Physiology & Behavior 140 (2015) 180–187

Contents lists available at ScienceDirect

Physiology & Behavior

journal homepage: www.elsevier.com/locate/phb

Is sensory-specific satiety for a bitter-sweet infusion modulated by context?

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HIGHLIGHTS

- Sensory-specific satiety (SSS) for infusions was proved in artificial and natural settings.
- SSS for odour and SSS for flavour showed differential sensitivity to context.
- The magnitude of olfactory SSS was lesser in the cafeteria compared to laboratory.
- Multiple SSS sessions showed a contextual control of the motivational ratings.

ARTICLE INFO

Article history:
Received 17 January 2014
Received in revised form 19 December 2014
Accepted 22 December 2014
Available online 24 December 2014

Keywords:
Bitter-sweet infusion
Context
Medium-term satiation
Sensory-specific satiety

ABSTRACT

The sensory-affective attributes of beverages have an important influence on a given intake and successive consumptions because of sensory-specific satiety (SSS; defined as a decrease in pleasantness ratings of a food eaten relative to uneaten foods). No studies have, however, investigated how multiple sessions of SSS for familiar drinks over a period of several days up to a week may change their pleasantness and how these hedonic-related judgments are affected by the context during SSS testing. With twenty-six participants, the present study explored the medium lasting and contextual effects of repeated SSS sessions for a bitter-sweet infusion on olfactory and flavour pleasantness over the course of three exposures in either a laboratory or a cafeteria setting. The results showed olfactory and flavour SSS for the infusion following each consumption in both the artificial and the natural setting. More interestingly, despite the failure to detect medium-term SSS (i.e., a greater decrease in pleasantness ratings of a food eaten relative to uneaten foods after repeated SSS sessions over several days as compared to the first SSS session), a contextual modulation of olfactory SSS was observed with a lesser overall magnitude in the cafeteria compared to the laboratory setting. To the best of our knowledge, the impact of eating location on the development of satiation and the differential contextual sensitivity of SSS for orthonasal odours and flavours has not been reported previously. The implications of potential environmental control of SSS are considered in this study.

1. Introduction

Among the affective processes involved in the regulation of the quantity and the type of food ingested during and following a meal, sensory-specific satiety (SSS) appears to be an extensively studied phenomenon. The effects of the SSS procedure within an eating session have been demonstrated by decreases in food-related responses such as food intake [1,2], salivation [3], rate of consuming [4], likelihood of food choice [5] and hedonic value ratings (i.e. liking) [6–8]. Moreover, this negative hedonic shift occurs for the food's flavour/taste [1], odour [9,10] and other sensory food attributes as texture [11] and visual appearance [12].

In addition to SSS within a single eating session, long-term SSS might influence eating over time periods of weeks or months. For instance, Rolls and de Waal [13] reported that the taste of foods that refugees in an Ethiopian refugee camp had been eating for approximately six months was less pleasant than the taste of new foods, whereas newly arrived refugees who had been eating that same diet for only two days found all foods equally pleasant. Regular consumption of high energy-dense snack foods for twelve weeks has also been found to alter SSS for these foods ([14], but not for potato chips, where differences in fat content do not seem to affect the development of SSS over

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http://dx.doi.org/10.1016/j.physbeh.2014.12.035
0031-9384/

10-day sessions [15]). In order to demonstrate the effect of limiting snack food variety on long-term SSS and monotony in overweight adults, Raynor, Niemeier and Wing [16] compared an experimental group that ate only one chosen snack food for the entire 8-week period with a control group that ate one snack per day but with no limit on the variety of choices for that snack; over time, the experimental group showed long-term SSS (in terms of greater decrease in pleasantness of the chosen food compared to the uneaten food) and food monotony (as greater decrease in hedonic ratings of the chosen food in the experimental vs. the control group). Therefore, a large body of evidence is available on SSS in the very short term (within a meal) and, to a lesser extent, in the very long term (over several weeks to months). However, to date no research has extended the study of development of SSS in the medium term (over a few days to a week), although combining eating a food to satiety and in-home evaluation over several days seems to show a decrease in liking ratings for more than 24 h [17].

An approach that supports the distinction between short- and medium- to long-term SSS comes from habituation, a mechanism generally proposed for SSS [18,19] that presents short as well as long forms including long-term habituation to food [20,21]. Taking into account associative theories of habituation, some hypotheses for SSS have been recently confirmed including, among others, stimulus specificity [22] and dishabituation [23,24] as new food can disrupt the development of SSS if it has not been completely established [25]. For our purposes, if, for instance, medium- to long-term SSS is due to long-term hedonic habituation, one should expect repetitive food offerings to result in a decrease in hedonic response that lasts for days or weeks, i.e. more rapid rehabituation and/or lower initial or average responses and/or less frequent responses than baseline [26]. These theories explain this by considering that long-term changes result from associations between the stimulus and the context in which the training occurs [27,28], causing anticipation of the stimulus and therefore lesser degree of processing. On this reasoning, response decrements between sessions would not be dependent solely on the parameters of test stimulus presentation, but would also include elements of the environmental situation in which it is presented [28,29]; and medium-term SSS for the infusion should be expected as a result of habituation to the infusion plus a context-infusion association. However, most of the information about long-term habituation comes from a non-food-related variety of responses in controlled human studies [18]. This associative hypothesis might not hold in the more complicated naturalistic settings in which human SSS takes place, especially since eating location seems to affect ingestive behaviour dramatically, including the cessation of eating [30–32]. In this sense, although many environmental cues influence satiety (e.g., number of people present, watching TV, or packages and dishware sizes) [33,34], the role of the physical location remains quite unexplored in short-term SSS and it is unexplored in medium- to long-term SSS, in part because the traditional view of SSS has neglected the influence of context [35].

