Adding Cocoa to Sucrose: The Effect on Cold Pain Tolerance

Kristina Eggleston[1], Theresa L. White[1,2] and Paul R. Sheehe[2]

[1]Department of Psychology, Le Moyne College, 1419 Salt Springs Road, Syracuse, NY 13214, USA and [2]Department of Neuroscience and Physiology, State University of New York, Upstate Medical University, 750 East Adams Street, Syracuse, NY 13210-2375, USA

Correspondence to be sent to: Theresa L. White, Department of Psychology, Le Moyne College, 1419 Salt Springs Road, Syracuse, NY 13214, USA. e-mail: whitetl@lemoyne.edu

Abstract

The sweet taste of sucrose acts as an analgesic, whereas the taste of a bitter substance decreases pain tolerance. The present experiment explores the analgesic effect of a complex taste and asks how adding cocoa, a substance often associated with sweet foods but that has a bitter taste, to a sucrose solution affects cold pain tolerance. The 24 male participants were exposed to Cold Pressor Tests (CPTs) while holding 1 of 3 tastants in their mouths: water, sucrose, or sucrose with cocoa added. After each CPT, participants rated pain intensity and tastant qualities. Intraoral sucrose increased the amount of time that men were able to leave their hands in cold water, whereas the cocoa solution did not. Solutions did not differ in pleasantness or sweetness, but the cocoa solution was rated as more bitter. Bitterness ratings of cocoa exceeded the ratings of sucrose (corrected for water) by an average of 16.9% ($P = 0.02$), which, in turn, produced a 30% reduction in the duration of pain tolerance ($P = 0.002$). These results suggest that the addition of a bitter substance reduces cues to the nutritive value of sucrose that may drive its analgesic effect.

Key words: bitter, chocolate, pain, sweet, taste

Introduction

Sucrose-based analgesia is a well-established phenomenon in which both people and animals seem better able to tolerate pain while tasting a sweet solution (Blass and Hoffmeyer 1991; Blass and Shide 1994; Lewkowski et al. 2003). For example, intraorally administered doses of a sucrose solution decreased crying in neonates and increased the activity of motor systems associated with feeding behavior (Smith et al. 1990; Blass and Hoffmeyer 1991) in a manner that is related to sucrose concentration (Haouari et al. 1995). Although the analgesic effect of sucrose was initially postulated to be due to postingestive consequences (Smith et al. 1990) or distraction from taste salience (Graillon et al. 1997), subsequent studies have indicated that at least some of the calming effect of sucrose is due to its sweet taste (Barr et al. 1999). Sucrose is naturally pleasant (Steiner et al. 2001), and the experience of its taste triggers the release of opioids that could create an analgesic effect (Segato et al. 1997). Support for this opioid mechanism comes from the finding that administering opioid antagonists to animals decreases the effectiveness of sucrose analgesia (Blass et al. 1990). Further evidence for an opioid-based mechanism underlying the analgesic effect in humans comes from the finding that infants born to methadone-dependent mothers (who have disrupted opioid systems) are not calmed by intraoral sucrose (Blass and Ciaramitaro 1994). From a functional perspective, the presence of an opioid-based analgesia could assist in maintaining an animal's food intake, a survival behavior, in the presence of painful stimuli (Foo and Mason 2005).

In addition to the increases in pain tolerance reported in animals and infants, the analgesic effects of sucrose may also be observed in human adults. Using adults as an experimental model increases evaluation possibilities, such as subjective reporting. Adults who kept intraoral sucrose solutions in their mouths while participating in a Cold Pressor Test (CPT) were able to keep their hands submerged in cold water longer, suggesting an increase in pain tolerance, though they did not report any change in pain intensity or discomfort levels (Lewkowski et al. 2003). A similar pattern of findings was observed in adults exposed to odors arising from sweet nutritive sources (such as caramel), rather than any intraoral stimulation (Prescott and Wilkie 2007). This suggests that even without the taste or ingestion of a sweet substance, conditioning may confer analgesic abilities on stimuli strongly associated with sucrose.

Although sucrose analgesia is an interesting phenomenon, people seldom ingest sucrose alone in everyday life. Instead, sucrose is generally encountered in combination with a range of other ingredients in complex food products. Despite their more common occurrence in a normal diet, complex foods containing sucrose have not been examined in terms of the effect that they may have on sucrose analgesia. It is possible that the presence of other ingredients might alter the analgesia normally observed with an intraoral sucrose solution and either increase or decrease its effectiveness.

