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Perceptual Qualities of Ethanol Depend on Concentration, and Variation in These Percepts Associates with Drinking Frequency

Alissa A. Nolden¹ and John E. Hayes¹

John E. Hayes: jeh40@psu.edu

¹Sensory Evaluation Center, Department of Food Science, College of Agricultural Sciences, The Pennsylvania State University, 220 Food Science Building, University Park, PA 16802, USA

Abstract

Introduction—Ethanol, the pharmaceutically active ingredient in all alcoholic beverages, elicits multiple percepts including sweet, bitter, drying, and burning. However, quality-specific perceptual dose-response functions have not been previously reported. Also, individual differences in ethanol perception may associate with differences in alcoholic beverage use. Here, we describe the chemosensory profile of ethanol across concentrations in a convenience sample of mixed-age adults; secondarily, we explore whether individual differences in various qualities from ethanol associate with alcohol use behaviors.

Methods—Participants ($n=100$, 33 men) aged 21 to 55 (mean 33 years) tasted ethanol in water (4, 8, 16, 32, and 48 % v/v) and rated sweetness, bitterness, drying, and burning/tingling on four general Labeled Magnitude Scales. Demographic question and alcohol use measures (years drinking and reported frequency of drinking occasions) were also collected.

Results—Intensity of most qualities increased as a function of ethanol concentration, although the dominant sensation differed with concentration. The dominant sensation for 8 and 16 % ethanol was bitterness (7.4 ± 1.0 ; 13.5 ± 1.4), whereas for 32 and 48 % ethanol, burning/tingling was the dominant sensation (29.7 ± 2.1 ; 44.7 ± 2.4). Variation in quality-specific intensities of sampled ethanol explained variability in the reported intake frequency for beer, wine, straight spirits, and number of drinking occasions. The number of years reported drinking (grand mean 10.5 ± 0.8) was not significantly associated with perceptual ratings for sampled ethanol.

Conclusions—In a convenience sample of mixed-aged adults, the sensations from suprathreshold ethanol varied by concentration: bitterness dominated at lower concentrations, while burn dominated at higher concentrations. Exploratory analyses also suggest that differences in chemosensory responses across participants may associate with measures of alcohol use.

Correspondence to: John E. Hayes, jeh40@psu.edu.

Compliance with Ethics Requirements

Conflict of Interest The lead author declares no conflict of interest. The corresponding author has received consulting fees from various industrial clients in the food industry. These organizations have no involvement with in this work and were not involved in study conception, design or interpretation, or the decision to publish these data

Ethics Declaration All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008. Informed consent was obtained from all participants included in the study.

Keywords

Individual differences; Ethanol; Alcohol use; Taste phenotypes; Psychophysics; Health outcomes

Introduction

Ethanol elicits both taste and chemesthetic responses, and it is well established that taste intensity (Mattes and DiMeglio 2001; Scinska et al. 2000) and oral irritation (Green 1987, 1988) both increase as a function of concentration. However, prior reports fail to consider taste and chemesthetic responses simultaneously. For ethanol in water, the taste detection threshold in humans (Mattes and DiMeglio 2001) and the preference threshold in rats (Richter 1956) are both approximately ~1.4 % (v/v). In humans, ethanol at and just above threshold has been shown to be predominately bitter (Mattes and DiMeglio 2001), although burn was not provided as a response option. Other work in humans suggests that 3 and 10 % (v/v) ethanol are predominately bitter, although roughly a third of participants endorsed sweetness in addition to bitterness when asked to describe the quality; again however, neither burn nor other chemesthetic qualities were assessed, as participants were only asked about sweet, salty, sour and bitter sensations (Scinska et al. 2000). Moreover, those authors also reported that quinine/sucrose mixtures were more qualitatively similar to 10 % ethanol than the same quinine concentration in isolation (Scinska et al. 2000); similarly, earlier work shows that 8 % sucrose in 10 % ethanol is isosweet with 10 % sucrose in water (Berg et al. 1955). Other early work on ethanol chemosensation reported recognition thresholds of 4.2 % for sweetness and 21.2 % for burning (Wilson et al. 1973); curiously, while the authors note that the quality at lower concentrations may be bitter or “like an almond,” they did not attempt to estimate a recognition threshold for bitterness. Collectively, these reports suggest that in addition to its well-accepted bitterness, ethanol has some inherent sweetness, at least at some concentrations. It also suggests that data on chemesthetic qualities are generally lacking, with a few exceptions (e.g., Green 1987, 1988; Wilson et al. 1973).