In order to dissociate and explore the impact of contextual and between-session effects in this study, SSS was assessed using the School cafeteria as a familiar, natural eating context for the study's university participants and our laboratory as a novel context, with half of the sessions conducted in each setting. It can be argued that the acquisition of a context-infusion association should be more prominent when a novel context is used as prior exposure to a stimulus tends to reduce the readiness of that stimulus to enter into new associations [36]. Thus, based on associative theories of habituation, it was hypothesized that repetitive infusion presentations would produce smaller initial hedonic ratings with a smaller magnitude of SSS, as well as more rapid SSS, across sessions in the laboratory compared to the cafeteria setting. SSS was represented by a decrease in pleasantness according to the traditional view, although SSS is not only related to hedonic but also to motivational aspects (i.e. wanting) [37]. Given the role played by olfactory cues in the stimulation of appetite as well as satiation [8], and that SSS has been shown to occur not only for the flavour of food but also for odours [10], both flavour SSS and olfactory SSS were included. Finally, repeated exposure to a novel food with intervals of days often increases the acceptability and intake of that food, reflecting a reduction in neophobia [38], among other phenomena. To prevent that novelty of the food affected the results and to minimize differences in the initial ratings for hedonic and motivational values, the test food was a typical and familiar food for the participants (drunk at least once a week): a yerba mate (*Ilex paraguariensis*) infusion, an herbal tea beverage widely consumed in South American countries.

2. Methods

2.1. Subjects

Prior to undertaking the study, a sample size calculation was performed with G*Power 3.1 using an α of 0.05, 80% power, and an average correlation of rho = .50 between the repeated measures for 6 within subject conditions in order to detect a small effect ($\eta2 = 0.045$). We calculated that the experiment required approximately twenty-four participants. The final number of enrollees was twenty-six healthy women, all of them students or staff of the University of Buenos Aires. Initial recruitment efforts for the second experiment did not target women exclusively but, given that study volunteers were predominantly women, the study was limited to women to improve homogeneity. Participants' (mean $\pm$ standard deviation) age was 28.8 $\pm$ 9.5 years and body mass index was 22.2 $\pm$ 4.2. As in the Pilot Study (see Inline Supplementary Material), participants were asked to complete the Three-Factor Eating Questionnaire (TFEQ) [39] and the Food Neophobia Scale (FNS) [40]. Their uncontrolled eating, emotional eating and cognitive restraint scores were 18.8 $\pm$ 2.8, 9.6 $\pm$ 1.8 and 18.7 $\pm$ 2.9, respectively. Food neophobia score was 27.7 $\pm$ 12.2. All subjects self-reported normal smell and taste sensitivity and none of them mentioned any allergies or aversions to any of the food ingredients used in the present study. They were informed of the general procedure but not the purpose of the experiment, and all participants gave their written consent. The study was approved by the institutional ethics committee of the School of Pharmacy and Biochemistry, University of Buenos Aires.

2.2. Apparatus and solutions

As test food, a sucrose-sweetened mate (SM) infusion prepared at 1.2% w/v by placing tea-like bags containing 3 g of yerba mate with sugar (5% w/v) in 250 mL of water at 90 °C for 6 min was used. The SM infusion and the control foods (crackers, light vanilla flavoured yoghurt and unsweetened corn flakes) were used, prepared and served as described in the Pilot Study (see Inline Supplementary Material). These foods were chosen because of their different sensory characteristics compared with the bitter-sweet infusion and with each other. The laboratory and cafeteria settings that served as contexts were located at the School of Pharmacy and Biochemistry, University of Buenos Aires. According to Meiselman's [41] categorization of environmental influences, the contextual changes were related only to the situation in which the SSS tests were conducted, keeping the food and individual variables constant across sessions. Environmental influences included differences in the dimensions of the room (the ratio of tables for laboratory/cafeteria was 1:10) and lighting (laboratory > cafeteria). Other differences between contexts were obviously the nature of the environment (a natural eating environment that already exists vs. a non-natural setting as the laboratory) and the number of people present in the room (cafeteria > laboratory). Since the variations necessary to differentiate two contexts are not clear, the changes applied in this study were similar to those successfully used to demonstrate contextual dependence of learning and memory in human subjects [42] and were based mainly on very dissimilar physical appearance. The sensory properties of foods (taste, temperature and variety), the type of SSS test, the temporal factors related to food (encompassing all foods and beverages recently consumed) and non-food (time of day, time interval of exposure and month of the year), the physiological characteristics (such as previous caloric intake and the level of hunger and thirst) and the social conditions during the SSS tests (number of co-eaters and familiarity between co-eaters) were kept similar in both locations.