One complex food often associated with sucrose is cocoa, the key ingredient in commercially produced chocolate products. Chocolate is a high-sweetness, highly palatable food that activates the opioid reward circuit of the brain (Small et al. 2001). Chocolate is made from a number of ingredients in addition to sucrose, most notably cocoa. Cocoa is the ground, fermented fruit of the cocoa pod and contains a range of compounds, such as caffeine, theobromine, antioxidants, phenylethylamine, tryptophan, and anandamide (Beckett 2008). How might the addition of cocoa change sucrose analgesia? Would it enhance the pain tolerance already provided by sucrose or limit its effect?

Cocoa might be expected to enhance sucrose analgesia because of its historical association with health and tranquility. An American treatise of the plants growing in English plantations, titled the *American Physitian*, circa 1672, documents chocolate's use as an ''anodyne,'' or painkiller, and its widespread prescription in the 1600s as a ''bromide,'' or cure-all (Fuller 1994)—qualities that suggest that cocoa might have pain-relieving or pain-reducing qualities of some type.

Knowledge of the ingredients within cocoa might also suggest that it would enhance sucrose analgesia. Cocoa contains several biologically active components that might affect pain tolerance, including methylxanthines, such as caffeine, though many are present at low levels that may not influence pain perception (Apgar and Tarka 1999; Benton 2004). For example, although caffeine consumption (rather than intraoral experiences) at appropriate levels results in decreased pain sensitivity (Ward et al. 1991; Keogh and Witt 2001), the levels are low in pure cocoa and are thus unlikely to produce observable behavioral effects (Knight 1999).

Enhancement of the analgesic properties of a sucrose solution when cocoa is added also might be expected because of cocoa's frequent association with sucrose in everyday food products. Simply due to conditioning (Prescott and Wilkie 2007), it is possible that cocoa's typical association with high levels of sweetness in commercially available chocolate could induce a sweet-based analgesic effect. So, it is possible that the mere odor of cocoa could produce noticeable analgesic effects.

If palatability were increased when cocoa is mixed with a sucrose solution, enhancement of analgesic effects might be effected because of the release of opioids, a mechanism postulated to underlie sucrose analgesia (Blass et al. 1990; Barr et al. 1999). Pleasant tasting foods, like chocolate, can evoke opioid mechanisms in the brain, causing a release of endorphins (Weil and Rosen 1998; Knight 1999; Kracke et al. 2005), neurotransmitters that typically result in increased pain tolerance (Olson et al. 1979).

It is also possible, however, because cocoa has a bitter taste, that the addition of cocoa to a sucrose solution may decrease pain tolerance in adults, similarly to the bitter tastant quinine (Lewkowski et al. 2003). The perception of bitterness may be intensified in people who are sensitive to the compound 6-*n*-propylthiouracil (PROP), which is associated with several members of the *TAS2R38* receptor gene family that encode taste receptors (Hayes et al. 2008). Heightened perception of oral stimuli (especially sensitivity to bitter and intensity of sweetness) has been studied extensively relative to PROP (Bartoshuk et al. 1994; Birch 1999; Ly and Drewnowski 2001), showing generally that individuals who perceive PROP strongly are also more sensitive to other taste qualities (Hayes et al. 2008).

The present study evaluates the effects of cocoa on sucrose analgesia by examining the results of a CPT in college-aged males. Knowing that cocoa is strongly associated with sweet taste (Small et al. 2001) but is in its pure form bitter (cocoa powder alone, rather than commercially available chocolate that contains high levels of sugar and fat), the present study asked how the addition of cocoa to a sweet sucrose solution would affect pain tolerance.

