and older consumers (≥ 26 -year-olds); we excluded 21 and 22-year-olds because of data irregularities. In California, adult-use cannabis retailers must verify that buyers are at least 21 years old using a valid form of identification. We obtained buyer birth years for 78.19% of the revenue in the custom Headset dataset. To determine buyer age, we subtracted birth year from purchase year. The dataset covered the purchase years 2018 to 2020, which corresponded to the birth years 1993 to 1997 for the consumers who turned 23 to 25 years of age.

The three control variables were: weekly cannabis sales; weekly cannabis sales as a percentage of state sales (Headset market coverage); and the percentage of California's

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3 population living in jurisdictions that allowed storefront cannabis retailers. For the latter, we
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5 obtained local law information using Fyllo’s CannaRegs commercial database
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7 (<https://hellofyllo.com/regulatorysolutions/cannabis/>), municipal law websites, and direct contact
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10 with city or county officials. For each week, we identified municipalities with an ordinance
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12 allowing storefront cannabis retailers that was in effect for at least 4 days in the given week,
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14 summed those jurisdictions' populations, and divided the sum by California’s total population
15
16 ([18](#)) to estimate the percentage of the state’s population living where storefront cannabis retailers
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18 were allowed.
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20 21 *Interrupted Time Series Analyses*

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24 Testing a potential effect of EVALI on sales required comparing observed weekly vape
25
26 sales to “expected” (i.e., counterfactual) values had the CDC’s advisories not affected vape sales.
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28 Devising these expected values assumes that vape sales appear normally and independently
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30 distributed over time and that the “expected” value of future weeks is the mean of past sales. A
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32 simple plot of sales (Figure 1), however, indicates that our outcome variable violated these
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34 assumptions. As described in the Results section, vape sales show a strong trend as well as the
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36 tendency for high (or low) values to persist, albeit in diminishing amounts, into subsequent
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38 weeks. The counterfactual for weekly vape sales, therefore, is not the mean of past vape sales. To
39
40 address this temporal patterning, we employed AutoRegressive, Integrated, Moving Average
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42 (ARIMA) time-series methods. Epidemiologists and health services researchers increasingly use
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44 these methods ([19](#), [20](#)), devised by Box and Jenkins ([21](#)), to estimate responses to “interruptions”
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46 in a time series. These models “fit” patterning (e.g., trend, seasonality) in the dependent variable
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48 such that the weekly residual series has a mean of zero and has values that are serially
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50 independent of one another.
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EVALI and cannabis vape sales

We first used Box-Jenkins ARIMA methods, implemented using Scientific Computing Associates software package (River Forest, IL), to identify and model autocorrelation in vape sales for the 85 weeks before the CDC's first EVALI report (i.e., January 1, 2018 to August 17, 2019). This "base model" incorporated the three aforementioned control variables. We defined the 95% detection interval of the residual series as the product of 1.96 and the residual series' standard deviation. We applied the model, with parameter values fixed to those estimated from the ARIMA model, to weekly sales for 156 weeks spanning January 1, 2018 to December 31, 2020. Next, we combined the residuals of vape sales for all 156 weeks and examined whether vape sales fell below the 95% detection interval in the twelve weeks immediately following the first EVALI report. Closer examination of residual values in the twelve week period was based on the approximate period of rapid decline of ENDS sales reported in other studies ([22](#), [23](#)). Cannabis vape sales were separately examined using total volume of vape sales and vape sales adjusted for the overall volume of cannabis sales (i.e., market share). The latter was examined to account for the possibility that the market share of vape products decreased while total vape sales increased over time, attributed to California's rapidly expanding cannabis market.

