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Examining links between cannabis potency and mental and physical health outcomes

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ABSTRACT

Cannabis use is associated with unwanted health outcomes, including anxiety, depression, poor sleep hygiene, and disrupted cognitive functioning. However, research to date has not been able to disentangle the complexities of these relations, leaving behavioral health service providers lacking clear direction for treatment. A limiting factor may be the common practices for cannabis use assessment. Cannabis use is typically assessed by frequency, even though to estimate the amount of psychoactive compounds ingested potency, quantity, and route of administration should also be assessed. This study, one of the first of its kind, takes an important step in assessing cannabis use by studying the link between cannabis potency and behavioral health (i.e., physical and mental health) outcomes. Self-reported data were analyzed using the New Statistics, which focuses on effect sizes and confidence intervals, rather than null hypothesis significance testing. Findings were inconsistent, with some positive, some negative, and some trivial associations across four domains (i.e., demographic variables, cannabis use variables, mental health, and physical health). The most valuable discovery was the importance of method of administration in understanding the link between potency and health. We observed a "potency valley" (i.e., a range of potencies for which products were not available) between flower potencies and concentrate potencies. Further, collapsing potency data across flower and concentrated cannabis obscured important relations between cannabis potency and behavioral health outcomes. Findings suggest that to more fully understand the relation between cannabis potency and behavioral health outcomes, researchers should examine potency separately across routes of administration.

1. Introduction

Approximately 22.2 million Americans 12 years of age or older report cannabis use in the past 30 days (CBHSQ, 2016). However, the effects of cannabis use on unwanted behavioral health outcomes are not widely known. The National Academies of Sciences, Engineering, and Medicine (NAS, 2017) reviewed over 10,000 research reports on the health effects of cannabis use and concluded that, to date, there is "insufficient evidence to support or refute" (pg. 120) conclusions regarding cannabis' effects on a host of physical and mental health outcomes. The NAS' inability to make strong conclusions may be because cannabis use is overwhelmingly measured by having participants report on use frequency only (e.g., number of times/days used in the last 7 or 30 days, 6-months, or lifetime; Casajuana et al., 2016). The problem with relying on frequency as a measure of cannabis use is that cannabis use is complex, with at least 3 determining variables: quantity (how much cannabis is being used, typically measured in grams in states where medical and/or recreational cannabis use is legal, typically measured in Imperial system units, e.g., 8th of an ounce, in states where cannabis is not legally available for purchase), frequency (how often is cannabis being used), and potency (e.g., typically expressed as the Δ9-tetrahydrocannabinol (Δ9-THC or THC) concentration; Asbridge, Duff, Marsh, & Erickson, 2014). Of these three key indicators of cannabis use, potency of cannabis products has received the least attention by researchers.

1.1. Cannabis potency and physical and mental health

At present, potency may be especially important to measure when assessing cannabis use (Curran et al., 2016), as potency of available cannabis products increased, threefold from 1995 (~4% THC) to 2014 (~12% THC) (e.g., ElSohly et al., 2016; Smart, Caulkins, Kilmer, Davenport, & Midgette, 2017). Moreover, in states where recreational and medical use of cannabis is legal, potency tends to be much higher, ranging from ~16% THC (for cannabis flower) to 95% THC (for concentrated cannabis products). Also, research supports dose-dependent

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effects for most drugs (McCrady & Epstein, 2013). As such, there is a belief among cannabis researchers that increasing potency is related to increasing negative consequences from cannabis use, including cannabis use disorder (e.g., Lafaye, Karila, Blecha, & Benyamina, 2017; Pierre, 2017) and physical and mental health outcomes (Hall, 2015). However, it is difficult to find research in the literature that supports a link between use of higher potency cannabis and increased physical and mental health consequences. This is the result of at least 3 factors. First, until recently, cannabis potency information was unavailable to researchers observing cannabis use in the natural environment because cannabis was illicit in all 50 states in the United States. Second, researchers conducting controlled lab studies of the effects of cannabis are required to have a Schedule I license (Drug Enforcement Administration, 2010 CFR 1301.18) and are required to use standardized cannabis acquired from the National Institute on Drug Abuse (Stith & Vigil, 2016). The advantage to standardized cannabis products is high internal validity derived from knowledge of precise potency information; however, the disadvantage is that standardized cannabis available to researchers with a Schedule I license consists of low potency flower, compared to what is available in recreational and medical cannabis dispensaries, limiting ecological validity. Third, there is a growing number of cannabis products available to recreational and medicinal users covering a range of potencies (i.e., 0%–95% THC) and, since Schedule I researchers are limited to conducting controlled research using flower, there is no way to assess the link between these products and behavioral health outcomes.

One of the benefits of recent legislative changes to recreational and medicinal cannabis is the regulation of legally available cannabis products (Parnes, Bravo, Conner, & Pearson, 2018; Choo & Emery, 2017). For instance, in Colorado, all cannabis products sold for either medicinal or recreational use must be labeled including information on quantity and potency of the product contained in the packaging (https://www.colorado.gov/pacific/enforcement/med-rules). This provides access to information that is typically not known in states where cannabis is still being purchased illegally, wherein potency is often unknown (Kilmer, 2014). The advantage of conducting cannabis research in one of the 9 states with legal recreational and medicinal cannabis use is the collection of potency data directly from state-regulated product labels purchased by recreational and medicinal cannabis users.

As noted above, research studies on cannabis potency and behavioral health are difficult to find. There have been some lab-based administration studies that have attempted to establish potency-dependent relations between cannabis use and physical and mental health outcomes. For example, Miller and Cornett (1978) found that higher concentrations of THC were related to worse memory free recall in 16 male participants. Tinkleberg and colleagues (1970) found potency-dependent effects of THC on immediate memory in 8 males. However, both of these studies were conducted in the 1970s with small samples of males, using only flower acquired from NIDA, limiting their generalizability. There has been at least one observational study on cannabis potency and prevalence of cannabis use disorder (CUD) symptoms, conducted in the Netherlands, which found a positive association between cannabis potency and CUD symptoms among recreational users who provided their own products (van der Pol et al., 2014). Taken together, over the past 5 decades, both laboratory and observational research on the association between cannabis potency and health outcomes is sparse, limited to flower, and limited in generalizability.

