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Modification of the bitterness of caffeine

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Abstract

Caffeine is the worlds most consumed psychoactive chemical and as such is a valuable commodity to the food and beverage industry. Caffeine also activates the bitter taste system causing a potential problem for manufacturers wanting to develop products containing caffeine. In the present study both oral peripheral and central cognitive strategies were used in an attempt to suppress the bitterness of caffeine. Subjects ($n = 33$) assessed the influence of sodium gluconate (100 mM), zinc lactate (5 mM), sucrose (125 mM and 250 mM), milk (0%, 2% and 4% milk fat), and aromas (coffee, chocolate, mocha) on the bitterness of caffeine (1.5, 3 and 4.5 mM). The oral peripheral strategies proved most effective at suppressing the bitterness of caffeine: zinc lactate (−71%, $p < 0.05$), non-fat milk (−49%, $p < 0.05$), and sodium gluconate (−31%). Central cognitive strategies were partially effective: 250 mM sucrose (−47%, $p < 0.05$) and mocha aroma (−10%) decreased bitterness, while chocolate (+32%) and coffee (+17%) aromas increased perceived bitterness. Overall, zinc lactate was the most effective bitterness inhibitor, however the utility of zinc in foods is negated by its ability to inhibit sweetness.

Keywords: Bitter; Taste; Smell; Inhibition; Suppression; Flavour modification

1. Introduction

Caffeine is the most commonly ingested psychoactive drug in the world, naturally occurring in coffee, cocoa (chocolate), and black teas, and as an additive in soft- and energy-drinks. The stimulant effect of foods that contain caffeine, such as the coffee bush berry, has been known for hundreds of years (Flament, 2002). The stimulant effect was due to caffeine and related methyl xanthines such as theophylline and theobromine whose physiologic mode of action is antagonism of the adenosine A1 and A2 receptors in the brain (Rainnie, Grunze, McCarley, & Greene, 1994).

As the site of action of caffeine is similar to the site of action of addictive drugs, it is not surprising that caffeine, at levels in common beverages, has been proposed to be an addictive drug (Holtzman, 1990). The dose of caffeine required to modify behaviour in humans is low (∼50 mg) (Nehlig, 1999), similar to the dose delivered in 500 ml common cola soft-drinks (∼53–65 mg, 0.55–0.67 mM). Behavioural studies have shown that the consumption of caffeine promotes a physiologic and psychologic dependence that is reinforced with repeat consumption (Garrett & Griffiths, 1998; Hughes, Oliveto, Bickel, & Higgins, 1993; Schuh & Griffiths, 1997). The common method of repeat caffeine consumption is via caffeinated foods such as coffee, tea, cocoa, and soft-drinks. Caffeine may promote liking and consumption of these foods via the development of flavour preferences; where individuals associate (unconsciously) a food/flavour with its post-ingestive consequences. The mode of action of caffeine in developing flavour preference is not immediate (Yeomans et al., 2000) as, for example, we experience with a sucrose solution (sweet and appetitive) but the positive influences occur post-consumption with increased vigilance and attention, enhanced mood and arousal as well as enhanced motor activity.

Caffeine may elicit bitterness depending on the concentration (Keast & Roper, 2007) and this can be a problem for food and beverage manufacturers. Solving this problem is complicated by the observation that the human bitter taste system is complex. It is subserved by approximately

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two dozen putative G-protein coupled receptors, the TAS2Rs (Adler et al., 2000; Chandrashekar et al., 2000), and several post-receptor transduction mechanisms (Huang et al., 1999; Kinnamon & Margolskee, 1996; Rossler, Kroner, Freitag, Noe, & Breer, 1998; Spielman, Huque, Whitney, & Brand, 1992; Wong, Gannon, & Margolskee, 1996). Moreover, caffeine may modify flavour at the peripheral level via interference with taste transduction (Peri et al., 2000; Rosenzweig, Yan, Dasso, & Spielman, 1999).

In general, there are three approaches to suppressing bitterness: physio-chemical interactions in a food or beverage matrix, oral peripheral physiological interactions with receptor cells (e.g., via receptor inhibitors), and central cognitive mixture suppression (e.g., via taste–taste and taste–aroma interactions).