2.3. Procedure

The experiment consisted of six different sessions with three sessions/week (seven participants participated in two sessions/week) between 1100 and 1300 h, 3 h after the end of breakfast. To avoid an order effect, half of the participants started the SSS sessions in the laboratory and the other half in the cafeteria, and the contexts were assigned to participants in random order. The choice of number of sessions was determined by the absence of empirical data on the dynamic aspects of liking using SSS protocols over successive days up to a week, and limited by the subjects' availability. In addition to their breakfast caloric intake, at the beginning and end of each session participants quantified their level of hunger, thirst and fullness on 10-cm VAS anchored from "Not at all" on the left to "Extremely" on the right. Participants were satiated and tested under conditions identical to those described in the Pilot, except for the distinction between olfactory and flavour pleasantness and the order of presentation of samples (Fig. 1 shows the flow chart of the experimental procedure; see Inline Supplementary Material for additional information). The question about pleasantness of food stimuli was specified for olfactory and flavour proprieties as follows: "How much do you like the odour of this food?" and "How much do you like the flavour of this food?" Subjects were instructed to (1) hold the sample close to their noses and take several deep sniffs while rating

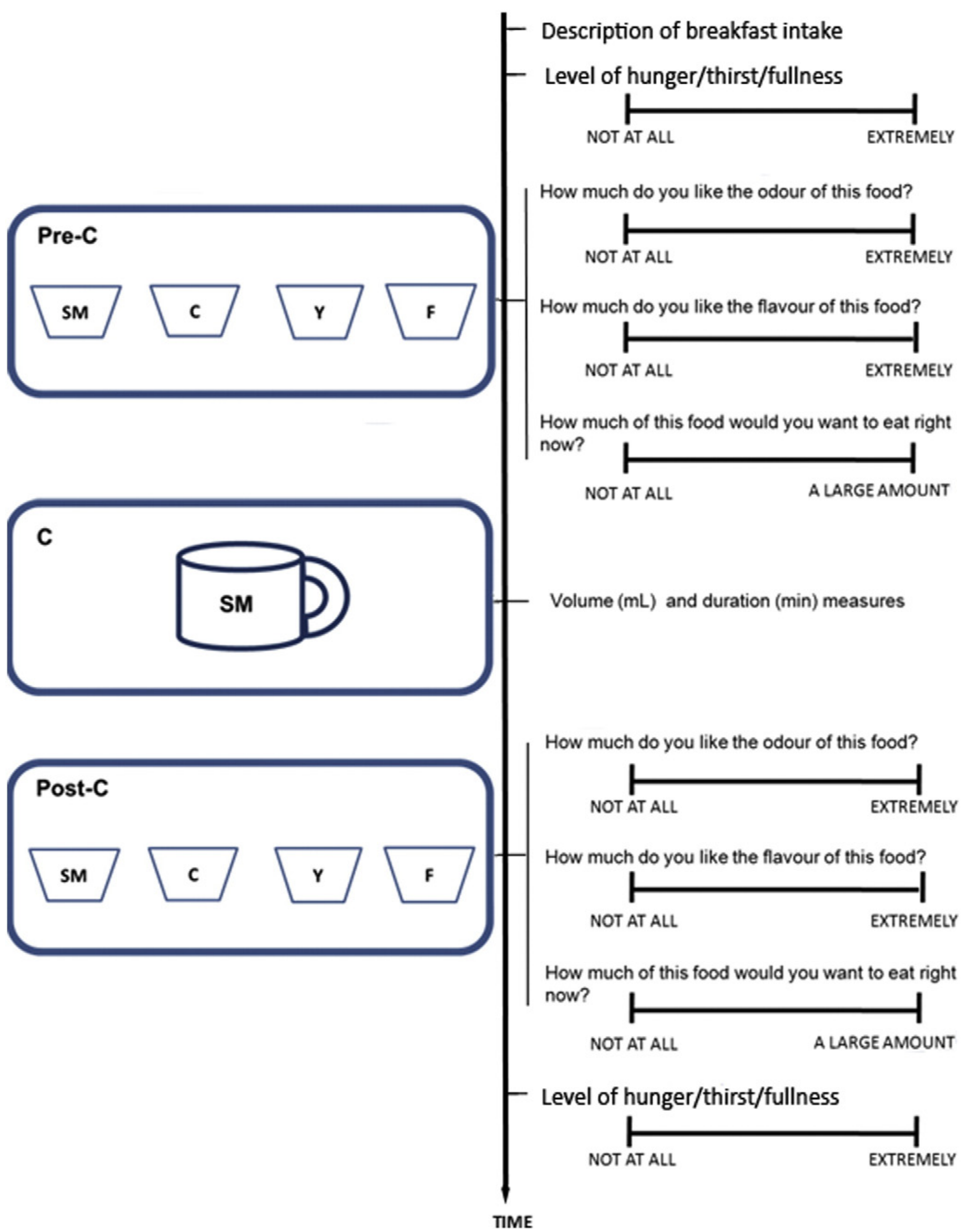

Fig. 1. Flow chart of the experimental procedure: pre-consumption (Pre-C), consumption (C) and post-consumption (Post-C) phases, with their respective measures. During Pre-C and Post-C, a tray with small 30-mL plastic cups containing bite-size samples of the sucrose-sweetened mate (SM) infusion and the control foods (crackers [C], yoghurt [Y] and flakes [F]) was presented. During the C, cups filled with 250 mL of SM were given to the participants, who consumed it ad libitum until pleasantly full. The same procedure was performed in laboratory and cafeteria settings across three sessions in each context.

