**Abstract**

Two studies explored the differences in tastant (salt, sour, bitter, sweet and spicy) concentration preference between recreational drug users and abstainers. In study 1, 250 opportunistically recruited abstainers, cannabis only users and multiple-drug users completed psychometric questionnaires and a concentration preference tastant test. In study 2, 76 participants purposefully recruited abstainers, daily tobacco users, recreational cannabis users and daily cannabis users completed the same protocol as study 1. Study 1 demonstrated that both multiple drug users and cannabis users had a higher preference for salt and sour tastants than abstainers. Study 2 showed that daily cannabis and tobacco users had a higher preference for sweet and spicy tastants than recreational cannabis users and abstainers. As predicted, recreational drug users scored higher on both sensation-seeking and impulsivity compared to abstainers.Participants who habitually smoke tobacco or cannabis daily have different concentration preference for specific tastants. The aim of the current study was to provide an explanation for the inconsistency in published results on taste preferences in recreational drug users. The data offered in this paper indicate that variation in recruitment strategy, definition of ‘drug users’, and mode of drug delivery, as well as multiple drug use, may explain the preference for stronger tastants in habitual drug users. Future research exploring the psychobiological underpinnings of the impact of drug use on food preferences should carefully define recreational drug user groups.

Key words: Recreational Drugs: Cannabis; Tobacco; Taste Preference; Multiple-drug use.

**Introduction**

A number of studies have demonstrated that taking recreational drugs, particularly those that activate the opioid and endocannabinoid systems, affects appetite regulation (Kirkham, 2009; Tallett *et al*., 2008; Yeomans, 1998). Many studies have reported that the use of recreational drugs, usually cannabis, resulted in a higher appreciation for, or uncontrolled cravings to consume, foods (Abel, 1971; Green *et al*., 2003; Mattes *et al*., 1994; Nail *et al*., 1974). One explanation for this has been that cannabis alters users’ perceptions of sweet tastants (Cooper, 2004; Jager & Witkamp, 2014; Tart, 1970); although both preferences for higher sour and bitter tastants have also been associated in the use of other recreational drugs (Mata, 1963; Spitzer, 1988). Moreover, at least one study has reported null findings in regards to the effects of recreational drugs on taste perception (Mattes *et al*., 1994). A prevailing view within the literature suggests that recreational drugs, such as cannabis, increase appetite through non-taste-related mechanisms (Jager & Witkamp, 2014). The mechanisms that have been implicated are olfactory processing (Soria-Gómez *et al*., 2014), reward (specifically ‘liking’ processing e.g. Mahler *et al*., 2007), and attention and memory (Mattes *et al*., 1994).

Unlike animal models, human participants’ drug use cannot always be precisely controlled. Individuals often use multiple recreational drugs sequentially and concurrently, making multiple drug use the norm rather than the exception (DuRant *et al*., 1993; Jones & Heaven, 1998; Suris *et al*., 2007), but this is rarely accounted for. Therefore, on the basis of current evidence it is difficult to disentangle the potential effects of individual recreational drugs on appetite or taste perception. Moreover, laboratory designed studies examining the impact of recreational drug use on taste perception have operated on a paradigm of administering the drug in question and then performing a taste test (e.g. Foltin *et al*., 1986; 1988; Mattes *et al*., 1994; Mata, 1963). This administration paradigm does not assess the effects of long-term habitual use of the drug and therefore tolerance, dosage and participants’ weight are not considered. Differences in taste perception observed with this method could be explained by variation within the participant's habitual use, lifestyle or level of intoxication rather than by drug use directly.

Personality characteristics that predict drug taking, such as sensation-seeking, could also provide an explanation of the differences in taste perception reported. The interaction between personality and drug use has been consistently shown (Cloninger *et al*., 1988; Conner *et al*., 2010; Deas & Thomas, 2002), with impulsivity frequently being identified as a key determinant (Allen *et al*., 1998; Hayaki *et al*., 2005). Consistent with the neophilic characteristics of impulsiveness, people with comparatively high levels of this personality attribute have been shown to have difficulties with healthy food choices (Kakoschke *et al*., 2015) and have a higher preference for sweeter tastants (Saliba *et al*., 2009). Interactions between personality and drug use on taste preference must be considered in order to uncover the specific impact of habitual use of a recreational drug on taste perception.

The four aims of the current study were to assess 1) if differences in taste perception were evident in participants who habitually used recreational drugs and those that did not. 2) To explore the relative impact of participant drug use categorisation/grouping on the outcome of taste perception/preference. In particular, we were interested in exploring loose grouping criteria of recreational drug use that simply compared participants who use recreational drugs against complete abstainers. 3) To improve our understanding of drug use categorisation, we also aimed to compare a purposeful sample of individuals recruited based on a history of only consuming a specific recreational drug (cannabis). 4) To assess the interaction between drug use and taste perception with reference to known personality characteristics that have been shown to also independently predict drug use. Due to the nature of the investigation, two separate studies employing different recruitment strategies were offered. Four primary research hypotheses were held based on the previous literature. These hypotheses were: a) Opportunistic sampling would uncover a highly heterogeneous sample of participants who use multiple types of recreational drugs. b) Differences in tastant preference will be observed in individuals who report taking recreational drugs and were grouped together based on loose inclusion criteria. c) No differences will be observed in tastant preferences when a strict inclusion criteria for the drug user group was applied. d) There will be an interaction between sensation-seeking, impulsivity and tastant preference. In particular, individuals with higher sensation-seeking and impulsivity will be more likely to use recreational drugs and prefer stronger sweet tastants than those with lower scores for these characteristics.