Additional information on the sensations from ethanol comes from descriptive analysis on alcoholic beverages or model wines rather than simple ethanol/water mixtures; it is clear from these data that the sensory profile of alcoholic beverages differs by ethanol concentration, at least up to ~15 % ethanol. For example, increased ethanol content in alcoholic beverages associates with instrumentally measured changes in physical viscosity and density (Langstaff et al. 1991; Nurgel and Pickering 2005; Pickering et al. 1998). Using a panel of 12 trained assessors, Nurgel and Pickering observed significant differences in perceived viscosity and density for model wines with increasing ethanol content (0, 3, 7, 10, 12, and 14 %) (Nurgel and Pickering 2005). In model red wines, greater ethanol concentration associates with increased intensity ratings for chemical, woody, spicy, bitterness, and burning sensations and decreased intensity ratings for fruity, floral, and caramel sensations (Villamor et al. 2013). Contrary to the inherent sweetness discussed above, changes in ethanol concentration did not appear to alter the sweetness of model ice wines containing glucose and fructose, although this may reflect the relatively narrow range of concentrations used (7 to 12 % v/v ethanol), as the change in bitterness across concentration also failed to reach significance (Nurgel and Pickering 2006). The ability to

detect ethanol retronasally varies by wine type and has been reported to range from 1.03 to 1.32 % (v/v) (Yu and Pickering 2008). In summary, the alcoholic beverage literature supports the idea that changes in ethanol concentration influence the sensory quality of these beverages. Nonetheless, there remains a surprising gap in the psychophysical literature regarding the multiple chemosensory qualities evoked by ethanol, as we have been unable to find dose-response data on sweetness, bitterness, and irritation of ethanol/water mixtures in a single group of participants. We address this gap here.

Other literature suggests alcoholic beverage liking and intake associates with sensations elicited by ethanol (Intranuovo and Powers 1998; Lanier et al. 2005). Individual differences in the perception of bitterness and sweetness have been previously associated with intake (Duffy et al. 2004a, b; Intranuovo and Powers 1998; Lanier et al. 2005) and alcohol dependence (Kampov-Polevoy et al. 1999, 2004); however, others have failed to replicate this association (Kranzler et al. 2001; Tremblay et al. 2009). The sweetness of foods and beverages, including alcohol, associates with increased liking and intake (Lanier et al. 2005), whereas bitterness drives disliking et al. 2011; Intranuovo and Powers 1998; Lanier et al. 2005). Accordingly, studies which explore individual qualities in isolation may be overly reductionist and misleading, as prior work suggests that multiple qualities influence liking and intake simultaneously. Lanier and colleagues found that increased sweetness and decreased bitterness elicited from sampled whiskey and beer are associated with greater liking and intake in undergraduate students of legal drinking age (Lanier et al. 2005). However, those authors did not consider burning sensations in their model. It remains unknown how chemesthetic sensations elicited from ethanol, such as burning, tingling, and drying, together with prototypical taste sensations like sweetness and bitterness, may associate with differential intake of alcoholic beverages.

Epidemiological surveys that quantify alcoholic beverage consumption typically use the concept of a standard drink. This unit of measure attempts to take into account the percentage of ethanol in a particular type of beverage (e.g., 12 oz beer, 1.5 oz of spirits, or 5 oz of wine). Critically, however, this well-accepted metric does not consider the differences in the chemosensory properties of beverages that may arise from different ethanol content. Accordingly, improving our understanding of the full range of chemosensory responses to ecologically relevant concentrations of ethanol (i.e., at levels found across classes of various alcohol beverages) may provide additional insight into how various sensations from ethanol (e.g., sweetness, bitterness, and irritation) potentially influence alcoholic use behaviors.

