doi:10.1111/add.15078

Characterizing the predictive validity of measures of susceptibility to future use of combustible, vaporized and edible cannabis products in adolescent never-users

Jessica L. Barrington-Trimis[1], Dayoung Bae[2], Sara Schiff[1], Jordan Davis[3], Jennifer B. Unger[1] & Adam M. Leventhal[1,4]

Department of Preventive Medicine, University of Southern California, Los Angeles, CA, USA,[1] Department of Home Economics Education, College of Education, Korea University, Seoul, South Korea,[2] Suzanne Dworak-Peck School of Social Work, University of Southern California, Los Angeles, CA, USA[3] and Department of Psychology, University of Southern California, Los Angeles, CA, USA[4]

ABSTRACT

Background and aims The construct of susceptibility to substance use initiation (i.e. cognitive proclivity to future use) is critical for prevention efforts in adolescent populations. This study aimed to provide empirical evidence for the validity of the susceptibility construct for different cannabis products (i.e. combustible, edible or vaporized cannabis), and evaluate whether susceptibility measures are predictive of subsequent initiation. **Design** Prospective cohort study including baseline data (Spring 2015) and four follow-up surveys administered every 6 months through Spring 2017. **Setting** Ten schools in the Los Angeles, California metropolitan area. **Participants** Adolescents [n = 2100; mean age = 16.1; standard deviation (SD) = 0.41; 54% female] who reported never having used any cannabis product at baseline. **Measurements** We assessed five indices of a susceptibility to use cannabis composite index at baseline, adapted from a validated tobacco use index (intention to use, willingness, curiosity and positive/negative cannabis use outcome expectancies, with four response categories, definitely not [1] to definitely yes [4]), by cannabis product (combustible, edible or vaporized). A composite index was created for each product by averaging responses across the five susceptibility items. Subsequent initiation of use of each cannabis product was assessed at each follow-up wave. **Findings** Factorial validity for unidimensionality for each five-item index (by product) was confirmed. The composite index for susceptibility to cannabis use was greatest for combustible (mean = 1.44; SD = 0.58), moderate for edible (mean = 1.37; SD = 0.53) and lowest for vaporized cannabis (mean = 1.30; SD = 0.44). The associations of each composite susceptibility index with subsequent initiation of that product and each of the other cannabis products over follow-up (i.e. cross-product associations) were statistically significant, with hazard ratios ranging from 2.30 to 2.80 across 24 months of follow-up (all Ps < 0.05). **Conclusions** A five-item susceptibility to cannabis use composite index (by product) appears to be useful for characterizing and predicting youth at risk for cannabis use initiation across a spectrum of cannabis products.

Keywords Adolescents, cannabis, combustible cannabis, edible cannabis, measures, prospective cohort, susceptibility, vaporized cannabis.

Correspondence to: Jessica Barrington-Trimis, Department of Preventive Medicine, University of Southern California, 2001 North Soto Street, 312G, Los Angeles, CA 90089, USA. E-mail: jtrimis@usc.edu

Submitted 25 August 2019; initial review completed 5 December 2019; final version accepted 27 March 2020

INTRODUCTION

The US cannabis policy landscape has changed substantially during the last two decades with the widespread legalization of medical and recreational cannabis use. Legalization and the corresponding commercialization of the cannabis industry has increased availability of a number of different types of cannabis products involving non-combustible methods of administration, which represent a rapidly growing sector of the cannabis market [1,2]. For example, vaporized cannabis products comprised of battery-powered devices capable of heating dry cannabis plant, cannabis oils or cannabinoid concentrates into inhalable aerosols have proliferated, and edible cannabis products, including commercially manufactured snacks, baked goods or candies infused with cannabis, have also become more widely available [2–7].

One of the chief public health priorities in responding to the evolving cannabis marketplace is the prevention of cannabis product use uptake among youth including, in particular, of alternative cannabis products that may be used by youth unlikely to have otherwise smoked combustible cannabis [7,8]. Recent estimates indicate that while combustible cannabis remains the most commonly-used cannabis product among adolescents, an appreciable proportion of youth also use alternative cannabis products [1,9–11]. Methods to identify youth at risk for future initiation of alternative cannabis products may be vital for the prevention of adolescent cannabis use in the current policy landscape, particularly if alternative products are drawing in new, low-risk youth to cannabis product use. However, data on measures that can identify youth at risk of use of alternative methods of cannabis are lacking.

Survey-based measures of substance use 'susceptibility' have long been used to identify youth at risk for tobacco use initiation and have more recently been adapted to alternative tobacco products. Such measures aim to characterize malleable cognitive precursors to substance use uptake that can be targeted in prevention curricula, media campaigns or policy interventions [12,13]. Susceptibility questionnaire items are designed to tap varying levels across the continuum of susceptibility [e.g. responses 'intention' to use items may identify youth at the high end of the spectrum (i.e. with intention to use a product soon), while 'curiosity' about a substance may identify youth at the low end of the spectrum (i.e. may be open to using a product but have not set intentions to do so)] [12,14]. While youth susceptibility to initiation of combustible cannabis and other substances has been characterized, susceptibility to use of alternative cannabis products such as cannabis edibles or vaporized cannabis has not been previously investigated. Given the unique characteristics of alternative cannabis products [e.g. availability in flavors (vaping) or in common food products (edibles)] that may differentially appeal to youth unlikely to use combustible cannabis products, the evaluation of adapted measures is needed to better understand whether such measures hold utility for identification of at-risk, susceptible youth.