**Method**

**Design** **(Study 1)**

A mixed-measures design was used to examine differences in preference for five flavours. The first independent between-subject variable was drug group, which had three levels – control, cannabis user and multiple drug user. The second repeated measures independent variable was tastant, which contained five domains – salty, sweet, sour, spicy, and bitter. The dependent variable was the individual’s reported preference for five different strengths of each tastant. Potential personality correlates were added to the analysis to explore if any interactive effects on recreational drug taking were evident. In particular, these correlates were sensation-seeking and its derivative subscales (Zuckerman, 1990) and impulsiveness (Eysenck & Eysenck, 1991), as these have been related to recreational drug use in past research (e.g. Donohew *et al*., 1999; Ersche *et al*., 2010). Participants were excluded if they reported having any allergies or disliking the test foods.

**Participants**

In the current paper, all individuals were deemed to be recreational rather than dependent drug users. We separated the term recreational drug user into three categories of light, moderate and heavy drug user depending on frequency of use. Light drug users were defined as those who had taken at least some form of recreational drug once a week for the last month, as well as having a history of taking recreational drugs on a monthly basis over the last year. Moderate users were defined as individuals who used recreational drugs at least once (but no more than four times) a week over the last month, and had a similar monthly profile of use over the last year. Heavy users were defined as individuals who consumed recreational drugs at least once a day, every day for the last month and reported that this was a typical monthly use profile for the last year. Multiple drug use was defined as habitual use of two or more recreational drugs.

Two hundred and fifty participants (91 male) were recruited using opportunistic sampling. The sample within study 1 were recruited from undergraduate and postgraduate student cohorts and aged between 19-24 years old, which was similar to all other published research in this domain. We followed similar recruitment protocols to previous research to explore the impact of the recruitment process on the outcome of the research. Fifteen participants were removed for incomplete data and a further 3 were removed due to errors in their reporting of their habitual drug use. Ten participants from the control group were excluded as they reported having tried at least one substance on at least one occasion in their past. This left a total control sample of 75 participants. Of the remaining participant pool, 147 individuals reported taking recreational drugs habitually and were further separated into multiple drug users (n=77) and cannabis only users (n=70). Therefore, 222 participants (86 male) were included in the analysis of study one. The average age was (20.82±1.29y), with the average weight of the sample being 67.1kg±13.2kg and their average height was 1.71m±0.1m. The average Body Mass Index (BMI) of the sample was 22.8±3.6 kg/m2 with 184 participants falling into the lean (BMI > 18.5kg/m2), 33 into overweight (BMI > 25 kg/m2) and 5 into the obese categories (BMI > 30kg/m2). Participants most frequently reported their ethnicity to be white (90%).

**Measures**.

**Food Neophobia and General Neophobia**. Levels of food and general neophobia were measured with the Food and General Neophobia Scales (Pliner & Hobden, 1992), which have been shown to be reliable and have high internal consistency (Richey *et al*., 2003; Rigal *et al*., 2006). The food neophobia scale was used to measure the fear/reluctance to try unfamiliar/new foods. Participants indicated their willingness to try 10 different food items using a 7-point Likert scale (1 *strongly disagree* to 7 *strongly agree*). The general neophobia scale consisted of a similar 8-item scale that measured a participant’s general response to novel situations. A high score on either of these scales indicated high levels of food or general neophobia. The internal consistency of the two subscales in the current study was 0.79 for the food neophobia scale and 0.82 for the general neophobia scale.

**Sensation-seeking**. The 40-item Interests and Preference Test (IPT), also known as form V of the Sensation-Seeking Scale (SSS-V) revised by Zuckerman (1994), was administered. Participants responded by choosing one of two opposing statements that best represented their behaviour. The questionnaire had four subscales: Thrill and Adventure Seeking (TAS); Experience Seeking (ES); Disinhibition (Dis); and Boredom Susceptibility (BS). The SSS-V has been extensively used in previous research and has demonstrated strong validity and reliability (Ferrando & Chico, 2001). The internal reliability coefficients for the current study were: TAS=0.78; ES=0.65; Dis=0.74; BS=0.57; and total score 0.82.

**Impulsiveness**. The Impulsiveness, Venturesomeness and Empathy (IVE) scale (Eysenck & Eysenck, 1991) comprises 54 self-rating items and yields three independent scores for impulsiveness (ranging from 0 to 19), venturesomeness (ranging from 0 to 19) and empathy (ranging from 0 to 16), where a high score on any scale indicates high levels of the corresponding personality dimension. This measure has been shown to have strong reliability (Jack & Ronan, 1998). Within the current study we only used the subscale of impulsiveness for a measure of impulsivity. A single subscale was used in order to limit item fatigue and avoid repetition with the sensation-seeking scale. The internal reliability coefficient for this measure in the current study was 0.81.