< Insert Figure 1 here >

Results

Panels A and B in Figure 1 show that total volume of legal cannabis vape product sales exhibited a strong increase over the test period for both younger adults (23-25 years) and older adults (>25 years). This trend was rather stable for younger adults until the onset of COVID-19 (week 115=March 9-15, 2020) which precipitated a sharp rise in sales. By contrast, cannabis vape sales for older adults exhibited an interruption in the rising trend after the CDC's EVALI report on August 17, 2019 (week 85), which was followed by slow growth in sales. As indicated

1 EVALI and cannabis vape sales

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3 in the plot of vape sales as a proportion of total sales (Figure 2), the market share of cannabis
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5 vape products increased similarly for younger and older adults in the first 18 months of legal
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7 sales in 2018 and 2019 but diverged thereafter. Vape products appeared more popular (as a
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9 fraction of total cannabis sales) for younger adults relative to older adults, especially from late
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11 summer 2019 onward. Further, the market share of cannabis vape products fell abruptly for older
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13 adults in early September 2019 (week 88=September 2-8, 2019) and remained low throughout
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15 2020, almost a year post EVALI. The market share of cannabis vape products for younger adults
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17 also fell in early September 2019 but gradually returned to pre-September 2019 levels.
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21 < Insert Figure 2 here >
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24 Inspection of total cannabis vape product sales (Figure 1) and market share (Figure 2),
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26 leading up to but not including the EVALI interruption (i.e., 85 weeks spanning January 1, 2018
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28 to August 17, 2019), revealed nuanced forms of autocorrelation. These patterns required
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30 inclusion of ARIMA parameters in the error term, which differed depending on the age group
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32 and outcome examined (Table 1). The resulting residual values from these four base models had
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34 a mean of 0 and exhibited no autocorrelation.
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38 < Insert Table 1 here >
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40 The residual plots of vape sales for younger adults (Panel A) and older adults (Panel B) in
41
42 Figure 3 indicate that residuals fell below the lower bound of the 95% detection interval for
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44 younger adults in one of the eight weeks following the initial EVALI report. For older adults,
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46 residuals fell below the 95% detection interval for 17 consecutive weeks from week 87 through
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48 week 104 (i.e., 8/26/2019 to 12/29/2019). The residual plot of vape sales, when controlling for
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50 overall sales, indicates an acute decline in market share for younger adults (Figure 4, Panel A) in
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52 the three weeks immediately following the initial EVALI report, and then a return to expected
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1 EVALI and cannabis vape sales

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3 levels. Residuals among older adults, by contrast, fell below expected levels in week 86 (i.e., one
4 week after the EVALI report) and never returned to pre-EVALI levels.
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8 Using the time-series plot in Figure 3B, the mean weekly decline in vape sales in the
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10 twelve weeks following the initial EVALI report was \$206,810. When compared to older adult
11 sales in the week before the advisory, the potential EVALI “effect” equates to an 8.0% decline
12 below expected levels. If one instead examines the market share of vape sales for older adults
13 (Figure 2), the EVALI “effect” equates to a reduction of market share from 0.295 to 0.236,
14 which is a decline of 20% relative to the base market share.
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21 < Insert Figures 3 & 4 here >
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24 Discussion

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26 Legalization of cannabis products for non-medical use in California led to a steady
27 increase in legal sales from 2018 to 2020. Despite this rise, the CDC’s EVALI advisory in
28 August 2019 may have curbed interest in cannabis vape products amongst older adults. Residuals
29 from the interrupted time-series analyses indicate a decline in cannabis vape sales and vape
30 market share, particularly among adults older than 25 years. The reduced market share (-20%) in
31 this age group aligns well with declining national ENDS sales (-21% to -29%) ([13](#), [22](#)). For older
32 adults, the reduction in market share of cannabis vape products persisted following dissemination
33 of the CDC’s advisory and never returned to pre-EVALI levels.
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44 A recent qualitative study on why younger adults continued to use ENDS throughout the
45 EVALI outbreak ([24](#)) may shed light on our findings of the group’s persistent use. Yang et al.
46 (2021) reported that younger adults rationalized their behavior on the basis of their low
47 frequency of ENDS use or their avoidance of “fake” cannabis obtained from unregulated
48 sources. The study participants observed by Yang et al. (2021) may be representative of
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1 EVALI and cannabis vape sales