In the current study, we use data from a prospective cohort of adolescents in the Los Angeles metropolitan area to provide the first characterization of the susceptibility to initiation construct among combustible, edible and vaporized cannabis products in never cannabis users. Given evidence that socio-demographic differences in use are non-equivalent among different types of cannabis products [15,16], we additionally examine whether differences in susceptibility to each cannabis product differ by socio-demographic characteristics, findings of which are relevant to inform targeted population-specific prevention efforts. Finally, we examine the association of susceptibility indices with subsequent initiation of cannabis use across each product (combustible, edible and vaporized) over 24 months of follow-up.

METHODS

Design

To examine the primary aims of the study, we used longitudinal data from five waves of our prospective cohort of youth, collected every 6 months from 10th to 12th grade (Spring 2015–Spring 2017). We examined the prevalence of, and correlates with, susceptibility to cannabis use at the baseline wave (10th grade) among those who had not used cannabis products, and then examined prospective associations of baseline susceptibility with subsequent initiation of use of each cannabis product over the subsequent four waves (24 months) of the study.

Participants and procedures

Data were drawn from the Happiness and Health Study—an ongoing prospective cohort study of substance use in adolescence and early adulthood [17]. Students from 10 high schools in the Los Angeles, CA metropolitan area were recruited for participation in the study. Schools were selected on the basis of their student body's diverse demographic characteristics and proximity to the study institution. Of the eligible 9th grade students enrolled in the participating schools in Fall 2013 (n = 4100), a total of 3396 (82.8%) provided assent and parental consent and were enrolled into the cohort. Paper-and-pencil surveys were administered on-site at participating high schools every 6 months from 9th to 12th grade (Spring 2017). We first collected information on use and susceptibility to use of edible and vaporized cannabis products in Spring 2015 (10th grade assessment), which served as the baseline in the current study. The current analytical sample included participants who reported no prior use of any cannabis product at the Spring 2015 (baseline) assessment (n = 2100). Of these students, 2088 completed at least one of the four semi-annual follow-up surveys over the subsequent 24 months [Fall 11th grade survey (n completed survey = 2028), Spring 11th grade (n = 1995), Fall 12th grade (n = 2008), Spring 12th grade (n = 2012)] and were included in analyses of cannabis use initiation. The University of Southern California Institutional Review Board approved the study.

Measures

Susceptibility to combustible, vaporized and edible cannabis use

At the Spring 10th grade survey, separate five-item sets were used to assess susceptibility to each of three cannabis products [:15] (a) combustible cannabis, 'smoking marijuana (pot, weed, hash, reefer or bud)', (b) edible cannabis,

'marijuana or tetrahydrocannabinol [THC] food or drinks (pot brownies, edibles, butter, oil)' and (c) vaporized cannabis, 'electronic device to vape liquid THC or hash oil (liquid pot, dabbing, weed pen)'. Items were derived from tobacco use susceptibility items that have demonstrated adequate psychometric properties in previous studies of high school students [18,19] and assess five different aspects of cannabis use susceptibility: (1) willingness to use—'Would you try [product] if one of your best friends offered it to you?'; (2) intention to use—'Do you think you would use [product] in the next 6 months?'; (3) curiosity—'Are you curious about using [product]?'; (4) anticipated pleasurable effects of use—'I think I might enjoy, experience pleasure, or feel good using [product]'; and (5) anticipated aversive effects of use—'I think I might feel bad, sick, or embarrassed using [product]'. Each susceptibility item included four forced-choice response options (definitely not/strongly disagree, probably not/disagree, probably yes/agree or definitely yes/strongly agree), which were assigned values from 1 to 4. The anticipated aversive effects item was reverse-coded such that higher scores reflected higher susceptibility to cannabis use (i.e. no expectations of aversive responses to cannabis use). In sensitivity analyses, we dichotomized the susceptibility measures, where a response of 'definitely not/strongly agree' was considered 'not susceptible', and a response of 'probably not/disagree', 'probably yes/agree' or 'definitely yes/strongly agree' was considered 'susceptible'.

Combustible, vaporized and edible cannabis product use initiation

At each survey, participants reported whether they ever used combustible, edible and vaporized cannabis products (in separate items). Participants were considered to have initiated use of a product if they reported lifetime use at any follow-up wave. A composite variable was created to evaluate initiation of any cannabis product, where those who initiated use of combustible, edible or vaporized cannabis were considered to have ever initiated any cannabis product; those who had not initiated use of any of the three products were categorized as having not initiated any cannabis use.

Socio-demographic characteristics

At study enrollment, self-administered questionnaires completed by participants were used to assess age, gender, race/ethnicity [Asian, black/African American, Hispanic/Latino, white, multi-ethnic/multi-racial, other (selected either: American Indian/Alaska Native, Native Hawaiian/Pacific, or do not self-identify with any race/ethnicity categories provided)], highest parental education (i.e. ≤ 8th grade, some high school, high school graduate, some college, college graduate, graduate degree) and eligibility for free or reduced lunch (designated for students of families with incomes ≤ 185% the US poverty line). As in previous work [15], we defined high family socio-economic status (SES) as having met both of the following conditions: (a) parental education equal or higher than some college degree and (b) ineligible for free or reduced lunch (family income > 185% poverty line).