**Drug Use Questionnaire**. Drug use was ascertained through a detailed demographic questionnaire. A series of questions were asked to ascertain the frequency of controlled substance use over the last week, month and year. In addition, questions concerning lifetime use were also included to gain insight into the population's experience and use of controlled substances. In order to ensure that the participants were truthful, additional questions concerning the price that they last paid for their preferred drugs were requested. This was then corroborated with the current market prices within the geographical region as known by the local Police force. Naloxone was included to identify false reporting. Naloxone is usually given to individuals who have overdosed and would not typically be taken as a recreational drug. The questionnaire is available on request and has been used in past research published in drug dependence literature (e.g. Sumnall et al., 2004).

**Taste Test.** The current paradigm was an adaptation of Mattes *et al* (1994) in which we substituted urea for angostura bitters. We also included a fifth dimension to taste – chilli/spiciness. This modality of taste would be akin to flavour perceptions rather than taste perceptions; however, this nociceptor-mediated component of taste perception has been frequently related to sensation-seeking (Zuckerman, 1979) and merited further investigation within this paradigm. Results for each individuals’ preference for each of the five tastants was derived by adding five different intensities of an ingredient (table salt, granulated sugar, lemon juice, tabasco sauce, angostura bitters) to 20ml of food items (tomato soup [salt], strawberry juice drink [sweet], diet lemonade [sour], salsa sauce [spicy], tonic water [bitter]). Participants were excluded if they reported not liking or not eating/drinking the test items. The solutions and concentrations presented were extensively piloted to ensure that they offered a wide range of intensity of tastants while still being within the bounds of acceptability. Table 1 describes the concentrations of tastants used in the test foods.

**Procedure**

Participants attended the laboratory between midday and 5pm after at least three hours since their last meal. Participants were seated in individual cubicles and given instructions for the taste test, in which they were asked to consume the samples in the presented order. Order of presentation was counter-balanced and fully randomised within tastant categories. A litre jug of water was provided, and participants were asked to consume water and wait at least thirty seconds between tastings (a clock was provided in the room). The overall preferred concentration choice in each tastant category was recorded as the dependent variable. Each sample was rated in order to aid the participant in choosing which sample they preferred. Participants were monitored by the experimenters using close circuit television to ensure compliance. Following completion of the taste trials, the participants were asked to complete the three questionnaires (Food and General Neophobia Scale, SSS-V and IVE-I; presented in a counter-balanced order). Participants were then debriefed and advised to refrain from eating any salty foods for the rest of the day in order to stay within recommended dietary guidance.

**Statistical Analysis**

Our analysis first considered correlations between all of the potential variables. Due to the number of correlations and the sample size, a conservative correction of the alpha level was applied. Alpha was divided by 16 allowing only probability scores below 0.003 and Spearman’s rho (ρ) values above 0.18 to be reported as significant. This ρ value meant that only small, medium or large effect size outcomes were reported as significant rather than values below what would be conventionally considered a small effect outcome. Only variables that significantly correlated with the independent variable were considered as potential covariates within the analysis.

All assumptions for parametric testing were met. For study 1, analysis of covariance (ANCOVA) was conducted, with significant outcomes followed up using Tukey’s-b test. Non-significant analyses were investigated through power analysis to uncover if any type 2 errors were evident. All analyses were performed on IBM SPSS statistics version 20 for Windows.

**Results (Study 1)**

**Demographics and Drug Use.** Participants reported their sex, age, ethnicity and prior life time drug use (with detailed frequency of use of eighteen different recreational drugs and estimated quantity consumed over the last week and month). Amphetamine (numbers within the brackets represent the number of participants who had tried the drug in the past followed by habitual users. Life time tried: n=57/77. Habitual monthly use in the last year: (n=23/77), heroin (n=3/77: n=0/77), ecstasy (n=76/77: n=66/77), cocaine (n=73/77: n=46/77), cannabis (n=76/76: n=65/77), tranquillisers (n=19/77: n=3/77), ketamine (n=28/77: n=14/77), crack (n=5/77: n=2/77), lysergic acid diethylamide (LSD) (n=28/77: n=7/77), glue and solvents (n=13/77: n=2/77), magic mushrooms (n=57/77: n=15/77), Viagra (n=7/77: n=4/77), gamma hydroxybutyrate (GHB) (n=6/77: n=4/77), poppers (n=76/77: n=27/77), and herbal highs (n=28/77: n=1/77). The multiple drug users reported often switching drugs, rather than consuming all chosen drugs regularly. None of the participants reported currently receiving professional help for substance abuse. For those individuals who reported currently consuming recreational polydrugs, the overwhelming majority reported taking them at the weekends. The average number of days of abstinence prior to the study day was as follows: amphetamine (5.9 days), ecstasy (11.3 days), cocaine (34.3 days), tranquillisers (5.3 days), ketamine (4.7 days), crack (2.7 days), LSD (10.1 days), glue and solvents (5.3 days), magic mushrooms (35.4 days), Viagra (11.6 days), and poppers (44.3 days). For heroin, herbal highs, and GHB there was either insufficient data to calculate last usage or none of the sample had consumed them in the last year. The cannabis only group were regular users of cannabis but had not tried any of the other drugs. All 222 participants reported consuming alcohol at least recreationally and 187 participants reported smoking recreationally (n=48) or daily (n=139).