1.2. Cannabis methods of administration

In addition to potency, it is important to assess how cannabis is being used. Common consumption methods include smoking flower (the unrefined bud of the plant) or concentrated cannabis products (refined from flower into a more potent form, such as wax, shatter, resin, use of which is often referred to as dabbing), vaporizing flower or concentrates, eating foods that contain cannabis, and using topical solutions that contain cannabis (Choo & Emery, 2017). There is variability both within and between methods of consumption in the amount of psychoactive compound ingested, potency, time to intoxication, and degree of intoxication (Williams & Bretteville-Jensen, 2014). It is also known that pharmacodynamics and pharmacokinetics of varying methods of administration of cannabis lead to differing rates of absorption of cannabinoids (Grotenherman, 2003; Ohlsson et al., 1980). In other words, it is possible that 0.25 g of flower at 20% THC will have a different impact on a person when compared to 0.0625 g of concentrated cannabis at 80% THC even though the amount of THC ingested is equivalent across these two preparations.

Anecdotally, cannabis users believe that certain methods of administration are “safer” or “healthier” than others, despite little research supporting these assumptions (e.g., Russell, Rueda, Room, Tyndall, & Fischer, 2018). In fact, most research either does not assess method of administration, or even when assessed, collapses cannabis use data into just a frequency variable, which imposes a number of assumptions that there is little to no research to support (NAS, 2017). For example, two individuals using at the same frequency may consume different quantities, and two individuals using the same quantity at the same frequency may consume products with different potency. These same two individuals may use the same amount at the same frequency, but use two different methods of consumption (e.g., smoking concentrates versus smoking flower). It follows that reporting on frequency alone gives no indication regarding how much of the active compounds of cannabis an individual has consumed. Collapsing cannabis use into a single data point, frequency, has likely negatively affected researchers' abilities to detect significant associations between cannabis use and mental and physical health outcomes. No research could be located assessing relations between cannabis methods of administration and behavioral health outcomes.

1.3. Known mental and physical health and cannabis associations

The comprehensive report produced by the National Academies of Sciences (2017) [1] reviews literature that indicates that there is moderate to strong evidence of the beneficial and adverse effects of cannabis use on physical and mental health, including development of CUD and alterations to digestion, mental health, and pulmonary functioning. It should be noted that, in most of the findings reviewed, cannabis use is measured as frequency of use. Cannabis use is positively associated with the development of CUD. It is also positively associated with schizophrenia and other psychotic disorders, however, there is also moderate evidence that cannabis use is associated with better cognitive performance in individuals diagnosed with psychotic disorders. Cannabis use is associated with increased symptoms of mania and hypomania in individuals diagnosed with bipolar disorders, along with an increased risk for developing depressive disorders. There is moderate evidence supporting an association between cannabis use and increased incidence of suicidal ideation, suicide attempts, and suicide completion. There is also moderate evidence of an association between cannabis use and the development of social anxiety disorder, which is paradoxical given research that indicates that individuals with social anxiety use cannabis to treat their symptoms (e.g., Rahm et al., 2018) and that indicates that a benefit of acute cannabis use is the reduction of social anxiety symptoms (NAS, 2017). There is substantial evidence that cannabis use is associated with worsening respiratory symptoms and more frequent chronic bronchitis episodes. There is strong evidence that cannabis use reduces chronic pain. Recent research (Mooney et al., 2018), conducted

[1] Note that all of the research reported in this section was reviewed in the NAS report, primary sources for these findings can be found here: http://www.nationalacademies.org/hmd/Reports/2017/health-effects-of-cannabis-and-cannabinoids.aspx.

after the NAS report, indicates a negative association between frequency of use in the past week and self-reported better global health, appetite, sleep, and cognitive functioning and fewer depression and anxiety symptoms. However, a number of areas where there is limited or no research support for the effects of cannabis use remain.

1.4. Unknown or inconclusive associations between cannabis use and mental and physical health

The primary consequence of the failure to adequately measure cannabis use (e.g., assessing quantity, frequency, potency, and method of administration) is a staggering number of unknown relations between cannabis and mental and physical health outcomes (NAS, 2017). Not only are there multiple medical and psychological conditions wherein the impact of cannabis use is unknown, including development of asthma, asthma exacerbation, alterations in cardiac functioning, impact on course or symptoms of depressive disorders, the development of posttraumatic stress disorder (PTSD), and the course of PTSD, there is limited research on the impacts of repeated cannabis administration on cognitive functioning and mood (NAS, 2017). Better understanding these relations is important, as recent research indicates that individuals seeking care in the emergency room who reported cannabis use were 5 times more likely to have a mental health disorder than those not reporting cannabis use (Hall et al., 2018).

An additional consequence of failures to accurately measure cannabis use is limited understanding of the medicinal uses of cannabis. While research supports the use of cannabis in treating some conditions (described above), without measures of dose, it is difficult to determine appropriate treatment regimens, even when preliminary research indicates that cannabis use may have ameliorative effects (Sznitman & Room, 2018). Though research has been conducted to determine medicinal benefits of cannabis, there are still a number of conditions for which no or insufficient evidence exists regarding whether cannabis is effective at treating, including cancers, anorexia nervosa, irritable bowel syndrome, epilepsy, symptoms of spinal cord injury, symptoms associated with amyotrophic lateral sclerosis, symptoms associated with Huntington's disease, symptoms associated with Parkinson's disease, or achieving abstinence from other licit and illicit substances (NAS, 2017). Given the number of unknowns, the WHO (2016) has called for epidemiological and longitudinal studies that include more complete measures of cannabis use to determine dose-response relations between cannabis use and different types of physical and mental health disorders.

Table 1
Descriptive data.