Data analysis

Characterizing susceptibility in the overall sample

The distribution of item-level susceptibility indicators (i.e. willingness to use, intention to use, curiosity, anticipated pleasurable effects, anticipated aversive effects) were first described for each cannabis product in the overall sample of never cannabis users at baseline. To create a composite index, we used confirmatory factor (CFA) analyses to test the latent structure of covariance among the 15 items (five items × three products). We compared the fit of our proposed model based on prior research of susceptibility indices [12,14] (a three-factor model that includes one factor per product, i.e. separate composite susceptibility indices for each cannabis product) relative to two alternative models with plausible latent structures: (1) a single-factor model represented [i.e. a composite index based on 15 survey questions (five susceptibility items × each of the three products); Supporting information, **Fig. S2**] and (2) a five-factor model [i.e. a composite susceptibility variable across the three cannabis products, separately for each susceptibility indicator (intention, willingness, curiosity, positive anticipated effects, negative effects); Supporting information, **Fig. S3**]. To enhance model fit, we allowed the residuals for certain indicators to be correlated. As shown in Figs S1–S3 and Table S1, the three-factor model (i.e. using one composite susceptibility measure for each cannabis product) best fitted the data based on low root mean square error of approximation (RMSEA = < 0.08) [20], and high comparative fit index (CFI > 0.95) [21] and Tucker–Lewis Index (TLI > 0.95) [21]. The three-factor composite susceptibility to cannabis use index (created by taking the arithmetic mean of the respective item scores, separately by cannabis product) showed adequate internal consistency in the sample for each factor (Cronbach's alpha: combustible = 0.76, edible = 0.73, vaporized = 0.65). In sensitivity analyses, we additionally created a composite index separately for each cannabis product based on the dichotomous susceptibility scores for each susceptibility item. CFAs were conducted using Mplus 8 [22] with the TYPE = COMPLEX command to adjust for potential bias in standard errors (SE) and χ^2 computation due to the lack of independence between observations within schools. We also conducted all analyses using bootstrapping to correct for potential optimism

bias in measures of predictive ability. Bias-corrected 95% confidence intervals (CIs) were computed using 1000 bootstrapped re-samples for each estimate, and the results remained unchanged.

To characterize within-person differences in susceptibility to use among cannabis products, the effects of product type (combustible versus edible versus vaporized) on item-level responses and the mean composite score (based on CFA results) were tested using Kruskal–Wallace and one-way within-participant analyses of variance (ANOVAs), respectively.

Demographic differences in susceptibility

Generalized estimating equation (GEE) [23] linear regression models were used to test for demographic differences in cannabis use susceptibility composite scores. We modeled the association of each demographic characteristic (age, gender, race/ethnicity, SES) with each within-person cannabis susceptibility composite measure, including a random effect for participant ID to account for correlated outcome measures. We additionally evaluated whether the association of demographic characteristics with within-participant differences in susceptibility composite scores differed by product by including an interaction term for within-subject susceptibility × demographic characteristics.

Association of susceptibility indexes with subsequent use initiation

Cox regression models were used to test the association between each susceptibility composite score and time to first initiation of each product (i.e. within 6, 12, 18 and 24 months of baseline) among never cannabis users at baseline in separate models. All models were adjusted for demographic characteristics (age, gender, race/ethnicity, SES), and included school as a fixed effect. We assessed whether associations differed by school, by including an interaction term for susceptibility × school in all models; all *P*-values were > 0.25, indicating that there was no substantive difference among schools included in the analysis. Missing covariate data were accounted for using a multiple-imputation approach [24]. Five multiply imputed data sets were created, and the parameter estimates from the models tested in each imputed data set were pooled and presented as a single estimate. In sensitivity analyses, we examined the association of each susceptibility composite score with any initiation of each cannabis product by wave 8 using logistic regression models adjusted for the same demographic covariates among never cannabis users at baseline. Association estimates from GEE linear regression models and Cox regression models were reported as unstandardized regression weights (*b*s) and hazard ratios (HRs), respectively, with 95% CIs. Logistic regression models are reported as odds ratios (ORs) and 95% CIs. *P*-values from two-tailed tests were considered statistically significant after correction for multiple testing using the Benjamini–Hochberg procedure to maintain a study-wide false discovery rate of 0.05 [25]. Statistical analyses were conducted using SPSS version 23. The analysis plan for this paper was not preregistered; thus, all results should be considered exploratory.

RESULTS

Descriptive results

Students in the analytical sample were, on average, aged 16.1 [standard deviation (SD) = 0.41] years, 54% female, and diverse with regard to SES (46% high, 54% low) and race/ethnicity [Asian: 21.8%, black/African American: 4.3%; Hispanic: 42.9%; white: 17.3%; multi-ethnic/multi-racial: 6.7%; other race/ethnicity: 7.0% (other: American Indian/Alaska Native, $n = 18$, Native Hawaiian/Pacific, $n = 95$ or do not self-identify with any race/ethnicity categories provided, $n = 32$); see Table 1]. Compared to the analytical sample, students excluded from analyses were more likely to be low SES (54.4 versus 71.3%, $P < 0.001$) and Hispanic (42.9 versus 59.0%, $P < 0.001$), and less likely to be Asian (21.8 versus 8.2%, $P < 0.001$).

Characterization of cannabis use susceptibility indices in overall sample

Within-product cross-item comparisons

Overall, the distribution of responses for each item were positively skewed, with most students reporting little or no susceptibility (i.e. 'definitely not' or 'probably not' responses to intention to use items) and smaller but appreciable proportions of youth reporting higher levels of susceptibility (i.e. 'probably yes' or 'definitely yes'; Table 2). Overall, mean susceptibility scores were successively greater for intention, willingness and curiosity items, which is consistent with the concept that intention to use taps the high end of the susceptibility continuum (most susceptible youth) and curiosity taps a lower end of the continuum. While expected aversive effect responses were still positively skewed, with more youth reporting definitely or probably yes to an expectation of experiencing aversive effects when using cannabis products, this indicator generated a more balanced distribution of responses, with approximately 24–27% of participants reporting probably or definitely not to expected aversive response.