Materials and methods

Participants

Twenty-four male college-aged students were recruited through local postings and undergraduate psychology classes for this study. All the participants were between the age of 18 and 25 years old. No exclusions were made on the basis of national origin or religious persuasion, but females were excluded from participation because pain sensitivity is altered by the chemical and hormonal fluctuations of the menstrual cycle (Hellstrom and Lundberg 2000). Similarly to other studies assessing sucrose analgesia (Prescott and Wilkie 2007), participants were excluded if they reported during a telephone screening any of the following conditions: medical disorders, such as diabetes, autoimmune disorders, circulatory disorders, cardiovascular disorders, neurological disorders, pain syndromes, serious cold injury, abnormal sense of taste, allergies to solution ingredients, vascular disorders, or thyroid disorder; ingestion of medications, such as antidepressants, anxiolytics, or analgesics, taken within 24 h of testing; or if the participant was unwilling to fast prior to testing. All participants were treated in accordance with approved Institutional Review Board (IRB) protocol.

Materials

Testing took place in a psychology laboratory at Le Moyne College in Syracuse, NY. The room had minimal

distractions, and any indications of time were removed or covered.

A CPT situation was constructed using a Lauda-Brinkmann Refrigerating Circulator (Model RM 20), which could be set and kept constant at a circulating 4 °C. A cardboard partition was constructed on one side of the CPT, both to keep the experimenter blind to the condition and to prevent the participant from seeing his hand in cold water. The partition contained a hole large enough for the participant's hand to fit through and comfortably into the water bath.

Three solutions were presented in the experiment: one was spring water (control), one 24% (w/v) sucrose (Sigma Sucrose, minimum, 99.5%), and the last 24% (w/v) sucrose with 12% (w/v) cocoa (Hershey's Cocoa, natural unsweetened). The concentration of the sucrose solution was the same level as reported by Lewkowski et al. (2003). The cocoa concentration was chosen after piloting so as to produce a solution that would be similar in palatability to the sucrose solution. The solutions were prepared fresh using a hot plate and stir bar each day and allowed to sit at room temperature for at least an hour prior to presentation to participants. A 20-mL aliquot of each solution was placed in a 1-ounce, clear plastic medicine cup and then positioned in a covered tin box by an experimenter not involved in time measurement.

Baking soda and sterile toothbrushes were used for the participants to brush their teeth between tastant presentations. A stopwatch was used to time the participants. Whatman 42.5-mm filter paper samples were soaked in a 3.2 mM PROP solution and then dried and preserved in the plastic wrap for presentation to participants.

Design

The experiment was a within-subjects design that took place over 2 days. On the first day, 2 conditions were presented, the control and an experimental solution. The second day involved the presentation of the control and the remaining solution.

The independent variable was defined in terms of 3 types of taste solution: water, sucrose solution, and cocoa solution. In pilot testing, it became clear that the order of presentation was important to experimental outcome. Therefore, participants were randomly allocated to 1 of 4 predetermined orders of stimulus presentation (see Table 1), which allowed counterbalancing across participants. Participants received either the cocoa solution or the sucrose solution, followed or preceded by the water control on one day and the remaining experimental solution (whichever they did not receive on the first day) followed or preceded by the water control on the second day.

The main dependent variables of interest were, primarily, duration of cold tolerance and, secondarily, perceived pain level. Participants also rated the pleasantness, sweetness, and bitterness of each solution, as well as the intensity of PROP.

Procedure

In order to ensure participant safety and accurate data, all interested participants took a screening questionnaire by telephone to ensure that they were viable candidates for the experiment. If they met the screening qualifications, participants were instructed to meet the following criteria: to fast (no caloric intake, only water) for 8 h prior to each trial day and to abstain from the use of any analgesic medication. Each experimental session was conducted at approximately the same time of day to avoid major differences in circadian rhythms that could interfere with pain and temperature perception.

After arriving fasted on the day of the first trial, the subjects acknowledged that they met the criteria discussed previously

Table 1 Outline of the analysis[a] in the randomized design

Participant group	Order of presentation[b]	Dependent variable[c]	ANOVA contrast coefficients[d]		
			C versus S	Water order	Interaction
1	S Ws | C Wc	(S − Ws) − (C − Wc)	−1	−1	−1
2	C Wc | S Ws	(C − Wc) − (S − Ws)	+1	−1	+1
3	Ws S | Wc C	(Ws − S) − (Wc − C)	+1	+1	−1
4	Wc C | Ws S	(Wc − C) − (Ws − S)	−1	+1	+1