the smell, (2) hold the sample in their mouths while rating the flavour, and (3) swallow the sample when the ratings had been completed. Samples were tested in the following order: mate infusion, corn flakes, yoghurt and crackers. It should be noted that the first food that was always presented after satiety was the mate infusion (i.e. the same food that was consumed to satiation) in order to stress the observation of medium-term SSS because if SSS is the result of habituation to the infusion, the intermediate tasting of the control foods might (at least to some extent) dishabituate the decreased ratings of the infusion [20]. Participants were asked not to eat or drink anything for 3 h prior to each test session, except water which was allowed up to 1 h before the session; they were also asked to consume a similar breakfast on each test day, to maintain similar exercise schedules for the 24 h preceding arrival at the laboratory, and to refrain from drinking alcohol.

2.4. Data analysis

Hedonic and motivational ratings were analysed using: 1) initial ratings; 2) change in ratings (as a percentage), calculated by subtracting pre-consumption from post-consumption scores; and 3) magnitude of the change in ratings (as a percentage), calculated as the change for the infusion minus the mean change score for the control foods (obtained by collapsing the data for crackers, yoghurt and corn flakes). Data on hunger, thirst and fullness were also analysed using the initial ratings and the change in ratings from before to after satiety. Differences in breakfast caloric intake (kcal), infusion intake (mL), duration of the intake (minutes from administration of infusion until satiety), initial ratings (cm) and changes (%) in ratings of hunger, thirst, fullness and desire to eat the infusion, as well as the magnitude of the change (%) in desire to eat ratings for the infusion, were tested with two-way repeated measures ANOVAs with context (laboratory and cafeteria) and session (1, 2 and 3) as factors. In order to determine short-term SSS, the change in olfactory/flavour hedonic ratings for the infusion compared to the mean change score of the control foods on each test day was analysed by t-tests. Medium-term SSS, defined as a greater decrease in pleasantness ratings of a food eaten relative to uneaten foods after repeated SSS sessions over several days as compared to the first SSS session, was determined using the initial olfactory/flavour hedonic ratings and the magnitude of the change in olfactory/flavour hedonic ratings for the infusion over time through separate two-way repeated measures ANOVAs with context (laboratory and cafeteria) and session (1, 2 and 3) as factors. Stability of the control foods was analysed using the mean change score in olfactory/flavour pleasantness and desire to eat ratings for the three control foods through two-way repeated measures ANOVAs with context (laboratory and cafeteria) and session (1, 2 and 3) as factors. Tukey's test was used for post-hoc comparisons of significant effects. P values $\leq .05$ were considered significant.

3. Results

3.1. Breakfast caloric intake, hunger, thirst and fullness

Breakfast intake was 289.4, 310.3 and 302.9 kcal for sessions 1, 2 and 3 in the laboratory; and 326.3, 298.4 and 312.4 kcal for sessions 1, 2 and 3 in the cafeteria. No significant effects of context, session or context by session interaction were found (all F-values < 1). Initial ratings or changes in ratings of hunger, thirst and fullness did not differ among sessions or contexts (highest $F_{[1,25]} = 3.10$, $p = .09$). Table 1 summarizes the mean change, as a percentage, between data collected across sessions in the laboratory and cafeteria conditions.

3.2. Olfactory pleasantness

Initial olfactory pleasantness of the infusion did not show any significant difference as a result of context, session or context by session interaction (all F-values < 1), with similar values across the three sessions for the laboratory (5.7, 5.8 and 5.8 cm, respectively) and cafeteria (6.0, 5.9 and 5.8 cm, respectively) conditions. After ingestion, the perceived pleasantness decreased, showing significant changes for the infusion compared to the control foods in each session (lowest $t_{[25]} = -2.33$, $p < .05$), indicative of short-term olfactory SSS (see Fig. 2A). Evidence of SSS was also obtained by an additional Food (infusion vs. control) × Context (laboratory vs. cafeteria) × Session (1 vs. 2 vs. 3) ANOVA, revealing a significant main effect of Food ($F_{[1,25]} = 21.72$, $p < .001$, $\eta 2 = .46$), with a higher pleasantness decrease for the consumed (−16.3%) compared to the non-consumed items (−3.8%) ($p < .001$). Interestingly, a marginally significant interaction between context and food ($F_{[1,25]} = 3.47$, $p = .07$, $\eta 2 = .14$) was determined, suggestive of a lesser pleasantness decrease for the infusion in the cafeteria (−15.1%) compared to the laboratory (−19.6%) setting, but not for the non-consumed items (−4.5% and −1.1%, respectively). No other main effects or interactions were significant (highest $F_{[2,50]} = 1.86$, $p = .16$). The magnitude of the change in olfactory pleasantness of the infusion showed a main effect of context ($F_{[1,25]} = 5.00$, $p < .05$, $\eta^2 = .17$), with a lower magnitude (i.e. a lesser degree of SSS) in the cafeteria (−10.6%) compared to the laboratory (−18.5%) setting. No significant effect of session or context by session interaction was found (all F-values < 1), with magnitudes of −12.8%, −14.5% and −16.3% for sessions 1, 2 and 3, respectively.