	Combined		Flower		Concentrate	
	%	M (SD)	%	M (SD)	%	M (SD)
THC Variables						
% THC		38% (27.5)		20% (6.3)		76% (13.2)
Type (% Flower)		55.6%		–		–
Demographic						
Age		30.4 (7.1)		31.1 (6.5)		29.8 (7.1)
Age of Onset		17.7 (5.5)		17.5 (5.7)		17.0 (2.8)
Industry (% Yes)		5.9%		7.4%		4.5%
Cannabis Use						
30 Day Use		24.3 (9.6)		25.9 (7.5)		28.1 (7.6)
Negative Consequences		7.3 (8.1)		7.8 (7.8)		6.4 (6.7)
CUD Symptom Count		3.9 (3.7)		4.1 (3.7)		4.0 (3.7)
Mental Health						
Any (% yes)		82.7%		87.2%		70.5%
Count		7.2 (6.2)		7.6 (6.3)		6.1 (6.6)
Depression		1.1 (1.2)		1.0 (1.1)		1.3 (1.3)
Anger		.81 (.94)		.79 (.92)		.88 (1.0)
Mania		.86 (1.2)		.90 (1.2)		.76 (1.2)
Anxiety		1.3 (1.2)		1.3 (1.2)		1.2 (1.3)
Somatic Symptoms		.91 (1.2)		.89 (1.2)		.88 (1.2)
Suicidal Ideation		.34 (.82)		.39 (.91)		.23 (.75)
Psychosis		.21 (.68)		.20 (.57)		.16 (.75)
Sleep Problems		.66 (1.0)		.58 (.90)		.72 (1.1)
Memory		.56 (.90)		.54 (.84)		.55 (1.0)
Repetitive Thoughts and Behaviors		.53 (.96)		.54 (.94)		.39 (1.0)
Dissociation		.45 (.92)		.43 (.85)		.51 (1.1)
Personality Functioning		.85 (1.1)		.83 (1.1)		.71 (1.0)
Substance Use		1.2 (1.5)		1.37 (1.6)		1.1 (1.4)
Physical Health (% Yes)						
Any Physical Health		82.8%		84.0%		81.8%
Count Physical Health		29.2 (51.3)		32.8 (52.7)		31.5 (56.5)
General Physical Health		60.4%		63.8%		50.0%
Ear/Nose/Throat		53.3%		53.2%		50.0%
Neck		34.3%		36.2%		38.6%
Respiratory		47.3%		51.1%		52.3%
Cardiovascular		37.9%		40.4%		31.8%
Gastrointestinal		54.4%		57.4%		50.0%
Orthopedic/Pain		52.1%		54.3%		56.8%

Note: % refers to percentage of participants endorsing the indicated option.

1.5. Present study

Given how little is known about the relations between physical and mental health outcomes and cannabis potency, we set out to explore these associations among cannabis users in Colorado. Our primary goal was to determine whether potency was associated with a range of physical and mental health outcomes, negative cannabis-related consequences, and cannabis use disorder. We also investigated whether different routes of administration were important in describing associations between potency and health. Given the lack of research in this area, we have only one directional hypothesis, i.e., that higher potency portends greater risk. More specifically, based on scientific conjecture and limited research, we expected a positive association between high potency cannabis products and physical and mental health outcomes, including cannabis-related outcomes. Finally, we sought to describe the range of potency available in a state with legal recreational cannabis for both flower and concentrated cannabis products.

2. Method

2.1. Participants

156 cannabis users were recruited using Facebook advertising limited to the Front Range region of Colorado (i.e., Denver, Boulder, Fort Collins, and surrounding areas). Participants were almost equally split male (47.9%) to female, predominantly self-identified one race[2] (88.4%), and non-Hispanic (80.3%). The average age of participants was 30.4 (SD = 7.1, 18.1 to 53.1). Participants reported using cannabis on average 24.2 days in the past 30 days (SD = 9.6). Additional descriptive information is provided in Table 1.

2.2. Procedures

At the time of data collection, Colorado had legalized recreational cannabis and retail stores were open and easily accessible. Participants who clicked on the Facebook advertisement were directed to a survey on a secure server where they completed informed consent electronically. Participation was anonymous. At the end of the survey, participants were sent to a separate webpage to enter their email address to receive a $10 Amazon gift card for their participation. Participants' email addresses could not be linked to their data. Eligibility criteria included: English-speaker; age 21–64 years (M = 30.4; SD = 7.1); and

[2] Due to a data collection error, exact frequency data on self-reported race is unavailable, however, given that the data were collected from the Denver, CO metropolitan area, in which 77.5% of the population self-report as White, one can assume that the majority of our sample would have self-identified as White.

at least monthly cannabis use. Eligibility criteria served to ensure participants could take part in all aspects of the study, were in the age range associated with the highest prevalence of cannabis use and used cannabis regularly. This research was approved by the Institutional Review Board of Colorado State University.

2.3. Measures

2.3.1. Demographics

Participants self-reported a number of demographic variables. For the present study, we included participant age and participant response to the question "Do you work in the marijuana industry?" in all analyses.

2.3.2. Cannabis use

Cannabis use frequency was assessed with a single self-report item asking participants to indicate "How many days in the past 30 days have you used marijuana?". We also assessed age of onset of cannabis use by asking participants "How old were you the first time you used marijuana?".

2.3.3. Cannabis potency

Participants were asked to report the percent THC of the products they reported using. In addition, participants were given the option to upload an image of the label that included potency information. While all participants self-reported potency data, only 24% of participants chose to upload an image. The images were compared to the self-report data and the concordance rate was 96%.

Participants were given the option to self-report potency information for up to 5 products (see Table 2). 60% of the total sample reported potency information for only one product. Of those reporting on one product, 63% reported potency for a flower product. For the purposes of the current study we did not include edible or topical cannabis products, as potency of these products is assessed differently (i.e., mg of THC) than inhaled products (i.e., flower and concentrated cannabis, with potency reported as % THC). Specifically, 21 out of 159 participants reported using only edible or topical products and were excluded. We included in our analyses the potency of one flower or concentrated cannabis product for which potency information was provided (N = 138). When participants reported multiple flower and/or concentrated cannabis products (n = 63), the product with the highest potency was used. This resulted in selecting the concentrated cannabis product over the flower product in all cases (n = 32). In cases where participants reported more than one product of the same type or with one flower or concentrate and an edible or topical product (n = 31; e.g., two or more flower products; two or more concentrated cannabis products; one flower or concentrated cannabis product and an edible or topical) the highest potency product was analyzed.

Table 2
Number of participants reporting product combinations by number of products.

One Product Reported (n = 75)					
F = 60	C = 15	~~O = 20~~			
Two Products Reported (n = 34)					
FF = 14	C**C** = 6	F**C** = 7	FO = 6	CO = 1	~~OO = 1~~
Three Products Reported (n = 17)					
FFF = 6	FF**C** = 2	F**C**C = 6	**C**CC = 3		
Four Products Reported (n = 9)					
FFFF = 4	FFF**C** = 1	F**C**OO = 1	**C**CCC = 3		
Five Products Reported (n = 3)					
FFF**C**C = 1	FFF**C**O = 1	**C**CCC = 1			

Note: F = Flower; Concentrate = C; O = Other; Other = Edibles and Topicals; ~~Strikethrough~~ = Individuals not included in analysis; **Bold** = **product chosen for analysis given like products ordered by potency**.

2.3.4. Cannabis-related negative consequences

Cannabis-related negative consequences were measured using the Marijuana Consequences Questionnaire (MACQ; Simons, Dvorak, Merrill, & Read, 2012). The MACQ assesses 50 cannabis-related negative consequences over the past month. Responses options are 1 = "yes" and 0 = "no". A sum of all endorsed items was used to calculate a total score, with higher scores indicating a greater number of negative consequences experienced.