[a]Five ANOVAs involve the following measures of a participant's response: I. Objective response values: natural logarithm of the duration of hand in water in CPT. II. Subjective response values: pain, pleasantness, sweetness, bitterness.
[b]S = sucrose solution, C = cocoa solution, Ws = water presented on the same day as the sucrose solution, Wc = water presented the same day as the cocoa solution, | = separation between day 1 and day 2.
[c]Note that the dependent variable is defined as the first minus the second response on the first day, minus the first response minus the second response on the second day. Tastant and water response differences that are used to define the dependent variables in the analysis: (S − Ws), (Ws − S), (C − Wc), (Wc − C). In the 2 subordinate analyses, the dependent variables would be: I. sucrose versus water (S − Ws) and II. cocoa versus water (C − Wc).
[d]Predefined ANOVA contrast coefficients in linear combinations of group means of a given dependent variable (i.e., a variable referring to duration, pain, pleasantness, sweetness, or bitterness). Primary and secondary contrast: C versus S, the effect of cocoa versus sucrose on log duration (primary) and pain rating (secondary). Order contrasts: water order effect within a session, Interactive effect. Note that the labels for these contrasts do not apply to the dependent variables in the subordinate analyses.

over the phone and that they were not currently in pain or feeling dizzy by completing the screening questionnaire in writing. Participants also completed the Le Moyne IRB-approved informed consent form prior to taking part in the experiment.

During each of the 2 sessions, the participants completed 2 trials in which they were instructed to hold a solution (either spring water control or an experimental solution) in their oral cavity for the duration of the CPT. With the solution in the oral cavity, the participant was instructed to place his dominant hand (up to the wrist fold) into the CPT for as long as possible (or until the maximum time of 4 min, established for safety reasons, was reached). An experimenter blind to the experimental condition recorded the length of time that each participant kept his hand in the water. Participants used the general Labeled Magnitude Scale (gLMS; Bartoshuk et al. 2004) to rate the intensity of pain immediately following each pain stimulus.

After the first condition was completed, a 15-min delay period followed, during which time the participant completed a poststimulus questionnaire, using the gLMS to rate the pleasantness, sweetness, and bitterness of the solution in the same order for each tastant and then brushed his teeth with a sterile, disposable toothbrush and baking soda paste to neutralize any remnant taste. Following the delay period, the participant repeated the procedure with the other solution designated for that day (and same hand). On the second trial day, the procedure was repeated with the control and remaining experimental solution.

At the end of the experiment (the end of the second session day), the participants' genetic abilities to taste PROP were examined. Participants were presented with a paper disc containing a 0.0032 molar sample of PROP (Bartoshuk 2000) and then asked to taste it and rate its intensity using the gLMS. Following the PROP presentation, participants were debriefed; any additional questions were answered by the experimenter, and each participant was given the option of a $20.00 compensation or extra course credit for participation.

Analysis

As detailed above, the present experimental design included a within-participant comparison of water-controlled responses to presentations of a sucrose solution and to the same solution with cocoa added. These presentations were randomized across 4 stimulus orders in order to balance for the effects of response order in 2 daily CPT sessions. Five responses were obtained from each stimulus presentation, an objective measure (duration in the CPT) and 4 subjective measures (gLMS ratings of pain intensity, pleasantness, sweetness, and bitterness). Each participant also rated the intensity of PROP using the gLMS.

Maintaining the integrity of the experimental design for each of the objective and subjective measures outlined above, single-factor analyses of variance (ANOVAs) across stimu-lus orders were performed followed by planned contrasts (see Table 1). The primary test was the examination of how the objective measure of pain tolerance, the duration of the CPT, differentiated responses to cocoa versus sucrose. The primary hypothesis was tested for significance at the 2-tailed $\alpha = 0.05$ level. The secondary test was a similar analysis of the subjective measure of pain intensity given through the gLMS ratings. This test was considered secondary because the instruction to "keep your hand in the water as long as possible" tends to blunt and possibly confound differences in the intensity levels at the time when the hand is removed. Intermediate analyses were also completed for each of the subjective measures of tastant qualities of pleasantness, sweetness, and bitterness. Their purpose was to seek evidence of differences in cocoa and sucrose taste characteristics that would be used as determinants of the primary (duration) or secondary (pain rating) differences, if any, and to test the effects of cocoa versus sucrose on the subjective response measures. Relevant taste characteristics identified in the intermediate analyses could be used to weight the observed effects of cocoa versus sucrose on individual participant's log durations of cold tolerance in a principal test of the overall weighted mean differences. This type of weighted analysis is analogous to Wilcoxon's classic signed rank test in which the larger weights of a relevant factor amplify the power to detect alternatives to the null hypothesis. Each measure (both objective and subjective) was also evaluated in 2 subordinate sets of analyses with dependent variables that compared each tastant solution with water. Constituents of the 4 orders of stimulus presentation (groups), including day of presentation and order of presentation, within a session were also compared, as well as an interaction, with a view toward indicating effects of order that were successfully counterbalanced by the design. For secondary, intermediate, interpretive, and the various subsidiary analyses, no adjustment for test multiplicity was made to their nominal P values. PROP ratings were correlated with pain tolerance and ratings of bitterness and sweetness.