**Variables Removed from the Overall Analysis.** Several variables had no impact on the paradigm nor provided any significant interactions, and were therefore removed from further analysis. These variables were sex (F(4, 872)=0.52, p=0.72, η2=.002), food (F(4, 872)=0.31, p=0.86, η2=.001) and general neophobia (F(4, 872)=1.03, p=0.39, η2=.005). In line with previous research, food (r(222)=-0.32, p<0.001) and general neophobia (r(222)=-0.28, p<0.001) were negatively associated with sensation-seeking, but did not interact with the tastant variables tested within the current paradigm.

**Drug Use and Taste Preference.** Table 2 offers the descriptive statistics for study 1. There was a significant interaction between the preference ratings of the different tastants and their drug user group (F(8, 876)=3.93, p<0.001). This was due to differences between the drug user groups' sour preference (F(2, 232)=15.16, p<0.001). For sour preference, significant differences between the three groups were observed. The abstinent group demonstrated a preference for a lower concentration (2.07±1.53), with the cannabis group preferring a moderate concentration (2.61±1.13) and the multiple drug use group preferring a higher concentration of sour tastant (3.12±1.11).

**Significant Correlations Between all Measured Variables (Study 1).** Total number of substances tried in the past was related to both sensation-seeking (ρ(222)=0.48, p<0.001) and impulsivity (ρ(222)=0.28, p<0.001). All subscales of the sensation-seeking scale significantly positively correlated with total number of substances tried (Thrill and adventure seeking (ρ(222)=0.21, p<0.001), Disinhibition (ρ(222)=0.28, p<0.001), Boredom Susceptibility (ρ(222)=0.25, p<0.001) and Experience Seeking (ρ(222)=0.49, p<0.001)). Habitual drug use was associated with the experience seeking subscale of the SSS-V (ρ(222)=0.45, p<0.001) and weakly associated with the impulsivity scale (ρ(222)=0.24, p<0.001). Only one personality factor, boredom susceptibility on the sensation-seeking scale, was weakly associated with a taste preference for salt (ρ(222)=0.35, p<0.001).

**Personality Variables Across/Between Drug Use Groups.** Strong significant differences were found between the three drug use groups on all of the personality variables measured (see Table 2). All aspects of the sensation-seeking scale were significantly different between the groups (Thrill and adventure seeking (F(2, 221)=4.08, p=0.018), Disinhibition (F(2, 221)=9.40, p<0.001), Boredom Susceptibility (F(2, 221)=4.52, p=0.012) and impulsiveness (F(2, 221)=6.72, p=0.001), with controls being significantly lower than the other two drug user groups (p<0.05). For experience seeking (F(2, 221)=31.5, p<0.001) all groups were significantly different from each other (all p<0.05), the abstinent group scored the lowest and multiple drug users scored the highest.

**Drug Use, Taste Preference and Personality Variables.** When experience seeking or impulsiveness was entered into the ANCOVA model they were not found to be significant covariates. Therefore, it was inferred that experience seeking and impulsivity predicted the propensity to engage in drug taking behaviour, but the interaction between drug user groups and taste preference was not due to these personality characteristics. Boredom susceptibility was independently related to tastant concentration preference (F(4, 872)=4.80, p=0.001), which was due to people with high boredom susceptibility having a higher preference for salt tastants than low scoring boredom susceptibility participants (t(220)=4.89, p<0.001). Boredom susceptibility and drug group were not interrelated and did not provide an overall interaction with taste preference (F(8, 864)=0.92, p=.0.53; η2=0.01). This indicated that sensation-seeking and specifically boredom susceptibility were independently related to taste preference.

**Study 2**

Due to the nature of the sampling strategy and the high levels of inter-dependence of the drug user groups in the first study (e.g. all multiple drug users used cannabis frequently and all cannabis users mixed cannabis with tobacco); it was difficult to draw definitive conclusions about alterations in taste preferences due to specific drug use. Therefore, a second study was devised to address these limitations.

**Methodological Alterations from Study 1.** Based on the findings of the first study, the second study only included the sensation-seeking and impulsivity questionnaires. The same taste preference paradigm was used; however, the recruitment strategy differed. The second study recruited a) from a community sample and b) using a strict set of inclusion criteria to only incorporate individuals with specific histories of recreational drug use - i.e. those who had only ever taken their drug of choice and had no history of consuming either multiple drugs or other drugs listed within the study. Four groups were created (controls, daily tobacco users, recreational cannabis users and daily cannabis users). An additional criterion of tobacco users was that they must have smoked at least ten cigarettes a day, every day for the last month, with a similar annual profile of use to be considered a daily user. Therefore, the second study used a 4 (drug user group) x 5 (tastant) mixed measures design.

**Participants**

Seventy-six participants (38 males and 38 females) recruited from the community and aged between 18 and 36 years (20.9±2.5) took part in the same paradigm outlined above. The participants were almost equally spread across the four conditions (control n=20, daily tobacco users n=16, recreational cannabis users n=20, daily cannabis users n=20). It was reported by the cannabis users that they all habitually smoked cannabis rather than ingested it. To assess if participants had a substance (cannabis) use disorder (SUD), the cannabis use disorder identification test (Adamson, Kay-Lambkin, Baker et al., 2010) was administered. Whilst twenty-two participants scored above 8 on the measure (indicating hazardous use), none scored above 12 (suggestive of a disorder). All participants who scored above 8 were interviewed and their habits were considered not indicative of a SUD.