Composite susceptibility measure evaluation

CFAs verified the appropriateness of the scoring algorithm of calculating the mean per item score among the five

Table 1 Demographic characteristics of participants included (versus not included) in the analytical sample.

	Analytical sample (n = 2100)	*Excluded from analysis (n = 1077)*	
	n (%) or mean (SD)	*n (%) or mean (SD)*	*P-value*
Female	1131 (53.9%)	584 (54.2%)	0.85
Age[a]	16.1 (0.4)	16.1 (0.4)	0.26
Low SES[b]	995 (54.4%)	659 (71.3%)	< 0.001
Race/ethnicity[c]			
Asian	451 (21.8%)	86 (8.2%)	< 0.001
Black	90 (4.3%)	59 (5.6%)	
Hispanic	889 (42.9%)	621 (59.0%)	
White	359 (17.3%)	148 (14.1%)	
Multi-ethnic/multi-racial	139 (6.7%)	68 (6.5%)	
Other[d]	145 (7.0%)	71 (6.7%)	

[a]Available sample size for the analytical sample is $n = 2090$ and for those excluded from analyses is $n = 1064$. [b]Available sample size for the analytical sample is $n = 1829$ and for those excluded from analyses is $n = 924$. [c]Available sample size for the analytical sample is $n = 2073$ and for those excluded from analyses is $n = 1053$. [d]Other category combines American Indian/Alaska Native, Native Hawaiian/Pacific Islander, and respondents who did not self-identify with any of the categories provided. SD = standard deviation; SES = socio-economic status.

susceptibility items for each product by demonstrating that a three-factor model (one factor per product, each represented by five unique susceptibility indicators with no item cross-loading) provided a superior fit relative to two alternative models (see Supporting information, Figs S1–S3, Table S1). With the exception of the expected aversive effects item, which had modest factor loadings (0.36–0.39), each of the other four indicators had factor loadings of 0.74 or higher on their respective product's latent susceptibility factor. Cross-factor correlations were high (> 0.68), indicating that susceptibility to use of one cannabis product relative to each students' respective peers corresponded to the susceptibility to use of the other products relative to peers.

Cross-product comparisons

Cross-product comparisons showed that in the overall sample, both the overall susceptibility composite score and individual mean scores within each item were highest for combustible cannabis use, moderate for edible products and lowest for vaporized cannabis for most indicators (see superscripts for estimates in Table 2), with small effect sizes for cross-product differences observed (0.07–0.14 differences in mean scores across the products).

Demographic differences in cannabis use susceptibility by product type

Overall, the composite susceptibility indices for each cannabis product were similar by gender, age and family SES, and in adjusted regression models these variables were generally not significantly associated with susceptibility to cannabis use averaged among the three products. Those of a Hispanic ethnicity (relative to Asian participants) reported higher levels of susceptibility on the composite index averaged across the three products ($b = 0.20$, $P < 0.001$; Supporting information, **Table S2**); no other differences by race/ethnicity were observed.

The difference in susceptibility to combustible versus vaporized cannabis products was significantly amplified in Hispanic and multi-ethnic youth versus Asian youth ($P < 0.05$; see Fig. 1). In addition, greater comparative susceptibility to edible versus vaporized cannabis was observed for females versus males, and for Hispanic, white, and multi-ethnic/multi-racial racial groups versus Asian youth. Few differences in susceptibility to combustible versus edible cannabis were observed, although the difference was again amplified in Hispanic versus Asian participants. We did not observe any significant relative differences in susceptibility among different cannabis products by SES.

Association of cannabis use susceptibility with subsequent use initiation over follow-up

By the end of the 24 months of follow-up, the cumulative incidence of initiation of any product was 27.5% overall, and was highest for combustible (24.2%), followed by edible (16.8%) and vaporized (10.4%) cannabis (see Table 3).

Susceptibility composite scores for each product type in 10th grade were significantly associated with time to initiation of cannabis use over follow-up for all products (see Table 4). The association estimates among all susceptibility measures (to each product) and for initiation of each product were relatively similar in magnitude—a 1-unit increase in mean susceptibility score was associated with a 2.2 to 2.9 greater hazards of initiation during follow-up. Results were similar when using a dichotomized (versus continuous) measure for each susceptibility item, with effect estimates ranging from 2.0 to 3.2 greater hazards of initiation associated with susceptibility. The effect estimates

Table 2 Descriptive statistics of susceptibility to combustible, edible and vaporized cannabis use indicators among never-users of cannabis.

