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Caffeine metabolism rate influences coffee perception, preferences and intake

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ABSTRACT

Several factors – genetic, demographic and environmental – contribute to individual differences in sensitivity to the pharmacological effects of caffeine. Caffeine metabolism influences coffee consumption, but its effect on bitterness perception in, and preference for, coffee is unknown.

This study explores the possible relationship between caffeine metabolism rate and coffee preferences and consumption habits. In addition, the extent to which caffeine metabolism interacted with variations in bitterness perception was investigated. Caffeine metabolism rate was assayed by competitive immuno-enzymatic assay in one-hundred thirty-five coffee consumers who provided saliva samples after 12 h caffeine abstinence and at 30 and 90 min after ingestion of caffeine (100 mg). A caffeine metabolism index (CmI) was computed as the ratio between the amount of residual caffeine in saliva 60 min after the adsorption peak and the amount of caffeine at the adsorption peak corrected with the baseline. Ninety-one subjects were selected to investigate the relationships between inter-individual variation in caffeine metabolism, bitterness perception and coffee preference. Subjects rated liking for, and sourness, bitterness and astringency of, six unsweetened and freely sweetened coffee samples varying in roasting degree, caffeine content and bitterness. They also rated the bitterness of six caffeine and six quinine (equi-intense) solutions. Finally, subjects choose coffee to drink on the basis of a label (strong vs balanced flavor) both after caffeine abstinence and after no restrictions on caffeine intake. The CmI was strongly associated with the frequency of daily coffee consumption. Subjects with lower CmI gave higher bitterness ratings than other subjects for both coffee and caffeine solutions, but not for quinine solutions. They also added more sugar to the coffee samples. Following caffeine abstinence, all subjects chose the "strong flavor" coffee, while without caffeine restrictions, subjects with lower CmI preferentially tended to choose the "balanced flavor" coffee. These results provide the first link between caffeine metabolism and bitterness perception, and to the use of sugar to modify coffee bitterness.

1. Introduction

Understanding the influences on preferences for bitter foods and beverages is a challenge because bitterness *per se* is innately disliked (Steiner, Glaser, Hawilo, & Berridge, 2001). Despite this, bitter beverages such as coffee and beer are amongst the most consumed beverages worldwide. Preferences for bitter food or beverage flavors are thought to be developed via associations between the flavor and the post-ingestive consequences of the consumed nutrients and pharmacoactive ingredients (Yeomans, 2010). Such flavor consequence learning (FCL; (Rozin & Zellner, 1985)) can be produced by ingestion of valued nutrients such as glutamate (Prescott, 2004), or energy in the form of sugars or fats (Yeomans & Mobini, 2006). In addition, the physiological and behavioral effects associated with stimulants such as alcohol, caffeine, theophylline, theobromine are also linked to the development of flavor preferences (Tinley, Yeomans, & Durlach, 2003; Yeomans, 2010).

Caffeine, in particular, has been found to promote flavor preferences (Tinley et al., 2003). Caffeine is a central nervous system and metabolic stimulant (Nehlig, Daval, & Debry, 1992) and it promotes wakefulness, enhances mood and cognition, and produces stimulatory effects (Haskell, Kennedy, Wesnes, & Scholey, 2005; Lieberman, Tharion, Shukitt-Hale, Speckman, & Tulley, 2002). Caffeine is absorbed rapidly and is converted mostly to

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paraxanthine (81.5%) (Campbell, Grant, Inaba, & Kalow, 1987; Gu, Gonzalez, Kalow, & Tang, 1992; Tassaneeyakul et al., 1994), by cytochrome P-450 enzymes, in particular the P-450 1A2, which is coded by the gene CYP1A2 (Lelo, Birkett, Robson, & Miners, 1986; Miners & Birkett, 1996). An A to C substitution at position −163 (rs762551) in the CYP1A2 gene may explain inter-individual variation in caffeine metabolism rate (Aklillu et al., 2003; Chevalier et al., 2001; Grosso & Bracken, 2005; Han et al., 2001; Nakajima et al., 1999; Sachse, Brockmoller, Bauer, & Roots, 1999; Sachse et al., 2003; Signorello et al., 2001). Carriers of the −163C allele can be considered slow caffeine metabolizers, whereas homozygous for the −163A allele are more rapid caffeine metabolizers (Cornelis, El-Sohemy, & Campos, 2007; Sachse et al., 1999).

In general, given the same caffeine intake, slow metabolizers will be more exposed to high internal caffeine levels than fast metabolizers (Bech, Autrup, Nohr, Henriksen, & Olsen, 2006; Santos, Cotta, Jiang, & Lima, 2015). People tend to adapt their coffee consumption to balance perceived negative and reinforcing symptoms that are affected by genetic variation (Cornelis et al., 2015). However, while caffeine intake itself increases the rate of caffeine metabolism (Berthou, Goasduff, Dréano, & Ménez, 1995; Tantcheva-Poòr, Zaigler, Rietbrock, & Fuhr, 1999), there has been no exploration of the ways in which caffeine metabolism rate, the variants in CYP1A2 and caffeine consumption are linked to coffee preference.