**Results (Study 2)**

**Variables Removed from the Overall Analysis.** As with study 1, sex differences did not affect taste preference (F(4, 272)=1.41, p=0.23, η2=0.02). Drug group was again associated with experience seeking on the sensation-seeking scale (ρ(76)=0.30, p=0.009), which also did not function as a covariate in an ANCOVA analysis.

**Drug Use and Taste Preference.** A significant interaction between drug use group and taste preference was again observed (F(12, 288)=1.66, p=0.037). This was due to differences in sweet (F(3, 70)=2.03, p=0.05) and chilli preferences (F(3, 70)=2.03, p=0.01). Specifically, the differences were between the control group and the daily cannabis users (Sweet Preference: t(38)=2.23, p=0.03, Chilli Preference: t(38)=2.27, p=0.03) and the daily tobacco smokers (Sweet Preference: t(34)=2.34, p=0.02, Chilli Preference: t(34)=2.85, p=0.01). In all instances, daily users of cannabis and daily users of tobacco reported higher preferences for higher concentrations of sweet and chilli tastants. No differences were observed between recreational users of cannabis and controls (Sweet Preference: t(38)=1.32, p=0.20, d=0.36. Chilli Preference: t(38)=1.30, p=0.20, d=0.38).

**Significant Correlations Between all Measured Variables (Study 2).** Table 3 offers the descriptive statistics for study two. Unlike in study 1, total sensation-seeking scores were positively associated with sweet preference (ρ(76)=0.56, p<0.001) and impulsiveness score was positively associated with preference for sour tastants (ρ(76)=0.35, p=0.002). Again, the analysis indicated that these continuous variables did not function as significant covariates.

**Personality Variables and Drug Use.** In the smaller sample of study 2, only Experience Seeking (F(3, 72)=5.99, p=0.001) and Boredom Susceptibility (F(3, 72)=3.88, p=0.01) were significantly different across the four drug groups. In both incidences, the control group was significantly lower than the three drug using groups. No differences were observed on any personality variables between the three drug using groups.

**Discussion**

The current study aimed to explore the impact of drug use on tastant (salt, sour, sweet, bitter and spicy) concentration preference. Past research has been inconsistent. A wide range of different tastants and taste preference have been linked with recreational drug use. To provide clarity on the impact of drug use, the secondary aim of the current paper was to explore the impact of drug categorisation and inclusion criteria on the outcome of the tests. In addition, to understand the impact of differential sampling strategies employed in past research, we compared outcomes from a purposeful sampling strategy with strict inclusion criteria for drug use against an opportunistic sampling strategy in two different studies. Finally, in order to consider the complex interplay between drug use and tastant preference, the potential confound of sensation-seeking and impulsiveness was also measured to explore the interactive impact of drug use and personality on tastant concentration preference.

Employing an opportunistic sampling strategy in study 1, it was shown that recreational multiple drug and cannabis users had a significantly higher concentration preference for sour tastants. Analysis of the personality variables suggested that these did not interact with taste preference and drug use directly. Rather, there was an independent association between drug use, impulsivity and sensation-seeking. As predicted, recreational drug users scored higher on both sensation-seeking and impulsivity compared to abstainers and the breadth of drugs sampled in the past was moderately associated with impulsivity. Boredom susceptibility within the sensation-seeking profile was independently related to salt preference; however, this did not appear to interact with the relationship between drug use and tastant preference. Therefore, according to the results in study 1, it would appear that impulsivity is independently associated with drug use and tastant preference. This finding was unexpected, but may suggest that sensation-seeking or impulsivity interact with drug use through the amount consumed or food choice rather than tastant preference (Nolen, 2013; Nolen & Stolze, 2012). Perhaps alternative paradigms exploring eating behaviour rather than taste preferences would uncover the exact nature of how these personality constructs interact with drug use.

The differences observed in study 1 appear to partially support the existing literature. Differences in sour tastant preferences have been reported (Grossman, 1968). Contrary to past research, Mata’s (1963) observation of differences in bitter preference or Foltin’s (1988) alterations in sweet tastant preference were not corroborated. Explanations and interpretations of the data in study 1 fall into one of three categories. The first could be simply that tastant perception is altered in those who use recreational drugs. The use of cannabis and/or a wide variety of drugs measured within study 1 alters an individual’s perception of taste so that they either prefer stronger concentration of tastants, or their sense of taste has been dulled so that they require a higher concentration of a given tastant to perceive it in a similar manner to abstainers.

The second potential explanation of the conflicts in the current published data and study 1 could be due to slight variations in paradigm between the studies. Past literature has focused on the administration of a small quantity of the drug under investigation and then offering a taste test during intoxication. This would indicate, unsurprisingly, that differences in taste perception stem from current intoxication; rather than being tested following chronic exposure to a drug(s) and during in a non-intoxicated state. Blood or urine testing would be necessary to differentiate this interaction. Taken together, the data suggest that intoxication with a recreational substance alters tastant perception, which appears to be consistent and maintained in individuals that use multiple drugs or cannabis for a moderate period of time.