2.3.5. Mental health

Mental health was assessed with the DSM-5 Cross-Cutting Symptom Measure – Adult (Narrow et al., 2013). Each item on the measure is rated on a 5 point Likert-type scale from 0 (None or Not at All) to 4 (Severe or Nearly Every Day). Initial scoring followed the rubric described by the scale developers. To score the measure, the highest score on any item within any of the 13 domains assessed (i.e., Depression, Anger, Mania, Anxiety, Somatic Symptoms, Suicidal Ideation, Psychosis, Sleep Problems, Memory, Repetitive Thoughts and Behaviors, Dissociation, Personality Functioning, Substance Use) is used as the domain score. We computed two additional mental health variables to better understand associations between potency and overall mental health. One indicating a sum of the highest domain scores across all domains, called Mental Health Count, and one that was a dichotomized variable indicating a score greater than zero in any domain, called Any Mental Health.

2.3.6. Physical health

Physical health was assessed with a general medical conditions checklist that was adapted from a set of tools available to medical practices offered by the American College of Physicians (https://www.acponline.org/), commonly used in hospitals and primary care settings. It is a checklist of possible conditions sorted into domains (e.g., ear, nose, throat, respiratory). For the current study we collected data on 54 conditions across 7 areas: General Physical Health, Head, Eyes, Ears, Nose, and Throat, Neck, Respiratory, Cardiovascular, Gastrointestinal, and Orthopedic domains. Participants were asked to check each box for conditions they have experienced within each domain on a recurrent basis. Data from this checklist were collapsed into endorsement of any condition in a domain receiving a score of 1 and no endorsements receiving a score of 0. Two variables were created to assess physical health, one indicating a sum of the conditions indicated across all conditions, referred to as Physical Health Count, and one that was a dichotomized variable indicating at least one condition endorsed across all domains, referred to as Any Physical Health. This novel approach allowed us to assess the relations among cannabis potency and both overall and symptom domain level physical health.

2.3.7. Cannabis use disorder

We assessed CUD with a measure consisting of questions that mapped onto the symptoms of CUD. The scale contains 13 questions (e.g., "In the past month, have you used marijuana in larger amounts or over a longer period than was intended?", "In the past month, have you continued to use marijuana use despite having persistent or recurrent social or interpersonal problems caused or exacerbated by the effects of marijuana.") rated on a 4 point Likert-type scale from 0 (Not at All) to 3 (To a Great Extent). Data were recoded so that a score greater than 0 on any item was scored as a 1 while all scores of 0 were scored as 0. The items were then summed, giving a CUD symptom count score.

2.4. Analyses

Given the limited research on the links between cannabis potency, type of cannabis (i.e., flower vs. concentrated cannabis) and physical and mental health outcomes, we adopted an analytic approach that places less of an emphasis on alpha levels connoting statistical significance and places a greater emphasis on interpreting the magnitude

of observed effects. Specifically, we used the New Statistics (cf. Cumming, 2013, 2014; Eich, 2014) to analyze data using strategies that do not rely on null hypothesis significance testing (NHST). This approach focuses on effect size estimates, confidence intervals, and the accumulation of evidence rather than on p-values to draw conclusions from data (Cumming, 2013; 2014). Effect sizes present information about the magnitude and direction of the effect, confidence intervals provide information about the precision of the estimates, and overall the focus shifts from dichotomous decision making (i.e., significant or not) to a focus on estimation of the effect. Further, effect size estimates are free from Type-I and Type-II error rates (which only apply to decisions based on p-values) and are more easily integrated with other research findings using meta-analytic strategies.

In the present study, all analyses were conducted in R (R Core Team, 2018). Figures were created using the GGPLOT2 package (Wickham, 2016). We reported Pearson's r effect sizes (Cohen, 1988) when comparing groups. Pearson's r has well-established cutoff values for small (0.1), medium (0.3), and large (0.5) effect sizes. We add to this list, "trivial", which we define as a correlation between 0 and an absolute value of 0.1. Asymmetrical confidence intervals can be calculated around these effect size values to provide information about the precision of the estimates (Cumming, 2013). It should be noted that, unlike confidence intervals around means, confidence intervals around Pearson's r correlations are not symmetrical because the distribution of r is skewed by being capped at −1 and 1. We calculated asymmetrical confidence intervals (CIs) based on equations provided in Loftus and Loftus (1988). Note that when interpreting point estimates and CIs, the most likely value for the parameter in a population is at the estimate with values near to the limits of the CIs being far less plausible (Cumming, 2013). Missing data were handled using pairwise deletion and CIs for each reported correlation were based on the n for that specific bivariate test.

3. Results

Analysis of the descriptive data indicated that, across methods of administration, cannabis potency averaged 38% THC, with 20% being the average for flower and 76% being the average for concentrated cannabis products. While average age in the total sample was approximately 30 years old, those reporting potency of only cannabis flower tended to be older than those reporting potency of concentrated cannabis. The average number of days of use was 24.3 days, with those reporting potency of concentrated cannabis use reporting higher past 30 day use frequency. Additionally, those who reported potency of a concentrated cannabis product reported less incidence of any mental health symptom (70.1% compared to the combined sample, 82.7% and those reporting flower potency 87.2%). While these were the largest differences, there were other, smaller, observable differences between descriptive statistics and method of administration (see Table 1).

Our directional hypothesis that higher cannabis potency would be associated with greater endorsement of health outcomes was not supported. Specifically, findings, which are described in detail below, were inconsistent. Table 3 presents the Pearson's r value and 95% CIs for the associations among combined potency (% THC across flower and concentrate products), method of administration (flower vs. concentrates), and outcome variables of interest arranged in the following domains: demographic variables, cannabis use variables, mental health variables, and physical health variables. We present separate correlations and 95% CIs broken down by potency within flower and concentrated cannabis products.

3.1. Potency overall

Correlations and 95% CIs between potency and the outcome variables are presented in Fig. 1. Among the demographic variables, the largest effect was for age, with younger participants reporting using higher potency products, this was followed by age of onset, in the same direction with smaller magnitude, while industry status had essentially no association with potency.

Table 3
Correlations and asymmetrical 95% confidence intervals.