3.3. Flavour pleasantness

There was no effect of context, session or context by session interaction on initial flavour pleasantness ratings (all F-values < 1), which were 5.0, 5.1 and 5.5 cm for sessions 1, 2 and 3 in the laboratory condition, and 5.2, 5.4 and 5.1 cm in the cafeteria condition. After ingestion, the pleasantness rating decreased, showing significant changes for the infusion compared to the control foods in each session (lowest $t_{[25]} = -2.12$, $p < .05$), indicative of short-term flavour SSS (see

Table 1
The mean initial (measured on a 10-cm visual analogue scale) ratings and change (%) in ratings after eating to satiation across the three sessions in each context.

		Laboratory			Cafeteria		
		Session 1	Session 2	Session 3	Session 1	Session 2	Session 3
Hunger	Initial	4.2 ± 1.8	4.0 ± 2.2	4.1 ± 1.9	4.1 ± 2.1	4.2 ± 2.2	4.2 ± 2.2
	Change	−17.8 ± 20.2	−15.4 ± 28.3	−18.7 ± 22.9	−17.9 ± 24.8	−17.2 ± 19.9	−19.8 ± 18.7
Thirst	Initial	4.6 ± 2.4	5.3 ± 2.3	4.9 ± 2.5	4.8 ± 2.6	4.8 ± 2.1	4.8 ± 2.4
	Change	−21.2 ± 22.1	−30.0 ± 23.2	−26.5 ± 21.4	−25.2 ± 24.6	−25.7 ± 17.2	−22.2 ± 22.6
Fullness	Initial	3.4 ± 2.2	3.7 ± 2.9	3.5 ± 2.2	3.5 ± 2.2	3.8 ± 2.1	3.6 ± 2.4
	Change	23.3 ± 37.9	24.7 ± 23.6	25.2 ± 21.2	28.6 ± 24.7	21.4 ± 27.1	25.2 ± 18.6

Note: Change in ratings was calculated by subtracting pre-consumption from post-consumption scores and then multiplied by 100. Values are expressed as means ± standard deviation. Initial ratings or changes in ratings did not differ among sessions or contexts.

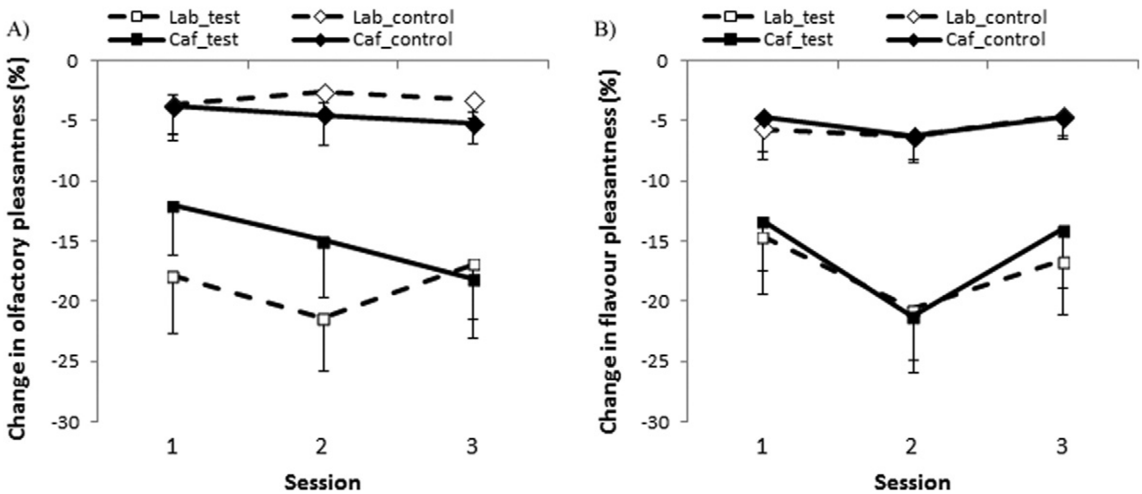

Fig. 2. Mean change (%) in olfactory (A) and flavour (B) pleasantness for test food (test) after eating to satiation and for control foods (control; collapsing data for crackers, yoghurt and corn flakes) when sessions were conducted in the laboratory (Lab) or the cafeteria (Caf). The perceived pleasantness of the infusion decreased significantly compared to the control foods in each session, indicative of short-term olfactory/flavour SSS ($ps < .05$). The magnitude of change in olfactory pleasantness of the infusion was lower in the cafeteria than in the laboratory. The error bars represent the SEM of the mean.