The final potential explanation could be the variation of how the drug user groups are assigned/created within past literature. Study 2 was designed to investigate this potential explanation. Strict inclusion criteria appear to have had a marked effect on the outcome. When very specific eligibility criteria were implemented, sweet and spicy tastant concentration preference was different between recreational drug users (cannabis and tobacco) compared to controls. This mirrors the findings of Foltin (1988) who also suggested alteration in sweet tastant preference following the use of cannabis. The difference between the Foltin (1988) study and its predecessors was that the small numbers of participants investigated were habitual cannabis users, who smoked recreationally, and lived in a laboratory for a period of time. In other studies, only a limited amount of self-report data was used to create the recreational drug user groups, or only self-reported cannabis users were allowed to take part. Equally, the field of research is lacking in any randomised double blinded placebo controlled trials in conjunction with carefully selected sample of different types of users. Therefore, at present, it cannot be definitively concluded that the design itself is responsible for the differences observed here. However, it is clear that papers with larger sample sizes and carefully controlled taste tests tend to report null findings. Furthermore, defining human drug use in taste perception paradigms is difficult. Arguments for and against administration paradigm vs habitual use cannot be resolved from this study. Thus we suggest that further large scale studies exploring the impact and effect of different drugs on taste perception, as well as the mode of delivery, will add further to the limited information currently available. Despite these caveats, we have tested the largest human sample to date. We suggest that habitual use, type of drug used and the mode of delivery are associated with an alteration in taste perception, and that these factors explain some of the inconsistency in published findings.

The results from study 2 appear to relate to the habitual and daily use of tobacco rather than being specific to cannabis. This is inferred as both tobacco and cannabis returned similar scores, with no additive effect of cannabis compared to smoking tobacco being observed. It has been long known that smoking affects taste perception for bitter tastants (Krut *et al*., 1961) and carefully controlled experiments of taste perception in smokers indicates that they are worse at discriminating all tastants irrespective of their modality (Sato *et al*., 2002). Moreover, the effect appears to be transient, as only daily use was shown to affect sweet taste perception in the current study, an observation that has been previously reported elsewhere (Redington, 2002). As all of the taste modalities have now been implicated as different in recreational drug users, it is likely that Sato *et al*'s (2002) observations apply to both tobacco and cannabis users.

The act of smoking a recreational substance appears to result in a short-term residual alteration to taste perception that leads to a preference for stronger tastants, an inability to taste specific items or a higher tolerance for tastants. Results in human participants who are asked to consume a recreational drug to explore impacts on taste perception have found a variety of changes in taste perception from null findings (Mattes *et al*., 1994) to large differences (Foltin *et al*., 1986; 1988). These differences can be explained by the method of delivery of the drug in question, cannabis in this instance, whereby one method was to ingest it (null results), while the other was to smoke it (effects observed). Furthermore, the manner in which participants are recruited and/or assigned to the category of 'recreational drug user' for the purposes of these studies has a dramatic effect on outcome. Duration, method of delivery, intoxication and frequency of use all appear to have a significant effect on the differences in tastant concentration preference observed in cannabis users (e.g. Foltin *et al*., 1986; 1988; Mattes *et al*., 1994; Nolan & Stolze, 2012).

One surprising finding was that personality traits previously independently linked to recreational drug use and tastant preference did not provide significant results in the current study. Although we can state that none of the personality variables measured here, sensation-seeking, impulsivity and food/general neophobia were not a covariate in the current analysis; there were some indications of association between taste perception and personality, as well as highly significant differences between these personality variables and recreational drug use. It is feasible to still suggest that these personality attributes may have a more long-term role in the decision to use recreational drugs and preference for stronger tastants. There was a moderate correlation between sensation-seeking and sweet preference, as well as sensation-seeking and recreational drug use uncovered in the current study. Therefore, it would be premature to conclude that personality attributes, recreational drug use and tastants do not interact together to predict preferences. The inference from this data was that these did not interact within a simplistic model.

It is important that several limitations of the current studies are noted. Firstly, information on participants’ recreational drug use was reliant on self-report. Although speculative, it is not unreasonable to suggest that some people did exaggerate or under-report their drug use. Future studies that can rationalise the expenditure may wish to consider urine toxicology testing. The eligibility criteria to participate could also be interpreted as being a significant limitation. The open criteria in the first study meant that a very heterogeneous sample was recruited. Ergo, placement of participants into specific groups was somewhat arbitrary based on the popularity of a particular recreational drug’s use within the sample or its current legality at the time of testing. In addition, although larger than any other published study in this area, the sample size in study 2 was only sufficient to show differences of a large effect. It is possible that more subtle differences would be observed with a greater sample size.

In addition to noting limitations, it is also equally important to highlight the strengths of the current paradigm and what these data add to the literature. These studies were the first to explore tastant concentration preferences between different recreational drug users rather than providing a dose of a drug and measuring its immediate effect. The sample size was much larger than previous research, which allows for more robust conclusions and interpretations of the data and how the variables have interacted.

To conclude, altered tastant preferences observed in recreational drug users are probably due to tobacco use. Specifically, higher concentrations of sweet and spicy tastants are preferred by daily users of tobacco and cannabis compared to light users and abstainers. Based on differences in recruitment strategy and subsequent grouping of participants, differences in tastant preferences observed between recreational drug users and abstainers are likely to be due to the frequency that the participants smoke their recreational drug of choice. It is clear from the current series of studies that definition, and resulting inclusion/exclusion criteria, of recreational drug use has a significant impact on the outcome of a taste preference study.