	Combined		Flower		Concentrate	
	r	95% CI	r	95% CI	r	95% CI
Demographic	n = 119–130		n = 82–88		n = 37–42	
Age	-.13	-.30, .05	-.16	-.36, .06	.02	-.31, .34
Age of Onset	-.09	-.26, .09	-.16	-.36, .06	-.03	-.34, .28
Industry	-.01	-.18, .16	-.14	-.34, .07	-.16	-.44, .15
Cannabis Use	n = 127–129		n = 86–88		n = 41–42	
30 Day Use	.24	.07, .40	.37	.17, .54	.47	.19, .68
Negative Consequences	-.02	-.19, .15	.11	-.10, .31	.26	-.05, .53
CUD	.03	-.14, .20	.09	-.12, .30	-.05	-.35, .26
Mental Health	n = 128–129		n = 87–88		n = 41	
Any	-.13	-.30, .04	-.08	-.28, .13	.34	.04, .59
Count	-.12	-.29, .05	-.20	-.39, .01	.23	-.08, .50
Depression	.14	-.03, .31	.02	-.19, .23	.17	-.15, .45
Anger	.04	-.14, .21	-.11	-.31, .10	.21	-.10, .49
Mania	-.01	-.18, .16	.01	-.20, .22	.25	-.06, .52
Anxiety	-.03	-.20, .14	.03	-.18, .24	.21	-.10, .49
Somatic Symptoms	-.01	-.18, .16	-.07	-.28, .14	.07	-.24, .37
Suicidal Ideation	-.09	-.26, .08	-.04	-.25, .17	.06	-.25, .36
Psychosis	-.04	-.21, .13	-.27	-.45, −.06	.11	-.20, .40
Sleep Problems	-.05	-.12, .22	-.07	-.28, .14	.14	-.18, .43
Memory	-.04	-.22, .12	-.26	-.45, −.05	.07	-.24, .37
Repetitive Thoughts and Behaviors	-.06	-.23, .11	-.10	-.30, .11	.10	-.21, .40
Dissociation	.05	-.12, .22	-.03	-.24, .18	.04	-.27, .34
Personality Functioning	-.03	-.20, .14	-.07	-.28, .14	.18	-.14, .47
Substance Use	-.10	-.27, .07	-.09	-.29, .12	.06	-.25, .36
Physical Health	n = 130		n = 88		n = 42	
Any Physical Health	.09	-.08, .26	.03	-.18, .24	.57	.32, .74
Count Physical Health	.00	-.17, .17	-.22	-.41, −.01	.16	-.15, .44
General Physical Health	-.08	-.25, .09	.07	-.14, .28	.18	-.13, .46
Ear/Nose/Throat	-.01	-.18, .16	-.13	-.33, .08	.25	-.06, .51
Neck	.03	-.14, .20	-.21	-.32, .09	.19	-.12, .47
Respiratory	.03	-.14, .20	-.24	-.43, −.03	.36	.06, .60
Cardiovascular	-.10	-.27, .07	-.18	-.38, .03	.10	-.21, .39
Gastrointestinal	-.05	-.22, .12	-.12	-.32, .09	.27	-.04, .53
Orthopedic/Pain	.05	-.12, .22	-.04	-.25, .17	.21	-.10, .48

Note: Pearson's r effect sizes are interpreted as trivial when between 0 and 0.1, small when between 0.1 and 0.3, moderate when between 0.3 and 0.5 and large when 0.5 or greater.

For cannabis use variables, there was a small to medium sized positive effect for past 30 day use, such that those who reported using more often also reported using higher potency products. The effects for the associations between cannabis potency and negative cannabis-related consequences and CUD symptoms were essentially zero.

Regarding mental health symptoms, there were small to moderate negative associations between %THC and reporting any mental health problems and with the count of mental health problems reported, such that overall, those who reported any or higher counts of mental health problems reported less potent products. In contrast, the strongest mental health effect overall for potency was with depression. This was a small to moderate positive association, such that those who reported depression symptoms also reported higher potency products. Of the remaining mental health symptoms, the two largest associations were with substance use and somatic complaints, both of which were small and negative. The remainder of mental health symptoms associations with potency were trivial to small and tended to be negative.

There was a small positive association between reporting any physical health symptom and potency, such that those who reported any physical health symptoms also reported higher potency products. However, this association did not hold for the count of physical health