The cross-sectional study described here extends previous work. In a convenience sample of mixed-age adults, we report on the chemosensory response to ethanol/water mixtures across a range of concentrations (4 to 48 % (v/v)) that are relevant to those typically found in alcoholic beverages (i.e., this range provides ecological validity). These data address a surprising gap in extent literature by illustrating dose-response functions for sweetness, bitterness, drying, and burning/tingling sensations across various concentrations within a single group of participants. As a secondary aim, we also explore whether individual differences in the sensations from sampled ethanol may associate with two measures of alcohol-related behaviors, including years drinking and drinking occasions in a convenience sample of mixed-age adults.

Materials and Methods

Study Overview

A convenience sample of reportedly healthy adults who had previously shown interest in participating in taste and smell experiments in our facility was recruited to participate in a single-session study. Interested subjects completed an initial online survey prior to the start of the test in order to determine if they were eligible to participate. Participants were invited to a single test session (~45 min), held at the Sensory Evaluation Center at Penn State, where they were asked to rate the intensity of five concentrations of ethanol in water and answer demographic questions, including several regarding alcohol use behaviors. Participants gave informed consent and were paid for their time.

Participants

Participants ($n=100$; 33 men; mean age=33.0; age range 21–55 years) were recruited from the Pennsylvania State University campus and surrounding area. Individuals who had previously indicated they were interested in taste and smell research were contacted via email and asked to complete an online survey to determine if they met study inclusion criteria. These criteria included the following: not pregnant or breast-feeding; non-smoker; no tongue, cheek, or lip piercing; no difficulty swallowing or history of choking, no known taste or smell defect; not an undergraduate student; not taking prescription pain medication; no hyperactive thyroid; and no history of chronic pain. Participants were also asked if they were willing to taste ethanol in the laboratory to ensure that participants had no objection to tasting ethanol, which might result from health, religious, or any other reason. Study procedures were exempted from review by the local Office of Research Protections staff under the exemption in 45 CFR 46.101(b)(6). All data were collected anonymously (i.e., participant identification was not linked to the sensory, or demographic data, including the alcohol use data).

Stimuli and Sampling Procedure

Participants rated 4, 8, 16, 32, and 48 % (v/v) ethanol in water, concentrations that cover the range of ethanol commonly found in beers, wines, and distilled spirits. An additional water (reverse osmosis) sample was included in the sample set as a control. To reduce effects of presentation order, all samples were presented in a counterbalanced Williams Design, which purported controls for effects of position, order, and carryover effects (Williams 1949). All samples were presented at room temperature in 10 mL aliquots in plastic medicine cups with a three-digit blinding code; they were prepared by diluting neat USP-grade ethanol with reverse osmosis water.

Participants were first asked to rinse with room temperature reverse osmosis (RO) water before tasting any stimuli. For each stimulus, participants were instructed to place the entire sample into their mouth and swish it around for 3 s, spit it out, and wait 5 s before making a rating, to account for the delayed onset of chemesthetic sensations. Participants rinsed with room temperature RO water to remove any lingering sensations; a minimum interstimulus interval of 2 min was enforced via software, and participants were also instructed to rinse until any remaining sensation from the stimulus was gone.

Psychophysical Scaling

Participants were asked to rate perceived intensity using a general Labeled Magnitude Scale (gLMS). The gLMS ranges from “no sensation” at 0 to “the strongest imaginable sensation of any kind” at 100, with empirically spaced adjectives at 1.4, 6, 17, 35, and 51 (“barely detectable,” “weak,” “moderate,” “strong,” and “very strong,” respectively). Four gLMS scales were presented for each stimulus, and participants used these to rate the intensity of the following: bitterness, sweetness, drying, and burning/tingling.