Results

Although 24 participants completed the study, 3 participants who consistently met the 4-min maximum time for the CPT that had been established for safety reasons were eliminated from the analysis. Thus, the results for 21 participants are reported below. Because the participants were randomly assigned to orders of stimulus presentation (groups) by a block order randomization, the excluded data were also distributed across stimulus ordering: leaving 5 participants in the first order, 6 in each of the second and third orders, and 4 in the last order.

Objective measurement of cold tolerance

The log duration time that participants kept their hands in the CPT was used as the objective measurement of cold tolerance. The log-transformed data were examined rather than

absolute reaction time data in order to better meet ANOVA specifications of normal distribution and homogeneous variances. Also, variances in the untransformed data became larger as their mean values increased (sucrose: mean [M] = 74.02, standard deviation [SD] = 54.72; cocoa: M = 54.92, SD = 48.86). So, logarithmic transformed durations are preferred over the absolute values (Clarke 1969).

The planned comparison in the primary analysis of the cocoa solution versus the sucrose solution showed that the mean duration of cold tolerance was 22% shorter while tasting the cocoa solution in comparison to the sucrose solution, $t_{17} = -2.02$, $P = 0.059$.

The planned comparison of sucrose and water showed that the sucrose solution significantly increased duration in the CPT, $t_{17} = 2.82$, $P = 0.012$, illustrating the expected increase in cold pain tolerance (see Figure 1). No demonstrable difference was observed in the analysis comparing the cocoa solution and water in terms of pain tolerance ($P = 0.79$).

Subjective measurements

Means and standard errors of participant ratings of pain intensity, as well as those of ratings of the pleasantness, sweetness, and bitterness of each tastant, are presented in Table 2. Single-factor ANOVAs, followed by planned contrasts were performed, as detailed in the analysis section above.

Cold pain intensity ratings

No significant differences in participant gLMS ratings of cold pain intensity between tastant conditions were observed. Neither the sucrose solution nor the cocoa solution was observed to affect pain intensity ratings differently than water, and no evidence of difference between the 2 solutions was seen (all P values > 0.10).
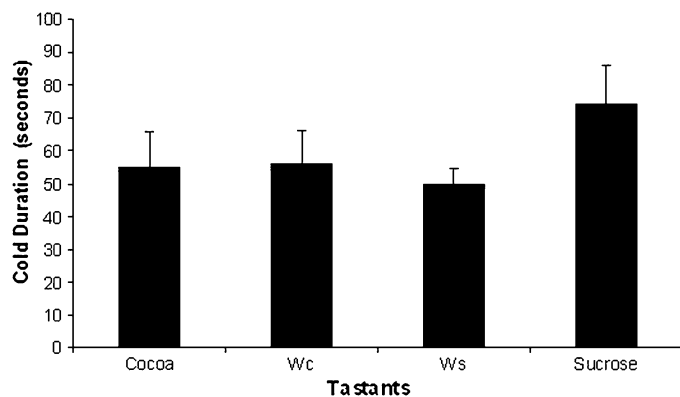

Figure 1 Untransformed average duration with standard error that participants kept their hands in cold water during the CPT. Wc refers to water presented the same day as the cocoa solution; Ws refers to water presented on the same day as the sucrose solution.

Pleasantness ratings

The subordinate analysis of cocoa solution versus water showed a significant difference between the 2 in pleasantness ratings, $t_{17} = 3.28$, $P = 0.004$ (see Figure 2). Ratings of the sucrose solution were not observed to differ significantly from either water, $t_{17} = 0.96$, $P = 0.35$, or the cocoa solution, $t_{17} = 0.37$, $P = 0.716$.