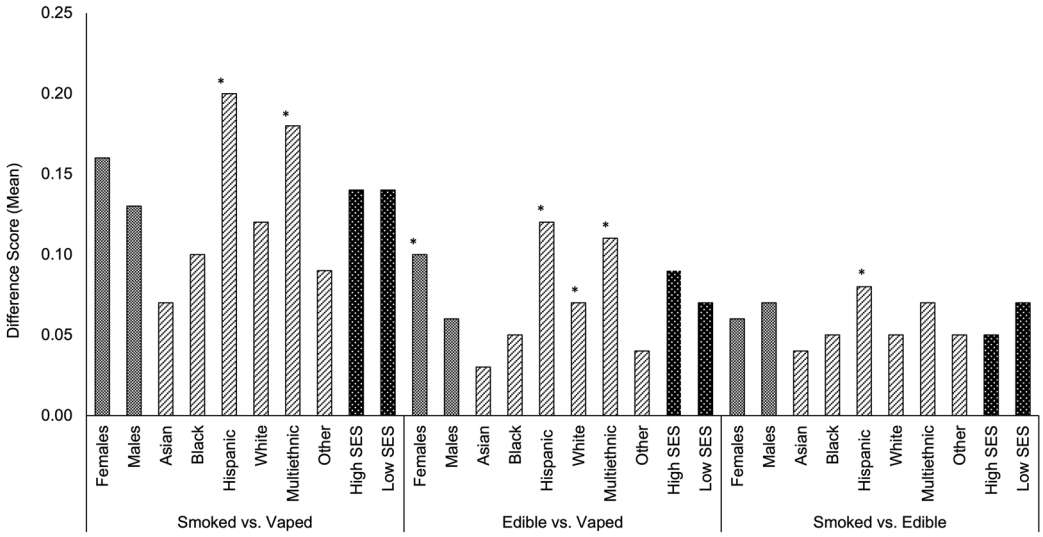
	Combustible	*Edible*	*Vaporized*
Susceptibility composite, *n*[f]	2008	2007	2006
Score, mean (SD)[a]	1.44 (0.58)[b]	1.37 (0.53)[c]	1.30 (0.44)[d]
Item responses			
Intend to use in the next 6 months, *n*	2042	2042	2043
Score, mean (SD)[a]	1.16 (0.45)[b]	1.12 (0.41)[c]	1.09 (0.33)[d]
Response, *n* (%)			
Definitely not	1794 (87.9)	1847 (90.5)	1897 (92.9)
Probably not	183 (9.0)	144 (7.1)	119 (5.8)
Probably yes	60 (2.9)	47 (2.3)	24 (1.2)
Definitely yes	5 (0.2)	4 (0.2)	3 (0.1)
Try if offered, *n*	2041	2038	2037
Score, mean (SD)[a]	1.28 (0.64)[b]	1.25 (0.60)[b]	1.16 (0.48)[c]
Response, *n* (%)			
Definitely not	1655 (81.1)	1698 (83.3)	1808 (88.8)
Probably not	211 (10.3)	193 (9.5)	154 (7.6)
Probably yes	155 (7.6)	130 (6.4)	63 (3.1)
Definitely yes	20 (1.0)	17 (0.8)	12 (0.6)
Curious about it, *n*	2042	2043	2039
Score, mean (SD)[a]	1.44 (0.87)[b]	1.33 (0.76)[c]	1.20 (0.60)[d]
Response, *n* (%)			
Definitely not	1563 (76.5)	1679 (82.2)	1797 (85.6)
Probably not	147 (7.2)	133 (6.5)	114 (5.4)
Probably yes	239 (11.7)	162 (7.9)	89 (4.2)
Definitely yes	93 (4.6)	69 (3.4)	39 (1.9)
Expected pleasurable effects from use, *n*	2037	2037	2037
Score, mean (SD)[a]	1.39 (0.75)[b]	1.30 (0.67)[c]	1.19 (0.52)[d]
Response, *n* (%)			
Strongly disagree	1556 (76.4)	1650 (81.0)	1751 (86.0)
Disagree	204 (10.0)	192 (9.4)	190 (9.3)
Agree	248 (12.2)	170 (8.3)	87 (4.3)
Strongly agree	29 (1.4)	25 (1.2)	9 (0.4)
Expected aversive effects from use,[e] *n*	2030	2032	2034
Score, mean (SD)[a]	1.93 (1.17)[b]	1.90 (1.17)[b]	1.85 (1.17)[c]
Response, *n* (%)			
Strongly agree	1077 (53.1)	1127 (55.5)	1186 (58.3)
Agree	393 (19.4)	368 (18.1)	349 (17.2)
Disagree	184 (9.1)	155 (7.6)	121 (5.9)
Strongly disagree	376 (18.5)	382 (18.8)	378 (18.6)

[a]Response ranges from definitely not/strongly disagree (1) to definitely yes/strongly agree (4). [b,c,d]Groups with different letter superscripts demonstrated statistically significant pairwise differences at $P < 0.05$ level when tested using the Kruskal–Wallis test. For susceptibility to cannabis use variable, pairwise differences were tested using one-way analysis of variance. [e]Reverse-coded, such that higher score means higher susceptibility (lower negative expectancy), response ranges from strongly agree (1) to strongly disagree (4). [f]Susceptibility to cannabis use was constructed by averaging five cannabis use susceptibility variables. SD = standard deviation.

using the dichotomized measure were slightly higher for the association of susceptibility to combustible or edible cannabis with initiation of each cannabis product and slightly lower for the association of susceptibility to vaporized cannabis with initiation of each product relative to estimates using a continuous susceptibility measure, although differences were not statistically significant. Sensitivity analyses examining the association of susceptibility to cannabis with any initiation of each cannabis product by wave 8 were moderately stronger, with each 1-unit increase in mean susceptibility score associated with a 2.8 to 3.7-fold greater odds in the initiation of a cannabis product by wave 8 (Supporting information, **Table S3**).

DISCUSSION

Overall, students in the current study reported highest susceptibility to combustible cannabis, followed by edible cannabis, with lowest susceptibility reported for vaporized cannabis. The initiation rates across the sample followed a similar pattern—the rates of initiation were highest for combustible cannabis, followed by edible and vaporized



Note. [a]The outcome variable is the difference in mean scores of susceptibility to each cannabis product (ie., smoked – vaped, edible – vaped, smoked – edible) by demographic characteristics. Difference scores that are positive indicate a higher susceptibility for the first product listed in each comparison.
*Indicates significant interactions of demographic characteristics, such that the difference in susceptibility to products (e.g., smoked – vaped) is greater in one strata of a demographic characteristic than in another, at $P < .05$. Reference groups are as follows: gender (male); race/ethnicity (Asian); SES (high SES).