Participants were not trained on the individual qualities ahead of time, and burning/tingling was treated as a single percept here to limit “smearing” bias that can occur when too many scales are provided (see discussion in (Bennett and Hayes 2012)). That said, other work suggests that these are distinct qualities, and they can be assessed separately under some circumstances (e.g., Bennett and Hayes 2012; Cliff and Heymann 1993). Also, it should be noted that while ethanol is frequently described as burning in the psychophysical literature, either explicitly (Green 1988; Allen et al. 2014) or implicitly (Duffy et al. 2004b), chemesthetic aspects of ethanol are often described as “heat” in the wine literature (e.g., Pickering and Robert 2006); such nuanced differences may potentially influence how participants perform the task. Finally, for simplicity sake, we also made the assumption that naive participants would consider warming, chemical heat, and mild irritation to be weaker versions of burning/tingling (for a conflicting view with other chemesthetic stimuli besides ethanol, see recent work by Byrnes et al. 2015).

Prior to rating any samples, participants were given written instructions on the use of the gLMS and rated 15 remembered or imagined sensations for a brief practice (Hayes et al. 2013). These items include both food and non-food items to emphasize that the scale should be used in context to all sensations. Participants’ ratings of the orientation items were evaluated to determine whether participants understood the instructions and were using the scale properly. Here, proper scale use was defined as rating items in appropriate order (i.e., dimly lit room < well lit room < brightest light imaginable and loudness of a whisper < conversation < loudest sound imaginable) and not rating items as 100 (with the exception of “scalding hot water,” “loudest sound,” and “brightest light”). Under these criteria, four participants failed to use the scale correctly (discussed in more detail below). All psychophysical and demographic data were collected using Compusense *five*, version 5.2 (Guelph, ONT).

Demographics and Measures of Alcohol Use

After tasting all stimuli, participants answered demographic questions on age and sex and six questions related to alcohol use (Table 1). These questions were adapted from quantity-frequency and food frequency questionnaires (e.g., Cahalan et al. 1969; Giovannucci et al. 1991) (see Feunekes et al. 1999 for a review). These questions were used to estimate the frequency at which participants usually consume alcohol, as well as consumption frequency of different types of alcoholic beverage. Specifically, participants were asked the following: “How often do you usually drink alcohol?” (“I never drink alcohol,” “less than once a month,” “less than once a week,” “on 1 or 2 days a week,” “on 3 to 4 days a week,” “on 5 to 6 days a week,” “everyday”) and “Over the last month, how often did you drink [type of

alcohol]?,” where a separate question was asked for beer, wine, straight spirits, and spirits with mixers. The response options for these five questions were as follows: “never,” “less than once per month,” “1 day per week,” “2 days per week,” “3 days per week,” “4 days per week,” “5 days per week,” “6 days per week,” and everyday. Finally, participants were asked, “How long have you been regularly consuming alcohol (in years)?”

Statistical Analysis

Alcoholic use measures were assigned ordinal scores that corresponded with their answers: 0–6 for overall intake and 0–8 for each beverage-specific question (i.e., beer, wine, straight spirits, and spirits with mixers). These values were converted to yearly frequency (e.g., one to two times/week= 12, three to four times/week=48, five to six times/week=72, etc.) and then quarter-root transformed to improve normality of the data. Sex was coded as 1 for males and 2 for females. All analyses were conducted using SAS 9.2 (Cary, NC). Pearson correlation (r) and t tests were conducted to test associations between age and sex, respectively, with reported alcohol drinking frequency measures and years drinking. Separate linear regression models were performed using “proc reg” to test associations between alcoholic beverage use measures and intensity ratings for each sensation across concentrations of sampled ethanol. Stepwise multiple regression analysis was conducted to determine the total amount of variability explained for alcohol use measures explained by all chemosensory ratings across all ethanol concentrations. For multiple regression, multicollinearity was determined for the final stepwise model via the variance inflation factor (“vif”) option. There was no evidence of multicollinearity here, as all VIF’s were less than three for all significant variables in the final models. Analysis of variance (ANOVA) models were performed via “proc mixed” to test associations between groups created based on alcohol use measures (drinker group and drinking experience) with quality-specific intensity ratings for sampled ethanol. Percent variance explained (R^2) is reported for both linear and stepwise regression, and semi-partial correlation (sr) is reported for stepwise regression.