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3 individuals who expressed positive sentiment about vaping on Twitter (25), which remained high
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5 and even exceeded negative sentiment in the summer of 2019. While age was not significantly
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7 associated with perceptions about ENDS hazards among current users during the outbreak (23),
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9 younger adult non-users had lower odds than non-using youth of having such negative
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11 perceptions. In a similar vein, age moderated the association between a lower risk perception of
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13 ENDS (vs. cigarettes) and subsequent use of ENDS (26), such that the association was more
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15 pronounced in older adults (55+; OR=2.82 (2.15, 3.70)) compared to younger adults (18-24;
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17 OR=1.81(1.44, 2.27)). In other words, the behavior of older adults observed by Elton-Marshall et
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19 al. (2020) was more influenced by risk perception, which could potentially account for the
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21 differential age effect in our study.
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26 Misperceptions about EVALI have persisted since the peak of the outbreak, exemplified
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28 by only ~17% of adult smokers who correctly perceived that cannabis/THC vape products were
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30 used by a majority of EVALI patients (10). Although media coverage on cannabis vape products
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32 and vitamin E acetate significantly increased since the CDC revised its advisory to include only
33
34 THC-containing vapes/e-cigarettes (November 8, 2019), news articles recommending the
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36 discontinuation of vaping THC increased slightly (9). The absence of age-specific sales data on
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38 cannabis vapes from illicit sources precluded a thorough examination of the potential risks and
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40 changes in purchasing behaviors throughout the EVALI outbreak. We can, however, conclude
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42 that younger adults who continued to purchase cannabis vaping products were adhering to the
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44 California Department of Public Health's recommendation (CDPH) to purchase such products
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46 from licensed cannabis retailers (27).
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51 Older adults' declining preference for cannabis vape products may reflect a more
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53 persistent impact of EVALI messaging regarding vaping. Some older adults may have heeded
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1 EVALI and cannabis vape sales

2
3 the CDPH's advice of avoiding all vaping products as the safest course of action, and switched to
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5 consuming cannabis using modes of administration that vary in risk. Some might argue that the
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7 older adults' declining preference for cannabis vape products reflects fewer harm reduction
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9 options, which are outlined in the National Institutes of Health's Lower-Risk Cannabis Use
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11 Guidelines (28). The third recommendation of the guidelines states that alternative delivery
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13 methods, such as vaporization, may be less harmful to the respiratory system than smoking.
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15 However, the guidelines caution against inhalation of high-potency cannabis extracts that my
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17 potentially cause adverse physical and mental effects, such as dependency and psychosis (29).
18
19 Emerging evidence also suggests that physical components of vaporizers, such as heating coils,
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21 are a potential source of heavy metal contamination (30). California regulations recently
22
23 expanded the definition of allowable "terpene" additives in inhaled products to include
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25 flavonoids, polyphenols, and other phytochemicals that contribute to the flavor of cannabis (31).
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29

30 *Strengths and Limitations*

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33 This study benefited from strong internal validity stemming from the few restrictive
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35 measures that affected the availability and sales of cannabis vaping products in California during
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37 the study period. It is possible that temporary local bans on cannabis vape products, such as the
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39 proposed moratorium in Los Angeles (32), had a short-term effect on sales. Yet, cannabis vape
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41 products in California were subject to far fewer sales restrictions during the EVALI outbreak
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43 compared to ENDS at the local or national level. Despite this advantage, our analysis of sales
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45 data at the state level precluded assessment of local policies that either restricted the sales of
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47 cannabis vape products or accessories (Contra Costa County, Pomona), or restricted marketing,
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49 accessibility, or other ordinances affecting younger adults (16). Another limitation of our study
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51 was the analysis of sales data from only licensed cannabis retailers in Headset's custom dataset.
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3 Consequently, we could not compare the effect of age on vape sales between licensed and
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5 unlicensed cannabis retailers. Finally, our study was limited by the exclusion of sales to 21- and
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7 22-year-olds due to data irregularities observed during the analyses. Their inclusion would have
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9 provided better representation of changes in sales to young adults.
10

11 *Conclusions* 12

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14 The initial decline in sales of cannabis vaping products, following the first EVALI
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16 advisory, may be attributed to misperceived harms of cannabis vape products acquired from
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18 licensed retailers. This finding highlights the importance of disseminating information about
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20 purchasing cannabis products from licensed retailers versus illicit sources. Regulated cannabis
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22 products are subject to manufacturing standards and testing requirements that can be evaded by
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24 unlicensed retailers in California (33). However, the full health implications of legalizing
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26 cannabis and allowing unfettered product diversification are largely unknown. Furthermore, little
27
28 is known about the long-term health effects of inhaling additives allowed in cannabis vaporizer
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30 products, such as terpenes and flavonoids. Three years after the EVALI outbreak, more
31
32 information is still urgently required to fully understand the relative harms associated with the
33
34 various modes of cannabis use, especially by age group. Both a more proactive regulatory
35
36 approach and additional research are needed to guide policy and better inform consumers.
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49 **Declaration of Interests** 50