Physio-chemical interactions can change flavour intensity or even generate new flavours. They occur in a simple aqueous solution: weak attractive forces, such as hydrogen or hydrophobic bonding, will result in altered structures; precipitation of the compounds will render them weaker or tasteless. The chemical composition of a food matrix will influence perceived flavour, changing from an aqueous to emulsion system (oil-in-water) decreased bitterness (Metcalf & Vicker, 2002).

Sodium and zinc salts inhibit the bitterness of certain compounds whether or not the salts elicit a taste, indicating that the inhibition is peripheral rather than based on perceptual interactions (Bartoshuk & Seibyl, 1982; Breslin & Beauchamp, 1995; Keast & Breslin, 2002, 2005; Keast, 2003; Kroeze & Bartoshuk, 1985). As well as lipid having a physio-chemical influence on bitterness, the components of fats, fatty acids, may also modify bitterness via interactions in the oral periphery (Koriyama, Kohata, Wananabe, & Abe, 2002; Koriyama, Wongso, Wananabe, & Abe, 2002).

Central cognitive effects can occur when different qualities of taste stimuli are mixed together and the perceived intensity of one or more of the components is diminished by the perception of the others. This is labeled mixture suppression (Pangborn, 1960) and is caused by cognitive interactions among taste qualities. As one example, mixture suppression occurs when you add sugar to coffee, both the sweetness of the sugar and bitterness of the coffee are reduced. Also, the combination of taste and aroma may influence the intensity of both the taste and aroma (Frank & Byram, 1988; Frank, Ducheny, & Mize, 1989). The primary requirement for an aroma influencing the perceived intensity of a taste is the congruency of the aroma–taste pair. For example, strawberry aroma increases perceived sweetness (we associate strawberry odour with sweetness) whereas peanut butter aroma does not increase perceived sweetness (we do not associate peanut butter aroma with sweetness).

The aim of this study was to investigate both central cognitive and oral peripheral factors that may modify the bitterness of caffeine.

2. Materials and methods

2.1. Subjects

Subjects ($n = 33$, 23 ± 4 years old, 28 female) between the ages of 18 and 38 were University students in Melbourne, Australia. All subjects were volunteers and agreed to participate and provided informed consent on an approved Institutional Review Board form. The subjects were asked to refrain from eating, drinking or chewing gum for 1 h prior to testing. Not all subjects participated in all experiments: Experiment 1, $n = 30$; Experiment 2, $n = 31$; Experiment 3, $n = 33$; Experiment 4, $n = 32$.

2.2. Subject training

Subjects were initially trained in the use of the general Labeled Magnitude Scale (gLMS) following the published standard procedures (Green, Shaffer, & Gilmore, 1993; Green et al., 1996) except the top of the scale was described as the strongest imaginable sensation of any kind (Bartoshuk, 2000). The gLMS is a psychophysical tool that requires subjects to rate perceived intensity along a vertical axis lined with adjectives: barely detectable = 1.5, weak = 6, moderate = 17, strong = 35, very strong = 52, strongest imaginable = 100; the adjectives are placed semi-logarithmically, based upon experimentally determined intervals to yield data equivalent to magnitude estimation (Green et al., 1993; Green et al., 1996). The scale only shows adjectives, not numbers, to the subjects, but the experimenter calculates numerical data from the scale. The gLMS was chosen for this study as it provides ratio quality data (Bartoshuk, 2000). A computerized data-collection program (Compusense 5) was used in all sessions.

Subjects were trained to identify each of the five taste qualities by presenting them with exemplars. Salty taste was identified as the predominant taste quality from 150 mM NaCl, bitterness as the predominant quality from 0.50 mM quinine–HCl, sweetness as the predominant quality from 300 mM sucrose, sourness as the predominant quality from 3 mM citric acid, and umami the predominant quality from a mixture of 100 mM MSG and 50 mM IMP. In addition, astringency was identified from 0.5 mM tannic acid. To help subjects understand a stimulus could elicit multiple taste quality, a mixture of 0.50 mM quinine–HCl and 3 mM citric acid (bitter and sour) and a mixture of 150 mM NaCl and 300 mM sucrose (salty and sweet) were employed as training stimuli. The gLMS was the scale used during taste quality training. All subjects were able to correctly identify taste and astringent qualities after training.

2.3. Standardization of gLMS ratings with heaviness ratings

The gLMS standardization methodology followed previously published methodology (Delwiche, Buletic, & Breslin, 2001) and is employed to minimize individual scale use