Results

Evaluation of Participants’ Use of the gLMS

Participants received written instructions describing the gLMS and proceeded to rate 15 remembered or imagined sensations on the gLMS to practice using the scale. Means and standard errors for the scale orientation items are shown in Table 2. These ratings were also used to determine participant’s ability to follow directions and evaluate their proper use of the scale. Of 100 participants who completed the study, data from four were removed (two participants rated loudest sound or brightest light less than 0.5, one participant only made ratings between 0 and 2 on a 100-point scale, and one participant rated five items as 100). All other participants ($n=96$) rated three sound and three light items in approximately the correct order (i.e., ratings were roughly monotonic, allowing for deviation of up to 5.0 units on a 100-point scale).

Sensations from Sampled Ethanol Varied with Concentration

The mean intensity ratings for burning/tingling, bitterness, and drying increased with increasing concentration, as expected, with differences in the rate at which each sensation increased (Fig. 1). The functions are shown visually in Fig. 1, and the power functions for each quality are given below. For 4 % ethanol, means for all sensations were similar and fell between barely detectable and weak. At 8 % ethanol, sweetness, drying, and burning/tingling were reported as below weak with bitterness rated just above weak. At 16 % ethanol, sensations began to differentiate in their intensities, with burning/tingling and bitterness falling below moderate, whereas drying was rated above weak and sweetness just below weak. At 32 and 48 % ethanol, intensity ratings for all sensations continue to diverge, with burning/tingling being the predominate sensation, with 32 % ethanol being rated above moderate and 48 % above strong. Some sweetness for ethanol was reported; however, the ratings fell between barely detectable and just above weak.

Using group means, the estimated quality-specific power functions for ethanol in water are as follows: burning/tingling= $0.86 [\text{ethanol}]^{1.26}$, bitterness= $0.92 [\text{ethanol}]^{0.88}$, drying= $0.79 [\text{ethanol}]^{0.98}$, and sweetness= $0.62 [\text{ethanol}]^{0.42}$, where ethanol concentration is given in percent (v/v).

Alcohol Intake Was Variable Across Study Participants

Individuals reported alcoholic beverage usage including overall frequency of drinking occasions and occasions drinking beer, wine, straight spirits, and mixed spirits. Most individuals reported consuming alcoholic beverages “1 or 2 days per week,” with beer and wine consumed 1 day per week, and straight spirits and mixed spirits were consumed less than once per month (see Table 1 for a summary of the characteristics of the 96 study participants). Age was not significantly correlated with frequency of overall alcohol intake (transformed) ($r=-0.15$, $p=0.14$) or frequency of intake for any specific type of alcohol beverage (beer $r=-0.10$; wine $r=-0.13$; straight spirits $r=-0.04$; mixed spirits $r=-0.04$; all $ps>0.1$).

Participants were placed into discrete categories based on the number of days that they reported consuming an alcoholic beverage in a typical week (see Table 1). Three participants reported never drinking alcohol. Thirty-six participants were categorized as “light” drinkers (consuming an alcoholic beverage less than once per week), 53 classified as moderate drinkers (consuming at least one alcoholic beverage between 1 and 4 days a week), and 4 were classified as “heavy” drinkers (consuming at least one alcoholic beverage between 5 days a week to everyday). Based on these data, we estimate that the modal frequency of drinking days in our cohort is between 53 and 106 days per year (based on one to two drinks/week); this level of intake is comparable to national surveillance data from the 1988 National Health Interview Survey (Russell et al. 2004).

To test for sex effects, a chi-square analysis was performed between drinker group and sex; the three individuals who reported never consuming alcohol (2 male and 1 female) were not included in this analysis. Chi-square analysis between drinker group and sex revealed no

relationship between intake frequency group (light, moderate, heavy) and sex ($X^2=1.69$, $p=0.43$).