Fig. 2B). Evidence of SSS was also obtained by an additional Food (infusion vs. control) × Context (laboratory vs. cafeteria) × Session (1 vs. 2 vs. 3) ANOVA, revealing a significant main effect of Food ($F [1,25] = 23.50$, $p < .001$, $\eta 2 = .48$), with a higher pleasantness decrease for the consumed (−16.7%) compared to the non-consumed items (−5.4%) ($p < .001$). No other main effects or interactions were significant (highest $F [2,50] = 1.61$, $p = .20$). Regarding the magnitude of the change in flavour pleasantness across the three sessions, there was no effect of context, session or context by session interaction (all F-values < 1); values were −8.9%, −14.3% and −12.0% for sessions 1, 2 and 3 in the laboratory condition, and −8.6%, −15.0% and −9.3% in the cafeteria condition.

3.4. Desire to eat

Initial desire to eat ratings for the infusion showed a context by session interaction ($F [2,50] = 3.20$, $p = .05$, $\eta^2 = .11$). As shown in Fig. 3(A), analysis of simple effects confirmed that the initial rating in session 3 was higher in the laboratory than in the cafeteria ($t [25] = 2.49$, $p < .05$). On the other hand, initial desire to eat the infusion varied across sessions for the laboratory condition ($F [2,50] = 3.26$, $p < .05$, $\eta^2 = .11$), with a higher initial rating in session 3 compared to session 1 ($t [25] = -2.2$, $p < .05$). This effect was not observed in the cafeteria condition. After ingestion, the motivational ratings decreased, showing significant changes for the infusion compared to the control food in each session (lowest $t [25] = -2.03$, $p = .05$) (Fig. 3B). The magnitude of the changes from before to after infusion intake showed a significant context by session interaction ($F [2,50] = 3.84$, $p < .05$, $\eta^2 = .13$). As shown in Fig. 3(C), analysis of simple effects confirmed that magnitude in session 3 for the laboratory was higher than for the cafeteria condition ($t [25] = -2.09$, $p < .05$). On the other hand, the magnitude of changes varied across sessions in the laboratory ($F [2,50] = 3.00$, $p = .06$, $\eta^2 = .11$), with a higher value in session 3 compared to session 1 ($p < .05$). This effect was not observed in the cafeteria. In order to determine the origin of the variations, the ratings of desire to eat after satiation were analysed and no effect of context, session or context by session interaction was found (highest $F [2,50] = 1.10$ $p = .34$); values were 2.4, 1.6 and 1.8 cm for sessions 1, 2 and 3 in the laboratory condition, and 1.7, 1.7 and 1.7 cm in the cafeteria condition.

3.5. Infusion intake and duration of infusion intake

Regarding infusion intake, no effect of session, context or context by session interaction was found (highest $F [2,50] = 2.91$, $p = .06$, $\eta^2 = .10$), with values of 243.4, 269.6 and 262.2 mL for sessions 1, 2 and 3 in the laboratory condition, and 259.0, 283.5 and 277.1 mL in the cafeteria condition. Regarding the duration of infusion consumption, a context by session interaction was found ($F [2,50] = 3.16$, $p = .05$, $\eta^2 = .11$). Mean duration to reach satiation was 8.7, 8.8 and 7.2 min for sessions 1, 2 and 3 in the laboratory condition, and 8.2, 8.7 and 9.7 min in the cafeteria condition. Analysis of simple effects confirmed that the time to reach satiety in session 3 was longer for the cafeteria than for the laboratory condition ($p < .01$). On the other hand, the duration of infusion intake varied across sessions, with a decrease between sessions 2 and 3 ($p = .05$) for the laboratory condition and an increase between sessions 1 and 3 for the cafeteria condition ($p = .05$).

3.6. Scores for pleasantness and desire to eat unconsumed control foods

Fig. 2(A, B) and Fig. 3(B) summarize the mean changes in olfactory hedonic, flavour hedonic and desire to eat ratings for the control foods after consumption of infusions in each session. No significant effect of session, context or session by context interaction was found for changes in olfactory/flavour hedonic rating (all F-values < 1).

4. Discussion

The aims of this study were to demonstrate the existence of short-term SSS for a sweet-bitter infusion of yerba mate, to explore medium-term changes in pleasantness and desire to eat as a result of repeated SSS tests, and to determine the extent to which SSS may be subject to context modulation. In terms of hedonic ratings, short-term SSS was observed for both smell and flavour of the SM infusion, as well as a greater reduction in desire to eat ratings compared to the control foods, for all six sessions. These findings provide further evidence that olfactory SSS and flavour SSS for a sugar-sweetened infusion are effective under laboratory [10] and natural conditions [9]. Although repeated consumption of the infusion until satiation across sessions in two different contexts provided no support for medium-term SSS, a lower overall magnitude of olfactory SSS was found in the cafeteria setting, while this