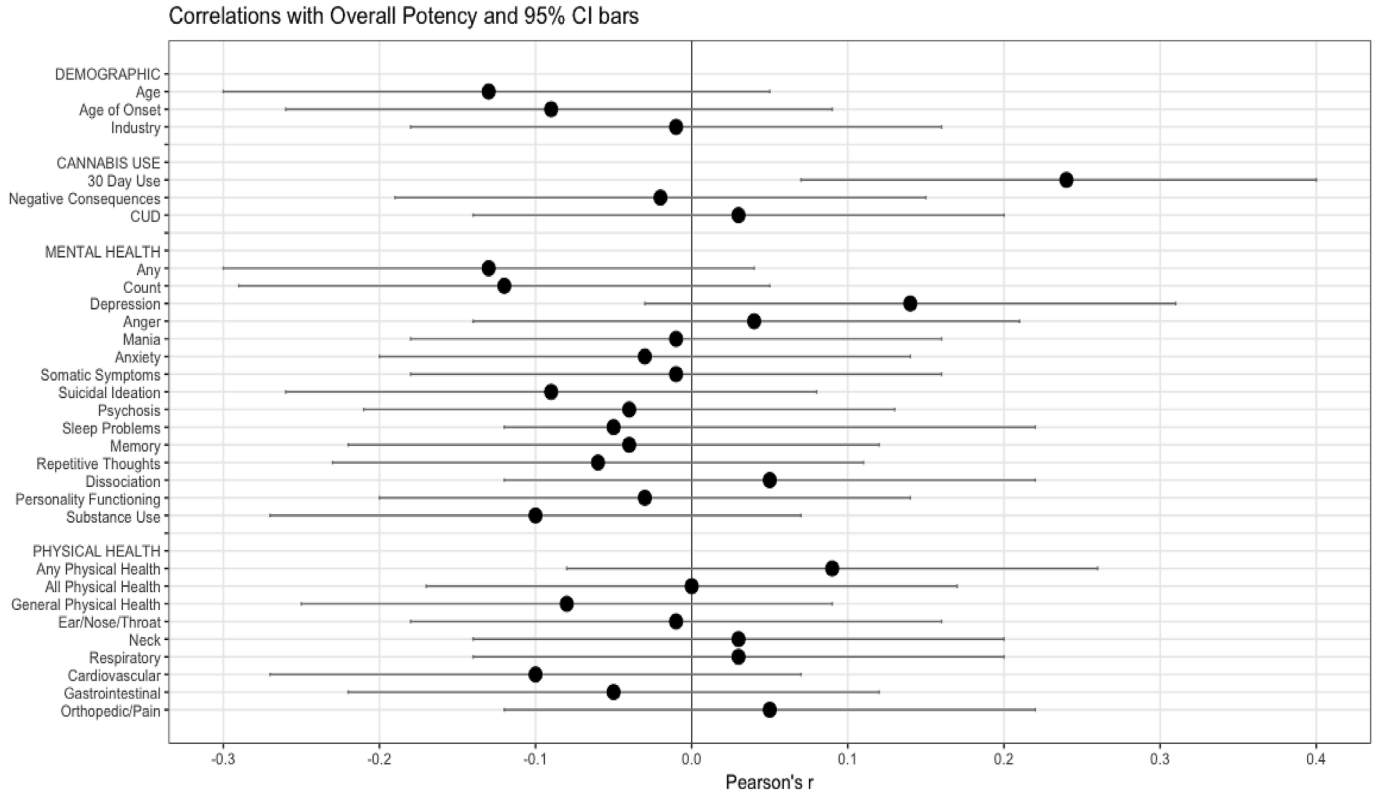

Fig. 1. Associations between THC potency and outcome variables collapsed across flower and concentrated cannabis products. The vertical line at 0 indicates no association. For each variable, the black dot represents the point estimate (i.e., the Pearson's r value), and the bars represent the 95% CIs. Note that the most likely value for the population level association is at the point estimate with values at the end of the interval being approximately 7 times less likely (Cumming, 2013).

symptoms, which had no association with potency. Regarding specific physical health symptoms, in general, associations were trivial and not in a consistent direction. Together, this suggests that there is not an interpretable association between physical health symptoms and potency.

Next, we examined correlations between cannabis potency and outcome variables by those reporting flower versus concentrated cannabis products. Overall, when examined separately, the effects were more pronounced and often in different directions (See Figs. 2 and 3).

3.2. Potency of flower

When examining the relations among demographic variables and potency of cannabis flower, all effects were small to moderate and negative, such that those who were younger, had a younger age of onset, and those who work in the cannabis industry reported higher potency flower. In contrast, among cannabis use variables all effects were small to moderate and positive, such that those who use more frequently, those who reported more negative consequences, and those who endorsed more CUD symptoms reported higher potency flower.

The associations between potency of cannabis flower and mental health symptoms tended to be negative, such that those reporting mental health symptoms also reported lower potency products. The association for the count of all mental health symptoms endorsed and potency of cannabis flower was between small and moderate, and the association with endorsing any mental health symptoms was small. For the specific mental health symptoms, effects tended to be negative and ranged from trivial to moderate, with the strongest effects being for psychosis, memory, depression, repetitive thoughts, and substance use, in that order.

Similarly, for physical health, most of the associations were small to moderate and negative. Participants who reported a greater count of physical health symptoms reported less potent cannabis flower, but the effect did not hold for those who endorsed any compared to no physical health symptoms. The largest negative associations were between respiratory problems, neck problems, cardiovascular problems, ear, nose, and throat problems, and GI problems, in that order, such that those endorsing these health symptoms also reported lower potency cannabis flower. The associations between general physical health and orthopedic pain and cannabis flower potency were trivial.

3.3. Potency of concentrates

When examining the relations among demographic variables and %THC of concentrated cannabis, there was a small to moderate effect for industry status, such that those who worked in the cannabis industry reported selecting higher potency concentrated cannabis products compared to those who did not report working in the industry. There was no association for age or age of onset with the %THC of cannabis concentrate. For cannabis use variables, there was a moderate to strong association with past 30 day use, such that those who reported using more frequently reported higher potency concentrated cannabis products. There was also a positive moderate association for negative cannabis related consequences such that those who reported more consequences reported higher potency concentrated cannabis products. There was no association between CUD symptoms and %THC of concentrated cannabis products.

Associations between mental health problems and cannabis concentrate %THC were generally positive and ranged from small to large, such that those who endorsed mental health symptoms also reported higher potency concentrated cannabis products. The effect was the largest for any mental health problem and was in the same direction but smaller for the count of mental health symptoms. For specific mental health symptoms, the largest positive association was between concentrated cannabis potency and mania, closely followed by anger and anxiety, and then by depression and personality. In all, 8 out of 13