Individuals also reported how long they have been regularly drinking alcohol in years: the grand mean was 10.5 years (± 0.84) with a median of 8 years and a range of 0 to 35 years. As would be expected, age was significantly associated with the number of years that participants reported regularly consuming alcohol ($r=0.70$; $p<0.0001$). However, by itself, age was not significantly associated with any sensations across any concentrations of sampled ethanol (all $ps>0.14$). Nor did sex associate with the number of years of regularly consuming alcohol ($t(31)=1.57$, $p=0.13$).

Reported Frequency of Drinking Occasions Associates with Chemosensory Perception for Sampled Ethanol

All reported frequencies of drinking occasions were quarter-root transformed for normality. Simple linear regressions were performed to determine the amount of variance of frequency of intake explained by reported intensity for each chemosensory sensation. Each sensation was explored separately, and separate regressions were conducted for each concentration.

For beer, significant associations were observed for the bitterness of 16, 32, and 48 % ethanol ($R^2=5.3$, 7.0 and 8.0 %; $p=0.02$, 0.009 and 0.005, respectively), along with burning/tingling for 32 % ethanol ($R^2=6.6$; $p=0.01$). No sex differences were observed for beer intake ($t(31)=1.01$; $p=0.95$).

Due to the conceptual and statistical redundancy in the univariate regression models above, stepwise regression was used to determine that the amount of variance chemosensory ratings (all sensations across all concentrations) might explain variability in the number of drinking occasions, as well as their relative importance in terms of variance explained; sex and age were also included in the stepwise models a priori. Total R^2 and semi-partial correlation coefficients (sr) are reported for the complete model and individual variables, respectively. For frequency of beer drinking occasions, the final model explained 18.08 % of the variance in intake frequency ($p<0.001$) with four significant predictors: bitterness of 48 % ethanol (sr=-0.22), burning of 32 % ethanol (sr=-0.17), drying of 8 % ethanol (sr=-0.17), and age (sr=+0.14). In summary, fewer occasions of beer consumption were associated with greater perceived bitterness and burning/tingling, decreased drying perception, and increased age.

Similarly, a multivariate stepwise model ($p=0.019$) explained 12.1 % of the variance in drinking occasions of wine via four significant predictors: bitterness of 8 % (sr=-0.04) and 48 % ethanol (sr=-0.22) and burning/tingling of 8 % ethanol (sr=-0.27), along with sweetness of 4 % ethanol (sr=+0.07). Greater sweetness, and less bitterness and burning/tingling were associated with more frequent occasions of wine intake. In the stepwise model for the frequency of consumption of spirits without mixers, two significant predictors explained 7.7 % of the variance ($p=0.02$). The final model included sweetness of 48 % ethanol (sr=-0.20) and burning/tingling of 8 % ethanol (sr=-0.17), which were both negatively associated with reported drinking occasions of straight spirits. Conversely, chemosensory responses from ethanol did not predict the frequency of consumption of spirits with mixers. Finally, overall alcoholic beverage drinking occasions resulted in a final

model composed of bitterness of 16 % ethanol ($sr=-0.25$), the burning/tingling of 16 % ethanol ($sr=+0.17$), and age ($sr=-0.17$), with the model explaining 11.09 % of the variance ($p=0.012$) in overall drinking occasions. Frequency of alcoholic beverage consumption occurrences was negatively associated with greater perceived bitterness and age and was positively associated with burning/tingling of ethanol.

Further analyses were conducted to determine the relationship between ethanol perception across concentrations and the total number of drinking occasions based on drinker groups, as described above (i.e., light, moderate, and heavy). Separate mixed-model ANOVAs were conducted to determine if there was a significant interaction effect between ethanol concentration and drinker group for each sensation (sweetness, bitterness, burning/tingling, drying). There were no significant interactions between drinker groups by concentration for any rated sensations for sampled ethanol.