51 No conflicts are declared by the authors.
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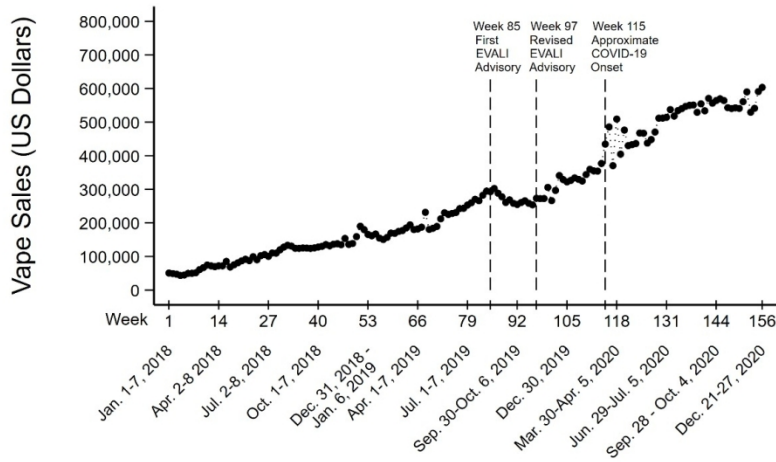
EVALI and cannabis vape sales

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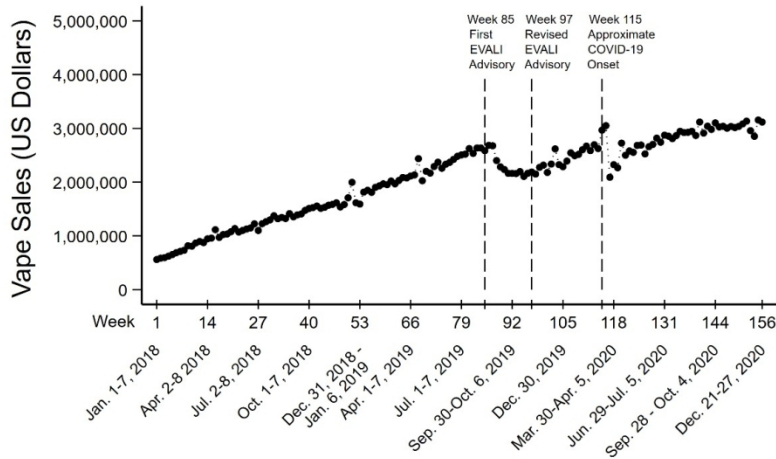
For Peer Review

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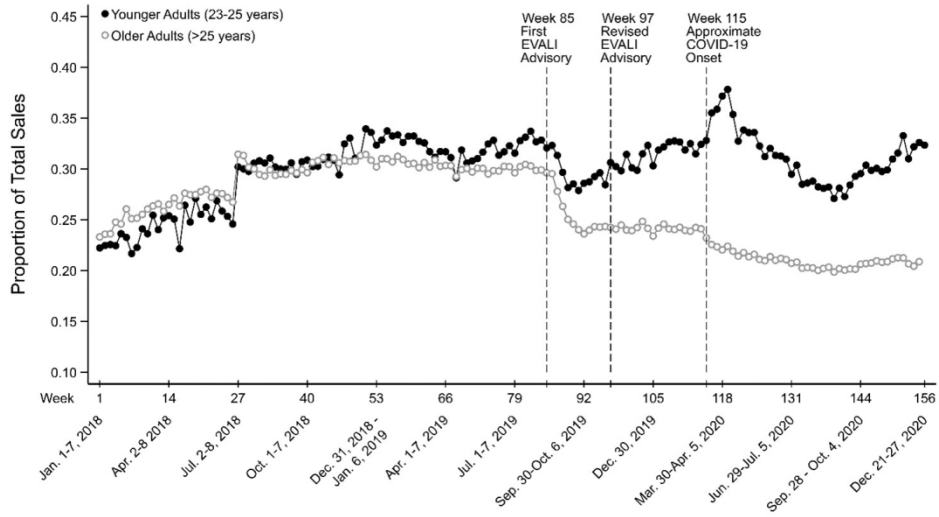
Panel A: Younger Adults (23 to 25 years)