Sweetness ratings

Planned comparisons with participant gLMS ratings of sweetness demonstrated 2 significant results: The sucrose solution was rated as more sweet than water, $t_{17} = 2.69$, $P = 0.015$, as was the cocoa solution, $t_{17} = 6.30$, $P = 0.0001$ (see Figure 2). The planned comparison of the cocoa and sucrose solutions did not indicate a difference, $t_{17} = 0.04$, $P = 0.967$.

Bitterness ratings

A planned contrast of cocoa versus sucrose showed that participants perceived the cocoa solution as significantly more bitter than the sucrose solution, $t_{17} = 2.57$, $P = 0.020$ (see Figure 2). Analysis of the cocoa solution and water showed that the cocoa solution was rated as significantly more bitter by 19.8% than the water control, $t_{17} = 3.34$, $P = 0.004$. A significant difference was not observed in the planned comparison of the sucrose and water for the bitterness rating, $P > 0.10$.

Principal analysis

As reported above for the 3 tastant qualities, only bitterness significantly differed between the cocoa and the sucrose solutions. The mean water-controlled bitterness rating for cocoa exceeded that for sucrose by 16.9% ($P = 0.020$). Therefore, in the weighted analysis, only the bitterness weight was applied to each participant's observed difference in log duration of cold tolerance. In that analysis, balanced across all order effects, exposure to the cocoa solution significantly shortened the mean duration of cold tolerance by 30% in comparison to that of sucrose, $t_{17} = -3.69$, $P = 0.002$.

Order effects

In the analysis of the objective measure of pain, log duration in the CPT of cocoa versus sucrose, no significant difference in day of testing or tastant order within a session was observed. There was a greater difference between the 2 when water preceded either the sucrose solution in a session, $t_{17} = -2.76$, $P = 0.013$, or the cocoa solution, $t_{17} = -3.27$, $P = 0.004$. No interaction effects were observed.

Order effects were only demonstrable in one of the subjective measures, the gLMS rating that participants made of the intensity of their pain. In that analysis, the excess pain rating for cocoa (as compared with sucrose) was greater on the second day, $t_{17} = -2.92$, $P = 0.009$. This effect was echoed in the analysis of sucrose versus water, in which participants

Table 2 Cocoa versus sucrose effects on pain perception ratings and pain tolerance durations

| Type of effect	Mean (SE) effect with P value								
	(C − Wc)			(S − Ws)			(C − Wc) versus (S − Ws)		
	M	SE	P	M	SE	P	M	SE	P
Primary: log duration	0.03	0.11	0.79	0.25	0.08	0.012	−0.22	0.11	0.059
Secondary: pain rating	−2.74	1.90	0.11	−3.43	2.05	0.11	0.68	2.56	0.79
Intermediate: pleasantness rating	21.29	6.48	0.004	16.97	10.02	0.35	4.32	11.62	0.72
Intermediate: sweetness rating	31.82	5.05	0.015	31.36	11.64	0.001	0.46	12.46	0.97
Intermediate: bitterness rating	19.81	5.93	0.004	2.88	2.58	0.28	16.93	6.58	0.02
Principal: bitterness weighted log duration	n/a			n/a			−0.36	0.098	0.002