Years of Alcohol Use Failed to Show Any Association with Chemosensory Perception of Sampled Ethanol

To explore potential associations between sensations and history of alcohol use, participants were segmented into two groups using a median split, with individuals reporting eight or fewer years in the “less experienced” group ($n=49$) and nine or more years in the “more experienced group” ($n=47$). In separate mixed-model ANOVAs (group by concentration), there was no evidence of a significant interaction between ethanol concentration and group for burning/tingling ratings [$F(4,376)=1.69$; $p=0.15$] or bitterness ratings [$F(4,376)=1.00$; $p=0.40$]. Nor did any of the other sensations from ethanol differ across either the groups based on median splits (not shown).

Discussion

This work confirms previous reports showing that the intensity of sampled ethanol increases as concentration increases (Green 1987; Mattes and DiMeglio 2001). We extend these findings here by quantifying the differences in intensities of sweetness, bitterness, drying, and burning/tingling elicited across a wide range of ethanol concentrations within a single group of individuals. At the concentrations presented here, bitterness was the predominate sensation for 4, 8, and 16 % ethanol. At higher concentrations 32 and 48 %, ethanol is primarily burning/tingling, followed by bitterness. Notably, sweetness was perceived across all concentrations, but at a much lower intensity (near barely detectable). These results should be used to guide the selection of the appropriate stimulus (i.e., ethanol concentration) for future studies on chemosensation and ethanol intake.

Regarding the varied qualities from ethanol, our data indicate that the power functions on the group means for bitterness, dryness, and sweetness have power exponents less than 1, suggesting that these psychophysical functions are negatively accelerating. Conversely, burning/tingling has a power exponent above 1, suggesting that it is a positivity accelerating function. Previously, warmth and pain (electric shock) have both been reported as having power exponents greater than 1 (although thermal pain reportedly has a power exponent near 1). To check our result against prior data on ethanol specifically, we extracted group means from Green (1987) and calculated power functions. Although not directly comparable due to

differences in attribute description (perceived irritation versus burning/tingling), delivery method (regional filter paper disks versus whole-mouth sip and spit), and scaling method (magnitude estimation versus gLMS), we find that the data of Green also shows a power exponent well above 1, at least on the middle of the tongue.

Years of experience drinking alcohol did not associate with any other perceived taste response from sampled ethanol nor frequency of drinking occasions of alcoholic beverages. Variation in chemosensory responses to sampled ethanol significantly explained variability in drinking occasions for beer, wine, straight spirits, and overall drinking frequency. In general, greater frequency of drinking occasions was associated with decreased bitterness and burning/tingling. Greater sweetness was associated with increased drinking frequency of wine but was negatively associated with intake of straight spirits. These findings generally support previous findings showing that greater perceived bitterness is associated with decreased intake (Intranuovo and Powers 1998; Lanier et al. 2005).

The present data suggest that future work on chemosensation and alcohol use, misuse, and abuse should carefully consider the ethanol concentration used within the context of the specific hypothesis being tested. For example, *TAS2R* bitter receptor gene variants fail to explain differential bitterness of, or liking for, sampled blended whiskey (Hayes et al. 2011); present data suggest that this may occur because ethanol at the concentration found in whiskey (40 % v/v; 80 proof) is more burning than bitter. Regarding potential health consequences, previous studies show protective effects of *TAS2R* variants on overall alcohol intake (Duffy et al. 2004a; Dotson et al. 2012). That said, such effects may be less robust in situations or cultures where spirits are the main source of alcohol that is consumed, as the present data suggest that burning is likely a more salient characteristic than bitterness in high ethanol content beverages. In these situations, *TRPV1* may be a more appropriate candidate gene (see Allen et al. 2014) than *TAS2Rs*. To date, no reports have attempted to link *TRPV1* variants to differences in alcohol use, misuse, or abuse.

Limitations

Our participants were asked to rate burning and tingling sensations on the same gLM scale. These two qualities were combined here in order to minimize participant confusion of these terms, as we assumed that naive participants might find it difficult to discriminate these two chemesthetic qualities, especially at low intensities (e.g., Bennett and Hayes 2012)). Although these two qualities may both be perceived via non-taste mechanisms, they are clearly distinct chemesthetic sensations. Thus, combining them together here under one rating scale limits our ability to explore nuanced differences in chemesthetic subqualities (e.g., burn, tingling, stinging, etc.). This is a limitation, as these qualities may potentially influence liking and intake of alcoholic beverages differently.