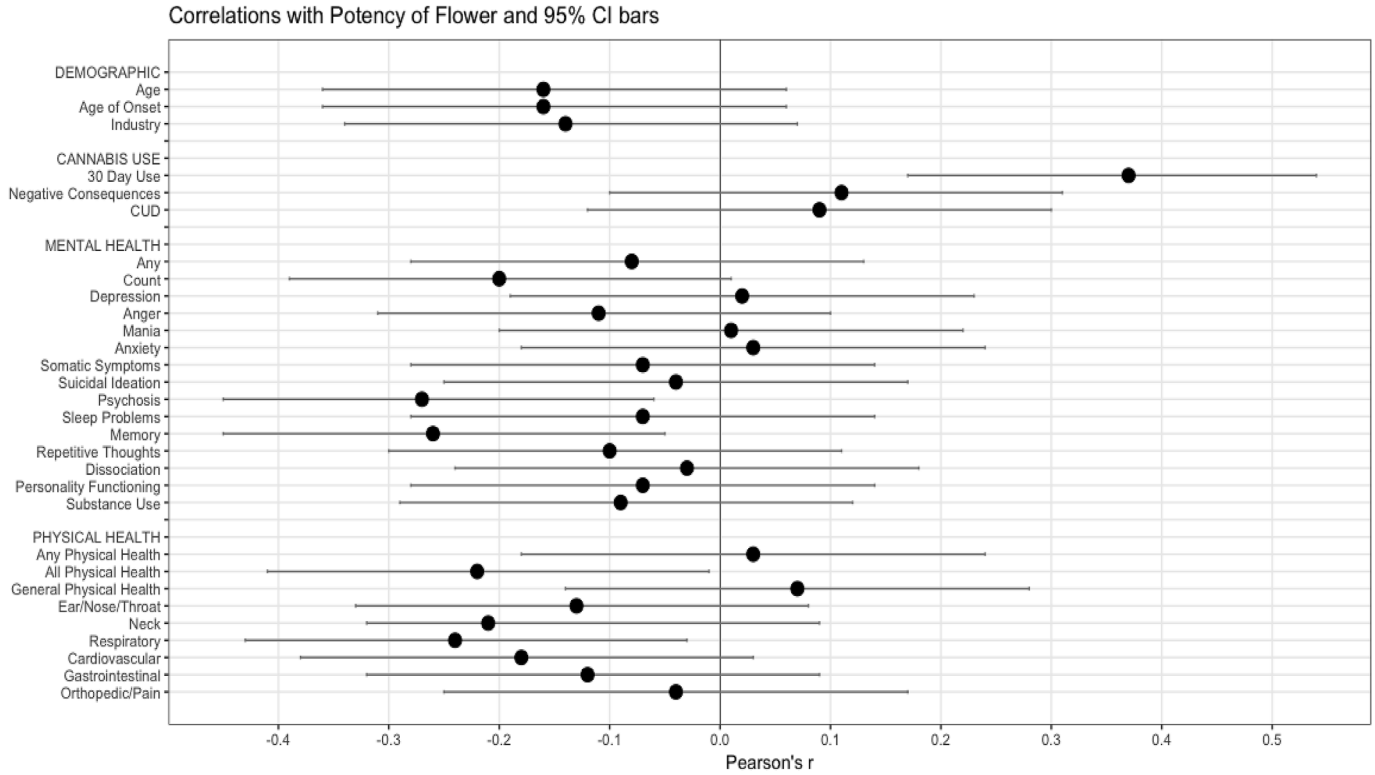

Fig. 2. Associations between THC potency and outcome variables for flower cannabis products.

mental health symptoms had a small to large positive association with concentrated cannabis potency, and the remaining 5 mental health symptoms were positive, but trivial to small.

Regarding the associations between physical health symptoms and concentrated cannabis potency, all of the effects were small to large and positive, such that those who reported physical health problems, also reported selecting higher potency concentrated cannabis products. The largest effect was for reporting any physical health symptom compared to none, and the effect held but was smaller for the count of physical health problems. Among the physical health symptom domains, the

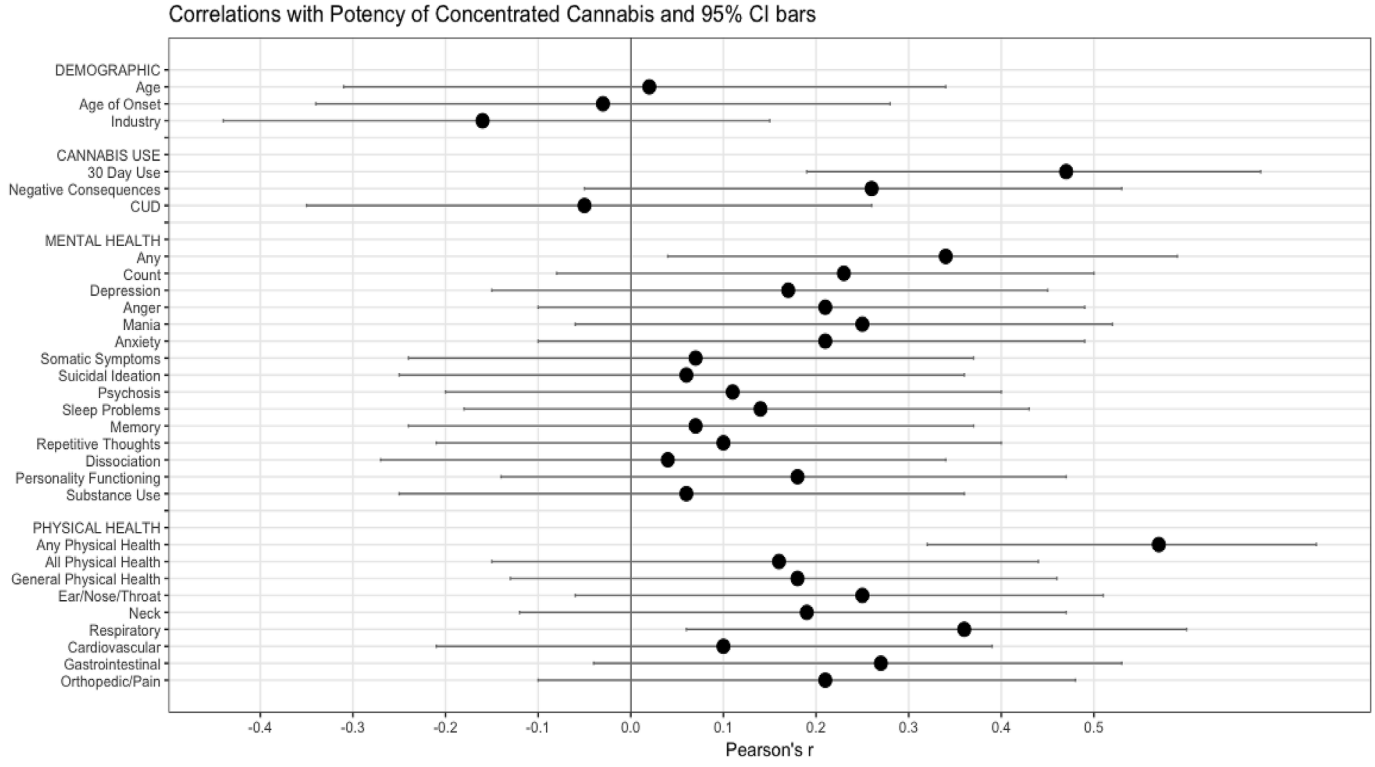

Fig. 3. Associations between THC potency and outcome variables for concentrated cannabis products.

strongest positive association was for respiratory problems, followed by ears, nose, and throat problems, and cardiovascular problems. The remaining physical health symptoms had weaker associations with the potency of concentrated cannabis, but all were greater than or equal to 0.1 (i.e., a small effect).

4. Discussion

4.1. Summary of findings

The current study explored the role of potency in the association between cannabis use and mental and physical health outcomes. The overall findings were inconsistent, with some positive, some negative, and some trivial associations across domains of interest (i.e., demographic variables, cannabis use variables, mental health, and physical health). Our data did not support our hypothesis that higher potency cannabis products would be associated with greater endorsement of negative outcomes across domains in the overall sample because of this inconsistency.

The most striking discovery was the importance of method of administration. We discovered an inherent bimodality of a combined potency variable with data clustered at values around 20% THC for flower and 76% THC for concentrated cannabis. In other words, we observed a "potency valley" between flower and concentrated cannabis products, making potency a discontinuous variable, resulting in a violation of the normality assumption for most parametric statistical tests. We found that collapsing potency data across flower and concentrated cannabis products obscured important relations. When analyzed separately, findings were more consistent for concentrates than for flower with effects between concentrates and outcomes all in the same, positive, direction but varying in magnitude. In fact, when analyzing concentrated THC products separately, we have support for our hypothesis. However, given the lack of previous research in this area, we were unable to hypothesize that the relation between potency and physical and mental health outcomes would vary so strongly by method of administration at the outset of the study.