SE, standard error; n/a, not applicable.
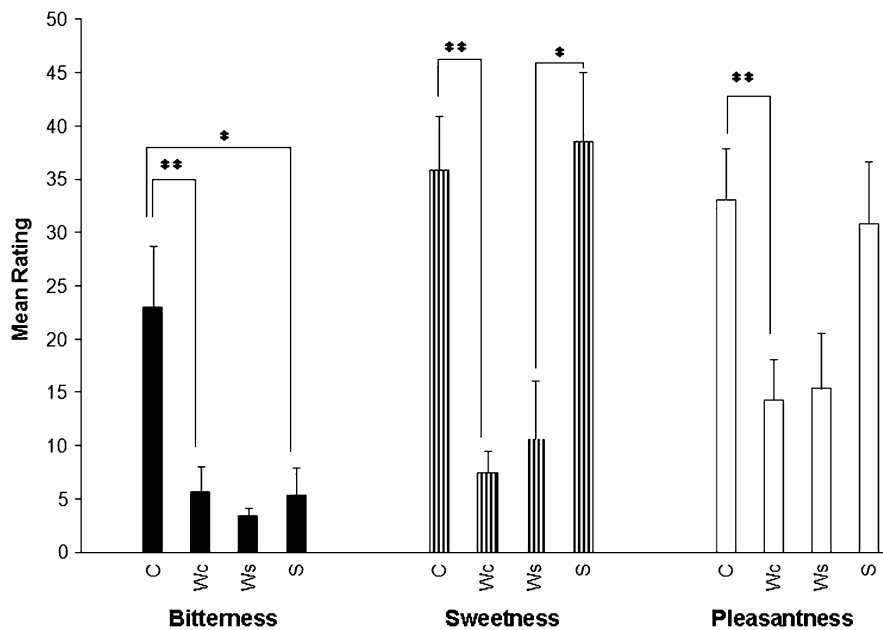
Figure 2 Mean values and standard errors of subjective response measures, with P values: pleasantness, sweetness, bitterness. S = sucrose solution, C = cocoa solution, Ws = water presented on the same day as the sucrose solution, Wc = water presented the same day as the cocoa solution. *$P < 0.05$, **$P < 0.01$.

reported a greater difference in ratings of pain when sucrose was presented on the first day, $t_{17} = 2.55$, $P = 0.021$. Significant effects of the order of encountering water within a testing session were observed in the effect of sucrose versus water, $t_{17} = −3.08$, $P = 0.006$, and the effect of cocoa solution versus water, $t_{17} = −3.61$, $P = 0.002$. Both these analyses indicate that encountering water first in a session produced greater disparity in ratings of pain between the tastant and water.

The analysis of cocoa versus water also showed an interactive effect, $t_{17} = 2.54$, $P = 0.02$. When water was presented after the cocoa solution the first day of testing, the difference in pain ratings between the 2 conditions was largest (M = −15.40), with the water condition being rated as more painful than the cocoa condition. In contrast, participants indicated

that the pain under the cocoa condition was greater when water was presented before the cocoa on the first day (M = 8.0), though the difference between the 2 conditions was more moderate. If water was presented after the cocoa solution on the second day of testing, the difference between the 2 was reduced (M = −4.83), with the water condition again being rated as more painful. If water preceded the cocoa condition on the second day, the difference between ratings of pain for the 2 conditions was quite small (M = −0.75).

PROP ratings

A Pearson's product moment correlation was used to analyze the relationship of participant rating of PROP intensity

with participant rating of cold pain intensity during the cocoa solution ($r = 0.21$, $n = 21$, $P = 0.361$) and with participant ratings of bitterness of the cocoa solution ($r = 0.24$, $n = 21$, $P = 0.29$). A similar correlation between participant ratings of PROP and cold tolerance, log duration in the CPT, under the cocoa solution condition approached but did not achieve significance ($r = 0.399$, $n = 21$, $P = 0.073$).

Discussion

The present study questioned whether the addition of cocoa to a sweet solution would enhance, leave unchanged, or diminish sucrose analgesia. The results provide 3 main findings that both support previous literature and contribute to understanding the mechanism of sucrose analgesia.

Findings from the present study first provide further evidence to support sucrose analgesia in adults. This experiment found that the sucrose tastant condition significantly increased pain tolerance over the water condition. In other words, participants withstood the CPT for significantly longer durations while experiencing the sucrose condition, as compared with the water condition. This finding is consistent with previous literature on sucrose-based analgesia, including work with neonates (Haouari et al. 1995) and adults (Lewkowski et al. 2003). The present results thus indicate that sucrose analgesia is a reliable finding that can be observed in a college-aged male population.