Panel B: Older Adults (>25 years)



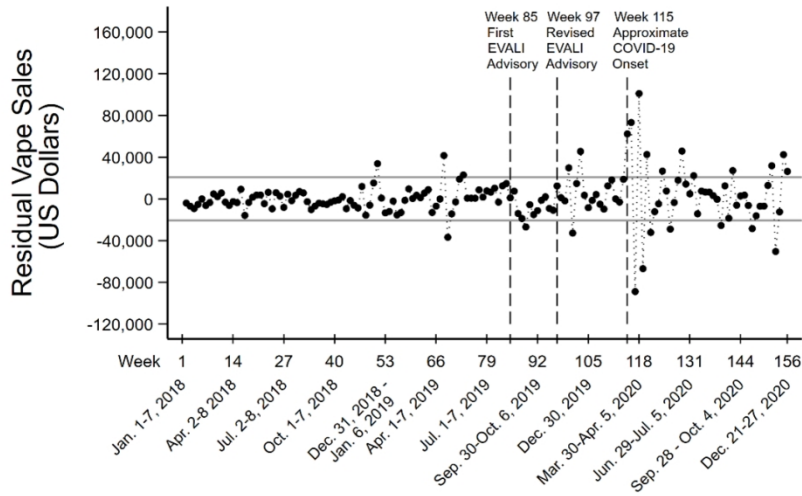
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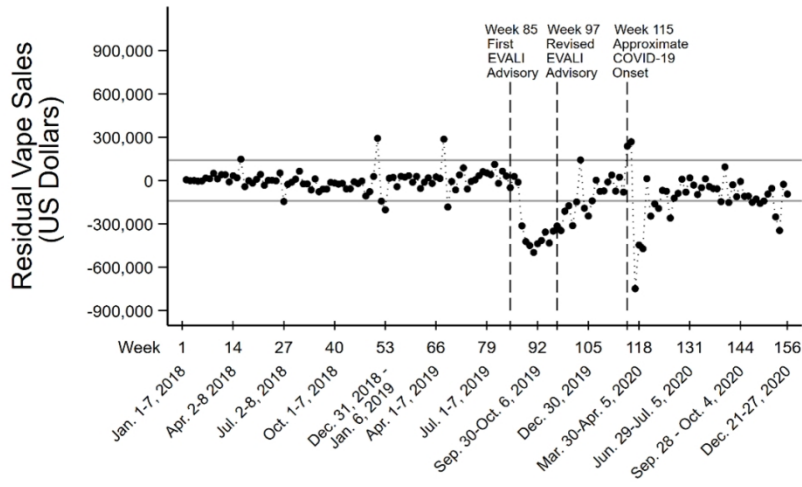
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Panel A: Younger Adults (23 to 25 years)



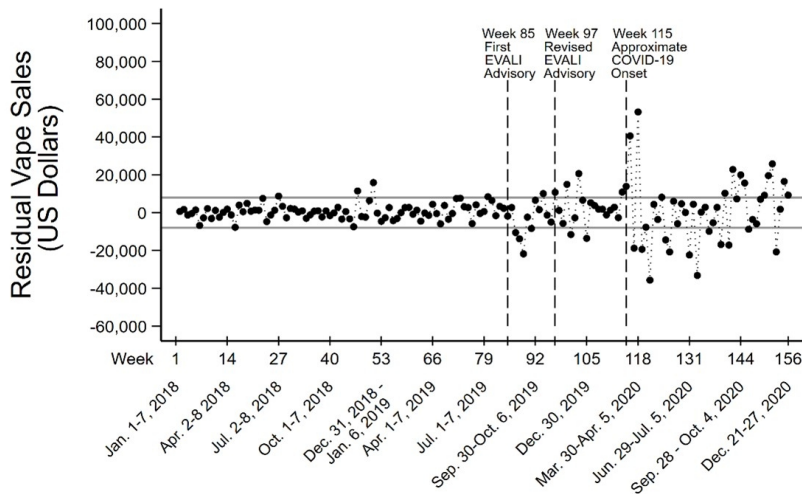
Panel B: Older Adults (>25 years)