A common finding in the literature is that negative cannabis-related consequences are associated with more frequent cannabis use (e.g., Pearson, Bravo, Conner, & MOST, 2017). In our data, those who reported using more frequently also reported using more potent products for both methods of administration and when analyzing combined data. Interestingly, when we analyzed data across methods of administration there was no association between negative consequences and potency, which would lead one to conclude that the link between cannabis use and negative consequences is due solely to frequency of cannabis use and not potency. However, when analyzing associations by methods of administration there was a small positive association between negative consequences and potency of flower, while there was a moderate positive association between negative consequences and potency of concentrated cannabis products. This pattern of findings, where there was no effect in the combined data and two positive effects in the separate data results from the potency valley. When taken together the effect appears to be 0, but when analyzed separately by method of administration the positive effects emerge, leading us to conclude that potency is positively associated with negative consequences. In other words, potency data must be analyzed by method of administration to observe the positive associations with negative consequences.

In the present study, the effect of the potency valley is best illustrated by examining the pattern of results relating health and potency. Specifically, in the combined data, the vast majority of associations between potency and physical and mental health were trivial. However, once separated by method of administration, two clear patterns emerged. For cannabis flower, associations between physical and mental health and potency were consistently negative ranging from trivial to moderate; whereas for concentrated cannabis products associations between physical and mental health and potency were consistently positive ranging from trivial to large. Another example includes one of the strongest associations we found with the collapsed potency data. For depression, those who reported more severe depressive symptoms reported using higher potency products. However, when separated by method of administration, there was no association between severity of depressive symptoms and potency of flower, while there was a small to moderate positive association with potency of concentrated cannabis products.

Once we determined the importance of method of administration in understanding the associations between cannabis potency and outcomes, we also saw patterns emerge among potency descriptive variables. Those reporting potency of concentrated cannabis reported fewer mental and physical health symptom incidence and total count, younger age of onset, younger age, and using more in the last 30 days. They also reported experiencing fewer negative consequences. This indicates that while concentrate reporters are younger and using at higher rates, they are currently experiencing fewer negative cannabis-related, mental health, and physical health consequences from their cannabis use. However, more research is needed as this may be related to the number of years they have been using.

A lurking variable in the relation between potency and health is percent CBD. It may be the case that negative relations observed between THC potency for flower and health outcomes results from participants selecting higher CBD products, as there is a common belief that CBD has ameliorative effects (NAS, 2017). In the current data, percent CBD was not consistently reported, but we can extrapolate from the recreational and medical markets where higher CBD cannabis flower contains lower THC levels due to properties of the plant (ElSohly, Radwan, Gul, Chandra, & Galal, 2017). Thus, negative associations may be driven by CBD potency, but more research is needed to confirm this hypothesis. A different picture emerges when considering the relations between health and concentrated cannabis potency, such that those choosing to use concentrated cannabis and who report more health symptoms are consistently choosing higher potency products. Concentrated cannabis products are not limited by the inverse relation between THC and CBD in flower due to manufacturing procedures overcoming limitations of cultivation.

When comparing the results of the present study to previous literature, our findings either confirm what has been previously reported (e.g., respiratory problems are consistently associated with cannabis use, NAS 2017) or provide preliminary evidence that research using a more complete definition of cannabis use, one that includes potency and method of administration, is needed. One finding from the current research that was surprising was the lack of association between potency, regardless of method of administration, and CUD. One would assume that those using higher potency products, and especially high potency concentrated cannabis would report more CUD symptoms, but we did not find evidence for that association. One potential explanation is that CUD symptoms result from habitual use, regardless of potency and method of administration.

4.2. Limitations

The current study provides valuable information about the links between cannabis potency and physical and mental health; however, the findings should be interpreted in light of the study's limitations. The 156 cannabis users from a state where recreational cannabis is legal and may not generalize to states with different cannabis laws. The cross-sectional study design limits causal inferences. We can only report on associations between potency and physical and mental health outcomes and cannot say whether cannabis use resulted in reported physical/mental health symptoms, if cannabis was used to cope with reported symptoms, or rule out other factors that may help to understand the link between cannabis potency and health outcomes. We relied on self-report measures of cannabis use and health outcomes. Self-reported information is known to suffer from retrospective recall bias and social

desirability (Carroll, 1995; Del Boca & Darkes, 2003; Johnson & Golub, 2007). We chose to analyze the highest potency product reported by each participant. This is one of many approaches to analyzing this complex data. One alternative would be analyzing all data using a multilevel framework; however, we were underpowered for this analytic approach. Another option would be using the lowest potency product reported; however, based on the limited literature available we hypothesized that higher potency products would be related to greater endorsement of outcomes of interest and selecting the lowest potency product would undermine our efforts to test this hypothesis. We did not collect frequency of use information by method of administration. This limits our ability to draw strong conclusions about the link between potency, method of administration, and consequences. One advantage of the current study was the inclusion of images of labels that contained potency information, which improves our confidence in the validity of the cannabis potency data.

4.3. Lessons learned and future directions

Given that this was one of the first studies expressly examining the role of potency and the associations between cannabis use and behavioral health outcomes, we have learned a number of valuable lessons in the process of conducting this study that can inform future research. The assessment of cannabis use is currently evolving. Our research group has examined the difficulties in assessing self-reported cannabis quantity (Prince, Conner, & Pearson, 2018). Moreover, Cuttler and Spradlin (2017) have developed a more comprehensive self-report measure for cannabis use that captures more information about frequency and route of administration, but is lacking in the assessment of cannabis potency. Throughout our research we have learned that cannabis use is complex and we recommend that researchers assess for quantity, frequency, and potency by route of administration. In addition to learning about cannabis assessment, we have identified an important analytic consideration. Specifically, we identified the potency valley, which if not considered obscures important relations between cannabis potency and outcomes.

Based on the findings reported and lessons learned, the next steps for researchers to better understand the relation between cannabis use, more comprehensively defined, and health outcomes are (a) longitudinal research that can support causal relations between cannabis use and health outcomes, (b) near real-time data collection to understand the links between cannabis use and acute versus chronic health outcomes, and (c) randomized clinical trials with high internal validity to elucidate dose dependent effects of cannabis on health outcomes.

Conflicts of Interest

Neither of the authors have any conflicts of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.brat.2018.11.008.

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