Here, we used ethanol in water mixtures to explore associations between perception and intake. It is critical to consider that ethanol is only one of many sensory active components found in alcoholic beverages. While ethanol contributes to the sweetness, bitterness, and burning sensations elicited by alcoholic beverages, other components such as hops and tannins on one hand, versus sucrose and glycerol on the other hand, also have the potential

to enhance or suppress these sensations. In terms of external validity, sampling different alcoholic beverages rather than ethanol in water may better mimic real-life situations outside the laboratory. Nonetheless, using ethanol in water as a model system helps tease apart the effects of various constituents and still reveals significant associations between chemosensation and self-reported alcohol behaviors. This suggests that at least some of the effects reported previously are likely due to ethanol itself and not merely other sensory active components like hops or tannins.

Regarding our participant cohort, of 96 participants, 93 reported consuming at least one alcoholic beverage in the past month. This is higher than national norms: in national surveillance data from 2013, ~64 to 69 % of adults aged 21 to 34 and ~59 to 61 % of adults aged 35–54 reported consuming alcohol in the last month (SAMSHA 2014). Given our recruitment criteria, this difference is not entirely unexpected. Critically however, our cohort provides sufficient variability in frequency of alcohol intake to allow us to test the hypotheses explored here. Additional research among alcohol-naïve individuals, as well as heavy and binge drinkers, is needed to better understand the potential influence of ethanol sensations on alcohol use, misuse, and abuse.

Conclusions

Chemosensory responses from ethanol differ greatly by concentration. Not only do intensities range from barely detectable to very strong, but the predominant sensation is concentration dependent. Here, oral chemosensory sensations from ethanol associated with self-reported measures of alcohol use outside the laboratory. Collectively, these findings suggest that ethanol tastes, particularly bitterness and sweetness, along with chemesthetic response, differ greatly depending on concentration and may provide more nuanced insight into preference and intake of alcoholic beverages.

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Fig. 1. Mean log intensity ($\pm$ SEM) burning/tingling, bitterness, drying, and sweetness ratings of sampled ethanol collected on a general Labeled Magnitude Scale (gLMS). At lower ethanol concentrations, bitterness is the dominant sensation; at higher concentrations, burn overtakes bitterness as the dominant sensation

Table 1

Characteristics of study participants

	Total (n=96)	Female (n=64)	Male (n=32)
Mean±SEM			
Age	32.7±0.8	32.6±0.9	33.0±1.5
Years drinking	10.5±0.8	9.8±0.9	11.9±1.7
Drinking frequency (%) ^a			
Never	3.2	1.5	6.2
Light	37.5	42.2	28.1
Moderate	55.2	51.6	62.5
Heavy	4.2	4.7	3.1

Drinking frequency groups were defined as follows: never—reported never consuming an alcoholic beverage, light—reported consuming an alcoholic beverage less than once per week, moderate—reported consuming at least one beverage between 1 and 4 days per week, and heavy—reported consuming at least one alcoholic beverage between 5 days a week to every day

^aPercentages are reported for each column

Table 2

Mean ratings for gLMS orientation items

Orientation question	Mean	±SEM
The brightest light you have ever seen	66.1	2.4
The loudest sound you have ever heard	65.4	2.3
The heat from dipping your hand in scalding hot water	60.3	2.3
The pain from biting your tongue	38.9	1.9
The sourness of a lemon	35.8	1.9
The sweetness of cotton candy	32.6	1.8
The brightness of a well-lit room	27.0	1.5
The bitter taste of black coffee	26.9	1.5
The burn from cinnamon gum	26.6	1.7
The strength of a firm handshake	23.5	1.2
The loudness of a conversation	20.1	1.2
The coolness from a peppermint candy	20.1	1.2
The warmth of a summer breeze on your face	18.8	1.2
The brightness of a dimly lit room	8.6	0.7
The loudness of a whisper	6.1	0.7

SEM standard error of the mean