**References**

Abel, E. L. (1971). Changes in anxiety feelings following marihuana smoking. *British Journal of Addiction, 66,* 185-187. doi: 10.1111/j.1360-0443.1971.tb02384.x

Adamson, S. J., Kay-Lambkin, F. J., Baker, A. L., Lewin, T. J., Thornton, L., Kelly, B. J., & Sellman, J. D. (2010). An improved brief measure of cannabis misuse: The Cannabis Use Disorders Identification Test-Revised (CUDIT-R). *Drug and Alcohol Dependence, 110,* 137-143. doi: 10.1016/j.drugalcdep.2010.02.017

Allen, T. J., Moeller, F. G., Rhoades, H. M., Cherek, D. R. (1998). Impulsivity and history of drug dependence. *Drug and Alcohol Dependence, 50,* 137-145. doi:10.1016/S0376-8716(98)00023-4

Cloninger, C. R., Sigvardsson, S., & Bohman, M. (1988). Childhood personality predicts alcohol abuse in young adults. *Clinical and Experimental Research, 12*, 494-505. doi: 10.1111/j.1530-0277.1988.tb00232.x

Conner, B. T., Hellemann, G. S., Ritchie, T. L., Noble, E. P. (2010). Genetic, personality, and environmental predictors of drug use in adolescents. *Journal of Substance Abuse Treatment, 38,* 178-190. doi: http://dx.doi.org/10.1016/j.jsat.2009.07.004

Cooper, S. J. (2004). Endocannabinoids and food consumption: comparisons with benzodiazepine and opioid palatability-dependent appetite. *European Journal of Pharmacology, 500,* 37-49. doi:10.1016/j.ejphar.2004.07.009

Deas, D., & Thomas, S. (2002). Comorbid psychiatric factors contributing to adolescent alcohol and other drug use. *Alcohol Research & Health, 26*, 116-121.

Donohew, R. L., Hoyle, R. H., Clayton, R. R., Skinner, W. F., Colon, S. E., & Rice, R. E. (1999). Sensation-seeking and drug use by adolescents and their friends: Models for marijuana and alcohol. *Journal of Studies on Alcohol and Drugs, 60*, 622-631. doi: http://dx.doi.org/10.15288/jsa.1999.60.622

DuRant, R. H., Rickert, V. I., Ashworth, C. S., Newman, C., & Slavens, G. (1993). Use of multiple drugs among adolescents who use anabolic steroids. *The New England Journal of Medicine, 328,* 922-926. doi: pdf/10.1056/NEJM199304013281304

Ersche, K. D., Turton, A. J., Pradhan, S., Bullmore, E. T., & Robbins, T. W. (2010). Drug addiction endophenotypes: Impulsive versus sensations-seeking personality traits. Biological Psychiatry, 68, 770-773. doi: 10.1016/j.biopsych.2010.06.015

Eysenck H. J. & Eysenck, S. B. G. (1991) *Adult Impulsiveness, Venturesomenes and Empathy Scale.* London, UK: Hodder and Stoughton Ltd.

Ferrando, P. J., & Chico, E. (2001). The construct of sensation-seeking as measured by Zuckerman’s SSS-V and Arnett’s AISS: A structural equation model. *Personality and Individual Differences, 31*, 1121-1133. doi:10.1016/S0191-8869(00)00208-7

Foltin, R. W., Brady, J. V., & Fischman, M. W. (1986). Behavioral analysis of marijuana effects on food intake in humans. *Phamacology, Biochemistry & Behavior, 25*, 577-582. doi:10.1016/0091-3057(86)90144-9

Foltin, R. W., Fischman, M. W. & Bryne, M. F. (1988). Effects of smoked marijuana on food intake and body weight of humans living in a residential laboratory. *Appetite, 11,* 1-14. doi:10.1016/S0195-6663(88)80017-5

Green, B., Kavanagh, D., & Young, R. (2003). Being stoned: a review of self-reported cannabis effects. *Drug and Alcohol Review, 22,* 453-460. doi: 10.1080/09595230310001613976

Hayaki, J., Stein, M. D., Lassor, J. A., Herman, D. S., & Anderson, B. J. (2005). Adversity among drug users: relationship to impulsivity. *Drug and Alcohol Dependence, 78,* 65-71. doi:10.1016/j.drugalcdep.2004.09.002

Jack, S. J. & Ronan, K. R. (1998). Sensation-seeking among high- and low-risk sports participants. *Personality and Individual Differences,* *25*, 1063-1083. doi:10.1016/S0191-8869(98)00081-6

Jager, G. & Witkamp, R. F. (2014). The endocannabinoid system and appetite: relevance for food reward. *Nutrition Research Reviews, 27,* 172-185. doi: http://dx.doi.org/10.1017/S0954422414000080

Jones, S. P., & Heaven, P. C. L. (1998). Psychosocial correlates of adolescent drug taking behaviour*. Journal of Adolescence, 21,* 127-134. doi:10.1006/jado.1997.0136

Kakoschke, N., Kemps, E., & Tiggeman, M. (2015). External eating mediates the relationship between impulsivity and unhealthy food intake. *Physiology & Behaviour, 147,* 117-121. doi:10.1016/j.physbeh.2015.04.030

Kirkham, T. C. (2009). Endocannabinoids and the non-homeostatic control of appetite. *Current Topics in Behavioural Neuroscience, 1,* 231-253. doi: 10.1007/978-3-540-88955-7\_9

Krut, L. H., Perrin, M. J., & Bronte-Stewart, B. (1961). Taste perception in smokers and non-smokers. *British Medical Journal, 1(5223),* 384-387.