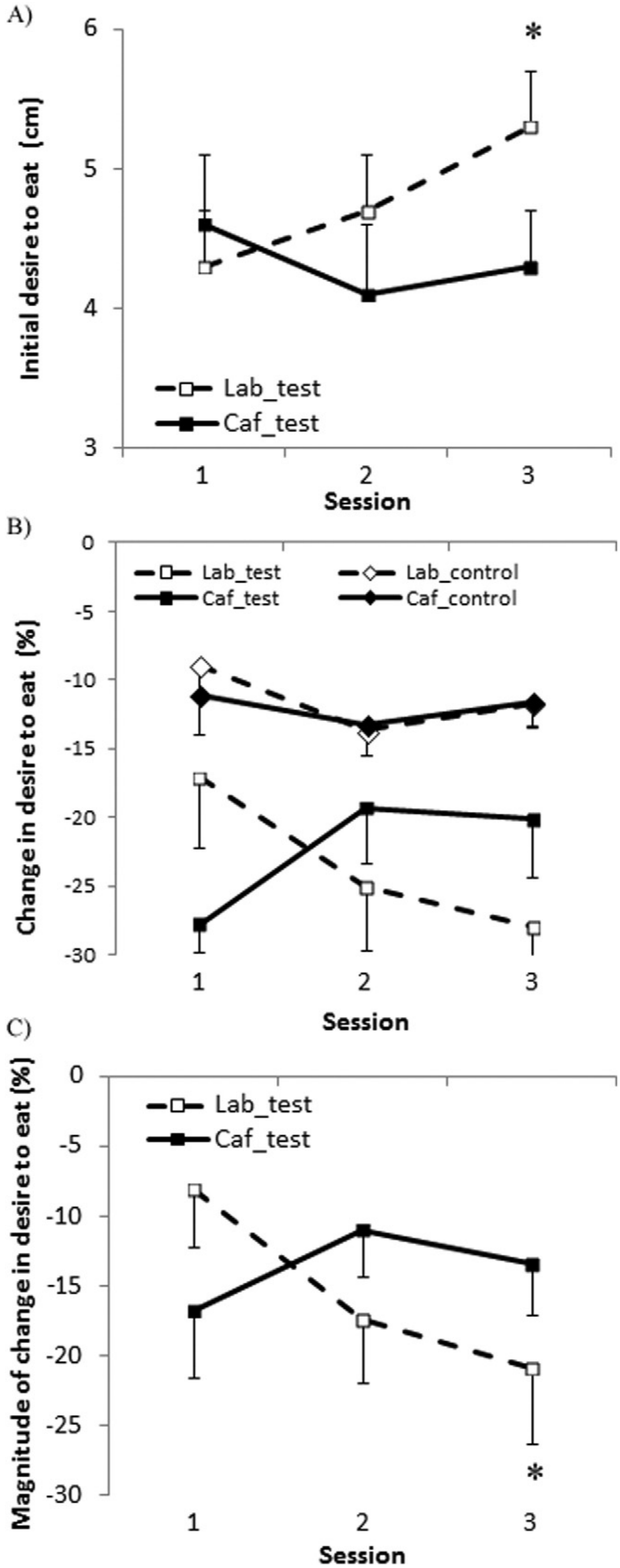

Fig. 3. Mean initial ratings (A) for desire to eat the test food (test); mean change (B) in desire to eat the test food after eating to satiation and the control foods (control; collapsing data for crackers, yoghurt and corn flakes); and mean magnitude of change (C) for the test food when sessions were conducted in the laboratory (Lab) or the cafeteria (Caf). * indicates significant differences between contexts ($p < .05$). Results showed higher initial rating and higher magnitude of change in the laboratory than in the cafeteria during session 3. The error bars represent the SEM of the mean.

context effect did not appear in flavour SSS. This difference in magnitude of satiation in the cafeteria (−10.6%) compared to the laboratory (−18.5%) setting was observed despite similar initial olfactory hedonic ratings (≈5.2 cm on 10-cm VAS) and similar amounts of infusion consumed in each context across SSS sessions (≈792 mL). Considering the absence of changes in olfactory pleasantness of non-consumed foods between contexts, such contextual modulation seems to have specific effects on olfactory SSS rather than a non-specific, general impact on food pleasantness.

To the best of our knowledge, the difference in impact of the context in which SSS occurs on the development of satiation for orthonasal odour and flavour has not been reported previously and might reflect higher effectiveness of food odours in the interaction with other contextual cues in order to modulate appetite suppression. Although SSS can have effects on liking ratings for more than 24 h [17], the data did not reveal medium-term SSS in terms of a greater decrease in initial olfactory/flavour hedonic ratings, greater reduction in the magnitude of olfactory/flavour SSS or more rapid SSS between subsequent sessions compared to the first one. In fact, a slower development of SSS between the first and third sessions was found in the cafeteria, while the time to reach satiation decreased between the second and third sessions in the laboratory. Unexpectedly, repeated exposure to the sugar-sweetened infusion increased the magnitude of change in motivational ratings in the laboratory (but not in the cafeteria) across SSS sessions, which was accounted for by the increase in initial assessment of desire to eat from the first to the third session.