Figure 1 Relative difference in susceptibility to cannabis use by demographic characteristics[a]

cannabis. The association of susceptibility to a given product with subsequent initiation of that product was strong and observed for all products; moreover, susceptibility to any type of product was associated with similar odds of initiation of any product.

The higher rates of susceptibility and subsequent initiation of combustible cannabis versus edible or vaporized cannabis could be the result of a number of different factors. Combustible cannabis may be more accessible to youth than other forms of cannabis. First, combustible cannabis is more widely used than other forms [15,26–29], which could increase overall popularity and availability to youth who are generally unable to purchase such products legally. Combustible cannabis has also been on the legal (and illegal) market for a longer period of time than some alternative cannabis products (e.g. vaporized cannabis) [30,31]. Secondly, combustible cannabis may be easier to access than vaporized cannabis (due to relative prevalence of use); vaporized cannabis requires purchasing additional equipment for use (i.e. a vaporizer) and can be price prohibitive [32–34]. Finally, youth may be more interested in combustible cannabis for the high that is generated from use of that product versus other products. Youth have often reported adverse experiences with using edible cannabis products, which can be challenging to dose [35,36], easy to use in excessive amounts [,6,36,37] which can lead to unpleasant psychological effects, [38,39] and the time between administration and peak effects is substantially longer for edible cannabis (30 minutes to 4 hours) than for combustible cannabis (a few seconds to 20 minutes) [35,40–42]. Despite differences in the prevalence of susceptibility and of initiation of all three cannabis products, use of each of the three cannabis products was not negligible and efforts should be made to target all cannabis products in prevention campaigns to prevent adverse consequences of cannabis use to the public health of youth.

The consistency of associations among all susceptibility measures and all products suggests that susceptibility measures targeted to a specific product may not be needed; an overall cannabis susceptibility measure may be as useful as individual measures in identifying youth at risk for subsequent initiation of any cannabis product. In national surveys with limited space for survey items, utilization of a single overall cannabis susceptibility measure may be sufficient. However, continued research is needed to understand how differences in susceptibility to different products may vary among subpopulations of youth. For example, the higher susceptibility scores among all products for Hispanic youth suggest that culturally tailored prevention messages aimed at reducing cannabis use in this population may have a substantial impact overall and in closing existing gaps in the public health of youth by ethnicity.

Table 3 Cumulative percentage of use for each cannabis product at 6-, 12-, 18- and 24-month follow-up.

Follow-up time-point	*Combustible initiation*	*Edible initiation*	*Vaporized initiation*	*Any product initiation*
6-month	4.1%	2.4%	1.9%	5.7%
12-month	11.0%	7.6%	3.7%	13.9%
18-month	16.3%	11.0%	5.7%	19.4%
24-month	24.2%	16.8%	10.4%	27.5%

Table 4 Associations of susceptibility to cannabis use with time to subsequent cannabis use initiation, by cannabis product.

	Association with initiation of respective cannabis product over 24-month follow-up, hazard ratio (95% CI)			
	Combustible initiation	*Edible initiation*	*Vaporized initiation*	*Initiation of any product*
Continuous susceptibility measures[a]				
Susceptibility to combustible	2.48 (2.18, 2.83)	2.37 (2.03, 2.77)	2.45 (2.02, 2.96)	2.38 (2.11, 2.70)
Susceptibility to edible	2.42 (2.11, 2.77)	2.36 (2.01, 2.78)	2.48 (2.04, 3.01)	2.39 (2.10, 2.72)
Susceptibility to vaped	2.41 (2.05, 2.84)	2.30 (1.88, 2.81)	2.80 (2.21, 3.53)	2.30 (1.97, 2.70)
Dichotomous susceptibility measures[b]				
Susceptibility to combustible	2.90 (2.32, 3.61)	2.88 (2.19, 3.77)	3.18 (2.23, 4.54)	2.78 (2.26, 3.42)
Susceptibility to edible	2.51 (2.04, 3.09)	2.47 (1.92, 3.18)	2.76 (1.98, 3.84)	2.42 (1.99, 2.93)
Susceptibility to vaped	2.13 (1.75, 2.59)	2.12 (1.67, 2.69)	2.60 (1.90, 3.57)	2.04 (1.70, 2.45)

[a]Results are from adjusted Cox regression models including the respective products susceptibility composite scores (range = 1–4; see Table 1 and Methods), respondents' demographic characteristics (i.e. age, gender, race/ethnicity, SES) and school fixed effects. All *P*s < 0.001. [b]Results are from adjusted Cox regression models including the binary respective products susceptibility [0 = definitely not (1); 1 = probably not (2), probably yes (3) and definitely yes (4)], respondents' demographic characteristics (i.e. age, gender, race/ethnicity, SES) and school fixed effects. All *P*s < 0.001. SES = socio-economic status; CI = confidence interval.

Limitations

This study used data from a prospective cohort of youth in the Los Angeles metropolitan area. Given the rapidly changing regulatory environment pertaining to cannabis use in the United States and elsewhere, additional research is needed to confirm the generalizability of results from this study—where medical marijuana has been legal since 1996 and possession of cannabis for recreational purposes legal for those aged 21 years or older in November 2016—to areas with different regulatory environments. While we were able to differentially investigate susceptibility to and subsequent initiation of three different cannabis products—combustible, edible and vaporized cannabis—we did not have additional susceptibility measures for other types of cannabis, including concentrated cannabis, which may present a substantial abuse liability risk to youth and young adult populations.