In addition to any direct pharmacological effects, coffee preferences, like those of other bitter foods and beverages (Dinehart, Hayes, Bartoshuk, Lanier, & Duffy, 2006; Duffy, Peterson, & Bartoshuk, 2004; Hayes et al., 2011; Mastaneh, Hayes, & Duffy, 2013), appear to be partially dependent on genetically-determined variations in taste responsiveness. Hence, differences in the intensity of the compound 6-n-propylthiouracil (PROP) were shown to affect the perception of bitterness of caffeine (Ly & Drewnowski, 2001) and the liking for coffee (Pirastu et al., 2014). Moreover, the density of lingual fungiform papillae (FP), PROP status (Masi, Dinnella, Monteleone, & Prescott, 2015) and the individual responsiveness to astringent stimuli (Dinnella, Recchia, Tuorila, & Monteleone, 2011; Fleming, Ziegler, & Hayes, 2016) influence the perception of bitter taste and the use of sweeteners in coffee. Indeed, preferences for coffee or other initially unpalatable foods/beverages can be facilitated by the addition of sweeteners that produce FCL due to the delivery of energy (Yeomans & Mobini, 2006) and also suppress disliked bitter, sour or irritant qualities (Prescott, Ripandelli, & Wakeling, 2001). Independently, choosing particular coffee styles that may vary in species, origins, processing factors, and brewing methods (Andueza, Paz De Peña, & Cid, 2003; Lindinger et al., 2008; Maeztu et al., 2001; Nebesny & Budryn, 2006; Schenker et al., 2002) allows consumers to choose coffees based on their taste responsiveness and their own preference for particular sensory properties.

The study reported here aimed to examine the relationship between caffeine metabolism rate, coffee preferences and consumption habits. In addition, we examined the extent to which caffeine metabolism was linked to variations in bitterness perception. We predicted that both fast caffeine metabolism rate and low responsiveness to bitter taste favor the preference for, and consumption of, the more bitter black coffee. The logic behind this it that the higher coffee consumption associated with a faster caffeine metabolism rate would allow a more rapid development of a preference for stronger coffee flavor, as is found with exposure to other unpalatable tastes (Methven, Langreney, & Prescott, 2012). In turn, this process may be further enhanced by a relatively low responsiveness to bitter taste. On the other hand, the use of sweeteners in coffee to mask its unpleasant bitter taste could result from the interplay between high responsiveness to bitterness and the relatively low consumption induced by a lower caffeine metabolism rate. Thus, the aim of this study was to investigate the possible relationship between caffeine metabolism rate and bitterness responsiveness and how these can influence intake of and preference for coffee, in terms of both sensory properties and use modality (with or without sweeteners).

2. Materials and methods

2.1. Subjects

One hundred and thirty-five subjects (Ss) (59 males and 76 females; aged 20–60 years; regular coffee consumers; 108 no smokers and 27 smokers; 19 oral contraceptive users) were recruited in the Florence area. The Ss had no history of disorders of oral perception. They were paid for their participation in the study. All studies adhered to the tenets of the Declaration of Helsinki. Approval for the research protocol was obtained from the Institutional Review Board of the Agricultural PhD School/Sustainable Management of Agricultural, Forestry and Food Systems - GESAAF, University of Florence. Written informed consent was obtained from each subject after the description of the experiment.

2.2. Samples

2.2.1. Coffee samples

Six espresso coffee samples (labeled A, B, C, D, E, G) were evaluated. Products were selected based on variations in their caffeine content, the roasting degree, the intensity of bitterness and typical descriptors of coffee flavor, as previously described (Masi et al., 2015). Coffee samples (25 g) were prepared with an espresso machine using coffee capsules. In the adopted experimental conditions, coffee temperature was 65–67 °C for aroma evaluation and 55–57 °C for in-mouth evaluation.

2.2.2. Taste stimuli

Six concentrations of caffeine (0, 3, 6, 12, 24, 48 mM) and quinine-HCl (0, 0.05, 0.10, 0.15, 0.20, 0.25 mM) were selected to obtain equi-intense solutions for bitterness. The concentrations of caffeine and quinine-HCl were chosen considering that on average the caffeine content in coffee is 3.2–6 g/l and also based on previous results (Keast & Roper, 2007) comparing responses to equi-intense solutions of caffeine and quinine-HCl. The twelve solutions, six of caffeine and six of quinine-HCl, were evaluated twice by a trained panel of twenty-nine subjects to verify that they were perceived as equi-intense. A single solution (3.2 mM) of 6-n-propylthiouracil (PROP) was selected to determine PROP taster classification (Hayes & Duffy, 2007; Prescott, Soo, Campbell, & Roberts, 2004). All solutions were prepared with deionized water and were stored in glass bottles and were brought to room temperature prior to testing. Ss were instructed to hold each sample (10 ml) in their mouth for 10 s, then expectorate, wait 20 s and evaluate the intensity of bitterness using the general Labeled Magnitude Scale (gLMS) (Bartoshuk et al., 2002; Green, Shaffer, & Gilmore, 1993).

2.3. Procedure

Ss participated in four separate evaluation sessions: in the first session, Ss were asked to smell and rate their liking for the aroma of the coffee samples first. Then they were asked to take a sip and rate their liking for the flavor (flavor1). Finally, they were asked to freely add sugar, if they thought it was necessary independently of their habit, take a sip and rate again their liking for the flavor (flavor2). In the second session, Ss rated the intensity of sourness, bitterness and astringency in the coffee samples using the gLMS. In the third session, Ss rated the intensity of bitterness in standard