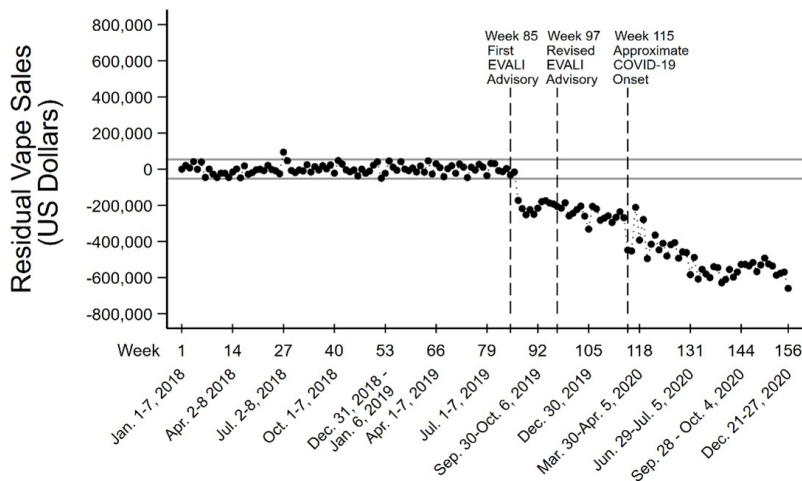
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Panel A: Younger Adults (23 to 25 years)



Panel B: Older Adults (>25 years)



140x187mm (220 x 220 DPI)

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Table 1. Time-Series Base Models predicting weekly values of selected indicators of cannabis vape sales in California for younger adults (23-25 years) and older adults (>25 years) as a function of control variables, after removal of autocorrelation (Jan. 1, 2018 to Aug. 17, 2019)

Parameter	Lag (wks)	Vape Product Sales with 2 Control Variables				Vape Product Sales with 3 Control Variables			
		Younger Adults		Older Adults		Younger Adults		Older Adults	
		Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE
Constant	—	2538.1**	836.2	25730.3**	1707.1	—	—	-1788800**	251030
Weekly cannabis sales in dataset	0	—	—	—	—	.24**	.01	.27**	.007
Weekly cannabis sales in dataset as a percentage of state sales	0	272.4	1240.9	8535.0	5631.3	1239.8*	512.4	13539.6**	3414.6
% of state population with access to cannabis storefront retailers	0	4090.5	4470.2	-22308.3	17117.7	3762.3**	1703.9	38896.2**	6926.3
AR	1	—	—	—	—	—	—	.60**	.09
I	1	✓	✓	✓	✓	✓	✓	—	—
MA	1	.40**	.10	.88**	.05	.22*	.10	—	—

*p<.05; **p<.01

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3 **Figure 1:** Weekly sales revenue for vape products in California for 156 weeks spanning Jan. 1,
4 2018 to Dec. 31, 2020, by age group
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6 **Figure 2.** Weekly sales revenue for vape products as a proportion of total sales in California, for
7 156 weeks spanning Jan. 1, 2018 to Dec. 31, 2020, by age group
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10 **Figure 3.** Residual weekly values of cannabis vape sales over 156 weeks (Jan. 1, 2018 to Dec.
11 31, 2020) after removing autocorrelation and controlling for weekly cannabis sales in dataset as a
12 percentage of state sales, and percentage of state population with access to cannabis storefront
13 retailers.
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16 Note: The horizontal lines represent the 95% detection interval (Panel A: ± 20723 ; Panel B: ± 139981).
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18 **Figure 4.** Residual weekly values of cannabis vape sales over 156 weeks (Jan. 1, 2018 to Dec.
19 31, 2020) after removing autocorrelation and controlling for weekly cannabis sales in dataset,
20 weekly cannabis sales in dataset as a percentage of state sales, and percentage of state population
21 with access to cannabis storefront retailers.
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24 Note: The horizontal lines represent the 95% detection interval (Panel A: ± 7979 ; Panel B: ± 53074).
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