CONCLUSIONS

In this study of youth in Southern California, adolescents with no history of cannabis use were most susceptible to initiation of combustible cannabis, followed by edible and vaporized cannabis. Throughout 24 months of follow-up, more than one-quarter of youth initiated cannabis use. Susceptibility to any type of cannabis use was associated with an approximately twofold increase in the likelihood of initiating use; susceptibility to cannabis use did not appear to differentiate type of product initiated. Generalized prevention efforts that focus on cannabis use overall—rather than on a specific cannabis product—may be effective in preventing initiation of all types of cannabis use among adolescents.

Declaration of interests

None.

Acknowledgements

Research reported in this publication was supported by grant numbers R01DA033296 and K01DA042950 from the National Institute for Drug Abuse at the National Institutes of Health, and grant 27-IR-0034 from the Tobacco Related Disease Research Program (TRDRP). The funder had no role in the design and conduct of the study; collection, management, analysis or interpretation of the data; or preparation, review or approval of the manuscript.

Author Contributions

Jessica Barrington-Trimis: Conceptualization; funding acquisition; investigation; methodology; project administration; resources; software; supervision; visualization. **Dayoung Bae:** Conceptualization; formal analysis; investigation; methodology; visualization. **Sara Schiff:** Investigation; project administration; visualization. **Jordan Davis:** Investigation; methodology; supervision; visualization. **Jennifer Unger:** Investigation; methodology; project administration; resources; supervision; visualization. **Adam Leventhal:** Conceptualization; data curation; funding acquisition; investigation; methodology; project administration; resources; supervision; validation; visualization.

References

1. Borodovsky J. T., Lee D. C., Crosier B. S., Gabrielli J. L., Sargent J. D., Budney A. J. U.S. cannabis legalization and use of vaping and edible products among youth. *Drug Alcohol Depend* 2017; **177**: 299–306.
2. Subritzky T., Pettigrew S., Lenton S. Issues in the implementation and evolution of the commercial recreational cannabis