An explanation for these findings can be offered by taking into account the orosensory (i.e. good taste) [43] and viscerosensory (i.e. calories) reinforcing attributes of the infusions. First, the consumption of the infusions to satiation within sessions reduced attractiveness of their orosensory-specific properties in the short-term. This devaluation was reflected in a decrease in hedonic response and incentive motivation to flavour of the infusions in order to cease ingestion. These changes in food flavour should also be reflected in its components such as odour, taste or texture [44], and this was the case giving rise to olfactory SSS as well. Although little is known about the contribution of each component of food flavour to SSS, it could be postulated that differences in stimulus processing between the olfactory and gustatory systems will produce differences between both types of SSS. For instance, if orthonasal olfaction is optimized for thw detection of food odorants together with background odours, and the gustatory system is primarily devoted to integration of information from the mouth, olfactory SSS would be more sensitive to the exteroceptive eating context than flavour SSS. This explanation is consistent with our observations of a contextual modulation of olfactory but not flavour SSS. Although our study does not allow the determination of the mechanisms involved, one hypothesis is that other odours from cafeteria foods might have delayed olfactory satiation for the infusion, as it happens with taste variety [45]. Evidence suggests that SSS may be attenuated before being completely attained when new foods are presented [22,25,46]. Further studies are needed to clarify the source of such contextual modulation given the range and number of variables that can be used in differentiating the cafeteria from the laboratory setting, and also the natural-artificial or familiarity-novelty dimensions.

Second, repeated exposure to SM infusion until satiation had a long-lasting effect on motivational ratings, though in opposite direction than expected. While the decrease in desire to eat the infusions was consistently greater than the decrease in desire to eat the control foods in each session, the initial ratings and the magnitude of change in the laboratory (but not in the cafeteria) increased across sessions. In order to account for these dissociations between short- and medium-term changes in motivational ratings, the nutritive component of the sugar-sweetened infusion should be now considered apart from its orosensory properties. When SM was devaluated during SSS across sessions, the hedonic and motivational decrements were related to its orosensory-specific properties but not to more general postingestive reinforcing properties such as calories. And it would be reasonable to assume that the nutritive actions of sugar paired with the context across sessions could alter the incentive salience of the infusion through context-nutrient associations, but only in the laboratory setting, as indicated earlier, by a higher associability of novel over familiar context (whose associability would have been reduced by prior exposure) [36,47]. In this sense, evidence suggests that contextual cues present when food is consumed may enter into associations and potentiate motivation for consumption of these foods in animals [48,49] and in humans [50].

The implications of our findings are relevant for a number of reasons. On the one hand, short- and medium-term SSS were also examined in a natural environment, thus enhancing the ecological validity of the research. In fact, food intake studies in the real world remain a major issue because of different results obtained in laboratory research compared to research on food choice, food acceptance and food consumption conducted in naturalistic settings [31]. On the other hand, since orthonasal olfaction mediates decisions to ingest prior to oral incorporation, larger negative shifts in olfactory pleasantness of a food (i.e. higher olfactory SSS) would prevent or reduce the ingestion of this food in the next meal [44]. Therefore, considering that the magnitude of (olfactory) SSS was sensitive to contextual manipulations, the use of environmental factors that modulate sensory satiation to either decrease or increase eating in dietary interventions might be of greater importance. Third, SSS as a technique for weight loss and appetite control interventions [16,21] should be however viewed with caution because of the risk of negative side-effects. In particular, repeated exposure to foods may increase the desire to eat (and possibly prospective consumption) in the long-term through associations between novel contexts and the nutritive consequences of these foods.

Regarding medium-term SSS, the acquisition and/or expression of SSS across sessions could be limited by the experimental parameters employed in this study. The fact that the number of sessions (three in each context) was not sufficient, that the inter-session interval (24–48 h) was long enough to produce the recovery of the ratings to baseline levels, or that the hedonic responses were reinstated after the presentation of new foods between sessions (e.g., during lunch and dinner) may be responsible for the failure to observe medium-term SSS. An alternative interpretation in terms of insensitivity to medium-term SSS for the mate infusion is possible as not all familiar foods show acceptance decline over repeated consumption. For example, acceptance for French fries and bread and butter stayed constant when repeatedly consumed [51,52]. This interpretation becomes more plausible in light of the findings of Hetherington et al. [51], which suggest that the magnitude of SSS during several tests on days 5, 10 and 15 was unaffected by repeated daily food consumption for 15 days.

5. Conclusions

Unlike evidence of short-term SSS for mate infusions, the results were inconclusive with regard to the existence of medium-term SSS and therefore as to the role of long-term habituation in this phenomenon. One might argue that the manipulation employed was too weak to produce any medium-term hedonic decrease and perhaps shorter intervals between sessions, such as intervals of meals rather than days, would be a more optimal and thus more effective procedure. But even so, this procedure revealed that contextual variables affect the motivational evaluation of and (olfactory) SSS for familiar infusions. Consequently, there is a need to explore when and why the magnitude of hedonic (SSS) and motivational assessments may be context-specific, especially in real-world eating situations. The sources of global context effects, as well as the specific contextual cues, are of special interest and must be identified on account of their implications for eating interventions in general and for the modulation of appetite specifically.

Acknowledgements

The main experiment was conducted during a stay funded by an international grant for mobility between Andalusian and Latin American Universities from the Ministry of Innovation, Science and Business of the Junta de Andalucia awarded to D. Garcia-Burgos. The authors thank Ms Edyt Tevez (IQUIMEFA, UBA-CONICET) for her assistance with the experiments and the volunteers who performed experimental tasks.

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.physbeh.2014.12.035.

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