Lötsch, J., & Hummel, T. (2014). Cannabinoid-related olfactory neuroscience in mice and humans. *Chemical Senses, 40,* 3-5. doi: 10.1093/chemse/bju054

Mahler, S. V., Smith, K. S., & Berridge, K. C. (2007). Endocannabinoid hedonic hotspot for sensory pleasure: anandamide in nucleus accumbens shell enhances ‘liking’ of a sweet reward. *Neuropsychopharmacology, 32*, 2267-2278. doi:10.1038/sj.npp.1301376

Mata, F. (1963). Effect of dextro-amphetamine on bitter taste threshold. Journal of Neuropsychology, *4,* 315-320.

Mattes, R. D., Shaw, L. M., & Engelman, K. (1994). Effects of cannabinoids (marijuana) on taste intensity and hedonic ratings and salivary flow of adults. *Chemical Senses, 19(2),* 125-140. doi: 10.1093/chemse/19.2.125

Nail, L., Richard, C. D. R., Gunderson, E., & Kolb, D. (1974). Motives for drug use among light and heavy users. *Journal of Nervous & Mental Disease, 159*, 131-136.

Nolen, L. J. (2013). Shared urges? The links between drugs of abuse, eating, and body weight. *Current Obesity Reports, 2*, 150-156. doi: 10.1007/s13679-013-0048-9

Nolan, L. J., & Stolze, M. R. (2012). Drug use is associated with elevated food consumption in college students. *Appetite, 58*, 898-906. doi: 10.1016/j.appet.2012.02.014

Pliner, P., & Hobden, K. (1992). Development of a scale to measure the trait of food neophobia in humans. *Appetite, 19,* 105-120. doi:10.1016/0195-6663(92)90014-W

Redington, K. (2002). Taste differences between cigarette smokers and nonsmokers. *Pharmacology, Biochemistry and Behavior, 21(2)*, 203-208. doi:10.1016/0091-3057(84)90215-6

Richey, P. N., Frank, R. A., Hursti, U. K., & Tuorila, H. (2003). Validation and cross-national comparison of the food neophobia scale (FNS) using confirmatory factor analysis. *Appetite, 40,* 163-173. doi:10.1016/S0195-6663(02)00134-4

Rigal, N., Frelut, M. L., Monneuse, M. O., Hladik, C. M., Simmen, B., & Pasquet, P. (2006). Food neophobia in the context of a varied diet induced by a weight reduction program in massively obese adolescents. *Appetite*, *46*, 207-214. doi:10.1016/j.appet.2006.01.001

Saliba, A. J., Wragg, K., & Richardson, P. (2009). Sweet taste preference and personality using a white wine. *Food Quality & Preference, 20,* 572-575. doi:10.1016/j.foodqual.2009.05.009

Sato, K., Endo, S., & Tomita, H. (2002). Sensitivity of three loci on the tongue and soft palate to four basic tastes in smokers and non-smokers. *Acta Oto-Laryngologica, 122(4),* 74-82. doi: 10.1080/00016480260046445

Soria-Gómez, E., Bellocchio, L., Reguero, L., Lepousez, G., Martin, C., Bendahmane, M., *et al*. (2014). The endocannabinoid system controls food intake via olfactory processes. *Nature Neuroscience, 17,* 407-415. doi:10.1038/nn.3647

Spitzer. M. E. (1988). Taste acuity in institutionalized and noninstitutionalized elderly men. *Journal of Gerontology: Psychological Sciences, 43*, 71-74. doi: 10.1093/geronj/43.3.P71

Sumnall, H. R., Tyler, E., Wagstaff, G. F., & Cole, J. C. (2004). A behavioural economic analysis of alcohol, amphetamine, cocaine and ecstasy purchases by polysubstance misusers. *Drug and Alcohol Dependence, 76,* 93-99.

Suris, J. C., Akre, C., Berchtold, A., Jeannin, A., Michaud, P-A. (2007). Some go without a cigarette: Characteristics of cannabis users who have never smoked tobacco. *Archives of Pediatric and Adolescent Medicine, 161(11),* 1042-1047. doi:10.1001/archpedi.161.11.1042

Tallett, A. J., Blundell, J. E., & Rodgers, R. J. (2008). Endogenous opioids and cannabinoids: system interactions in the regulation of appetite, grooming and scratching. *Physiology & Behavior, 94*, 422-431. doi:10.1016/j.physbeh.2008.02.009

Tart, C. T. (1970). Marijuana intoxication: Common experiences. *Nature, 226*, 701-704. doi: http://dx.doi.org/10.1038/226701a0

Yeomans, M. R. (1998). Taste, palatability and the control of appetite. *Proceedings of the Nutrition Society, 57*, 609-615. doi: http://dx.doi.org/10.1079/PNS19980089

Zuckerman, M., (1979). Sensation-seeking. Hillsdale NJ: Laurence Erlbaum Associates.

Zuckerman, M., (1990). The psychophysiology of sensation-seeking. *Journal of Personality, 58,* 313-345. doi: 10.1111/j.1467-6494.1990.tb00918.x

Zuckerman, M., (1994). *Behavioral Expressions and Biosocial Bases of Sensation-seeking*. Cambridge: Cambridge University Press.