market in Colorado. *Int J Drug Policy* 2015; https://doi.org/10.1016/j.drugpo.2015.12.001.
3. Drug Enforcement Administration (DEA). What You Should Know About Marijuana Concentrates. Springfield, CA: DEA; 2014.
4. Brohl B., Kammerzell R., Koski W. *Colorado Marijuana Enforcement Division: Annual Update*. Lakewood, CO: Colorado Department of Revenue; 2015.
5. Jones C. B., Hill M. L., Pardini D. A., Meier M. H. Prevalence and correlates of vaping cannabis in a sample of young adults. *Psychol Addict Behav* 2016; **30**: 915–21.
6. MacCoun R. J., Mello M. M. Half-baked—the retail promotion of marijuana edibles. *N Engl J Med* 2015; **372**: 989–91.
7. Budney A. J., Sargent J. D., Lee D. C. Vaping cannabis (marijuana): parallel concerns to e-cigs? *Addiction* 2015; **110**: 1699–704.
8. Friese B., Slater M. D., Annechino R., Battle R. S. Teen use of marijuana edibles: a focus group study of an emerging issue. *J Prim Prev* 2016; **37**: 303–9.
9. Miech R., Schulenberg J., Johnston L., Bachman J., O'Malley P., Patrick M. National Adolescent Drug Trends in 2017: Findings Released. Ann Arbor, MI: Monitoring the Future; December 14, 2017.
10. Friese B., Slater M. D., Battle R. S. Use of marijuana edibles by adolescents in California. *J Prim Prev* 2017; **38**: 279–94.
11. Morean M. E., Kong G., Camenga D. R., Cavallo D. A., Krishnan-Sarin S. High school students' use of electronic cigarettes to vaporize cannabis. *Pediatrics* 2015; **136**: 611–6.
12. Unger J. B., Johnson C. A., Stoddard J. L., Nezami E., Chou C. P. Identification of adolescents at risk for smoking initiation: validation of a measure of susceptibility. *Addict Behav* 1997; **22**: 81–91.
13. Forrester K., Biglan A., Severson H. H., Smolkowski K. Predictors of smoking onset over two years. *Nicotine Tob Res* 2007; **9**: 1259–67.
14. Pierce J. P., Choi W. S., Gilpin E. A., Farkas A. J., Merritt R. K. Validation of susceptibility as a predictor of which adolescents take up smoking in the United States. *Health Psychol* 1996; **15**: 355–61.
15. Peters E. N., Bae D., Barrington-Trimis J. L., Jarvis B. P., Leventhal A. M. Prevalence and sociodemographic correlates of adolescent use and polyuse of combustible, vaporized, and edible cannabis products. *JAMA Netw Open* 2018; **1**: e182765.
16. Daniulaityte R., Lamy F. R., Barratt M., Nahhas R. W., Martins S. S., Boyer E. W., *et al*. Characterizing marijuana concentrate users: a web-based survey. *Drug Alcohol Depend* 2017; **178**: 399–407.
17. Leventhal A. M., Strong D. R., Kirkpatrick M. G., Unger J. B., Sussman S., Riggs N. R., *et al*. Association of electronic cigarette use with initiation of combustible tobacco product smoking in early adolescence. *JAMA* 2015; **314**: 700–7.
18. Stone M. D., Audrain-McGovern J., Leventhal A. M. association of anhedonia with adolescent smoking susceptibility and initiation. *Nicotine Tob Res* 2017; **19**: 738–42.
19. Barrington-Trimis J. L., Leventhal A. M., Alonzo T. A., Cruz T. B., Urman R., Liu F., *et al*. Performance of cigarette susceptibility index among e-cigarette and hookah users. *Drug Alcohol Depend* 2018; **183**: 43–50.
20. Steiger J. H., Lind J. M. *Statistically based tests for the number of common factors*. Iowa City: Annual Meeting of the Psychometric Society, IA; 1980.
21. Bentler P. M. Comparative fit indexes in structural models. *Psychol Bull* 1990; **107**: 238–46.
22. Muthén K. L., Muthén B. O. *Mplus User's Guide, 7th edn. Los Angeles, CA: Muthén & Muthén; 1998–2017*.
23. Zeger S. L., Liang K. Y., Albert P. S. Models for longitudinal data: a generalized estimating equation approach. *Biometrics* 1988; **44**: 1049–60.
24. Rubin D. B. *Multiple Imputation for Nonresponse in Surveys*. Hoboken, NJ: John Wiley & Sons; 2004.
25. Benjamini Y., Hochberg Y. Controlling the false discovery rate: a practical and powerful approach to multiple testing. *J R Stat Soc B Methodol* 1995; **57**: 289–300.
26. Schauer G. L., King B. A., Bunnell R. E., Promoff G., McAfee T. A. Toking, vaping, and eating for health or fun: marijuana use patterns in adults, U.S., 2014. *Am J Prev Med* 2016; **50**: 1–8.
27. Singh T., Kennedy S. M., Sharapova S. S., Schauer G. L., Rolle I. V. Modes of ever marijuana use among adult tobacco users and non-tobacco users. *J Subst Use* 2016; **21**: 631–5.
28. Johnson R. M., Brooks-Russell A., Ma M., Fairman B. J., Tolliver R. L., Levinson A. H. Usual modes of marijuana consumption among high school students in Colorado. *J Stud Alcohol Drugs* 2016; **77**: 580–8.
29. Murphy F., Sales P., Murphy S., Averill S., Lau N., Sato S.-O. Baby boomers and cannabis delivery systems. *J Drug Issues* 2015; **45**: 293–313.
30. Warf B. High points: an historical geography of cannabis. *Geogr Rev* 2014; **104**: 414–38.
31. Johnston L. D., Miech R. A., O'Malley P. M., Bachman J. G., Schulenberg J. E., Patrick M. E.. Monitoring the Future National Survey Results on Drug use, 1975–2017: Overview, Key Findings on Adolescent Drug Use. Ann Arbor, MI: Institute for Social Research, University of Michigan; 2018.
32. Harpin S. B., Brooks-Russell A., Ma M., James K. A., Levinson A. H. Adolescent marijuana use and perceived ease of access before and after recreational marijuana implementation in Colorado. *Subst Use Misuse* 2018; **53**: 451–6.
33. Chan G. C. K., Hall W., Freeman T. P., Ferris J., Kelly A. B., Winstock A. User characteristics and effect profile of butane hash oil: an extremely high-potency cannabis concentrate. *Drug Alcohol Depend* 2017; **178**: 32–8.
34. Stogner J. M., Miller B. L. Assessing the dangers of 'dabbing': mere marijuana or harmful new trend? *Pediatrics* 2015; **136**: 1–3.
35. Monte A. A., Zane R. D., Heard K. J. The implications of marijuana legalization in Colorado. *JAMA* 2015; **313**: 241–2.
36. Vandrey R., Raber J. C., Raber M. E., Douglass B., Miller C., Bonn-Miller M. O. Cannabinoid dose and label accuracy in edible medical cannabis products. *JAMA* 2015; **313**: 2491–3.
37. Novak S. P., Peiper N., Wiley J. Linking animal models to human self-administration practices among medical cannabis patients: a daily diary study. *Drug Alcohol Depend* 2017; **100**: e153–e154.
38. Cavazos-Rehg P. A., Zewdie K., Krauss M. J., Sowles S. J. 'No high like a brownie high': a content analysis of edible marijuana tweets. *Am J Health Promot* 2018; **32**: 880–6.
39. Lamy F. R., Daniulaityte R., Sheth A., Nahhas R. W., Martins S. S., Boyer E. W., *et al*. 'Those edibles hit hard': exploration of twitter data on cannabis edibles in the U.S. *Drug Alcohol Depend* 2016; **164**: 64–70.
40. Barrus D. G., Capogrossi K. L., Cates S. C., Gourdet C. K., Peiper N. C., Novak S. P. *et al*. *Tasty THC: Promises and Challenges of Cannabis Edibles*. Methods Rep RTI Press; 2016. https://doi.org/10.3768/rtipress.2016.op.0035.1611.
41. Grotenhermen F. Pharmacokinetics and pharmacodynamics of cannabinoids. *Clin Pharmacokinet* 2003; **42**: 327–60.

42. Colorado Department of Public Health and Environment. Monitoring Health Concerns Related to Marijuana in Colorado: 2014. Denver, CO: Colorado Department of Public Health and Environment; 2014.

Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Table S1 Model fit comparison
Table S2 Association of demographic characteristics with susceptibility to cannabis use
Table S3 Associations of susceptibility to cannabis use with ever use of cannabis by wave 8, by cannabis product.

Figure S1 3-Factor CFA of susceptibility to cannabis use by susceptibility indicators
Fig S2 Single factor CFA of susceptibility to cannabis use
Fig S3 5-factor CFA of susceptibility to cannabis use.