The second finding of this experiment was that the addition of cocoa to a sucrose solution was not observed to increase pain tolerance and did not produce an analgesic effect in the way that sucrose did. In contrast to the sucrose solution alone, participants did not tolerate the pain much differently when holding an intraoral solution of cocoa combined with sucrose than when they were holding water in their mouths. Thus, the addition of cocoa to the sucrose solution does not increase its analgesic effects, but rather, cold pain tolerance levels were similar to those of the control. This finding is in contrast to expectations that arose from a number of sources of reasoning, such as the historical use of cocoa for treating ailments (Bruinsma and Taren 1999), cocoa's pleasant odor typically associated with a sweet taste (Prescott and Wilkie 2007), or an increase in endorphin levels due to pleasant tasting foods (Weil and Rosen 1998; Knight 1999; Kracke et al. 2005). Perhaps, the analgesia was not produced in this condition due to the bitter taste quality of the cocoa solution. Although participants rated the cocoa solution as comparatively sweet and pleasant to the sucrose solution, which did produce an analgesic effect, they also rated the cocoa solution as significantly more bitter than the sucrose and control tastants. Thus, it is likely that participants responded to the bitter taste quality of the cocoa solution similarly to other bitter tastes that do not show analgesic effects (Lewkowski et al. 2003).

The third finding of this experiment is that instead of producing an analgesic effect, the addition of cocoa to the sucrose solution used in the present experiment produced a lower cold tolerance duration than did the sucrose solution. Because participants rated the cocoa solution as more bitter than the sucrose solution, an analysis of the pain tolerance data weighted by bitterness ratings for each experimental solution was possible, and it indicated a difference between the cocoa and sucrose solution. Thus, the bitterness seems to have been more salient than sweetness in the cocoa solution, and the analgesic effect of the sucrose was reduced. Most literature (Birch 1999; Kracke et al. 2005) would suggest an antagonistic relationship between sweet and most bitter tastes in which the sweet suppresses the bitter taste quality of a substance. Theoretically, if participants rated the cocoa solution as more bitter than the sucrose solution, they should have also rated the cocoa solution as less sweet (not similarly sweet) compared with the sucrose solution due to the inhibitory suppressive effects many bitter tastants have on perceived sweetness (Birch 1999). However, at least one of the sources of cocoa's bitterness is its caffeine content, which does not suppress the sweetness of sucrose (Calvino et al. 1990). The participant ratings clearly demonstrate that cocoa has the same taste quality of sweetness as the sucrose solution, in addition to the taste quality of bitter. Our analyses suggest that the bitter taste quality of the cocoa solution is the main mechanism underlying the change in cold tolerance duration seen when cocoa is added to the sucrose solution.

The relationship between the bitter taste quality of the cocoa and the CPT duration time data can possibly be explained when considered in the context of the evolutionary "feeding withdrawal conflict" theory (Foo and Mason 2005). This theory suggests that nutritive cues trump simultaneous cues for escape behavior due to the more immediate necessity of nutrition for survival and is one explanation for sucrose analgesia (Foo and Mason 2005). In other words, feeding is optimized in potentially threatening situations because the nutrition immediately gained suppresses pain (or avoidance) cues. Because sweetness is generally a cue to incoming calories for an organism, this cue may be source of the sucrose analgesia. In the present experiment, participants not only rated the cocoa solution as sweet and pleasant, acknowledging its nutritive value and hedonic quality but they also rated it as relatively bitter. Because bitter is often an evolutionary cue to danger that is associated with poison (Glendinning, 1994), the nutritive value of the solution was suspect. Further, the bitter taste quality was much more salient and received more attention than the sweet taste quality in the cocoa solution as negative qualities of a stimulus typically demand attention (Förster and Stepper 2000). So, the attention to bitterness in the cocoa solution decreased cold pain tolerance relative to the sucrose condition.

Despite the relevance of the three main findings, several aspects of the present experiment bear further consideration. For example, one might expect that if the bitter taste quality of the cocoa solution is believed to be the driving mechanism of these results, then a significant negative correlation

between the PROP ratings and cold tolerance duration in the cocoa solution condition would be observable. Although a correlation approaching significance was observed, it was positive, rather than negative. This may be due to error, considering the small population of participants used in the present experiment, which may have prohibited the broad range of PROP tasters necessary to demonstrate a true relationship. It is also plausible that PROP taster status only measures sensitivity to one particular type of bitterness, and the bitterness related to cocoa may involve another set of genes unrelated to PROP perception (Hansen et al. 2006).

Significant effects of experiencing tastant conditions in a certain order on both in the CPT duration data and in the subjective ratings of pain intensity were observed. Never the less, these effects not only were neutralized in our analyses of cocoa versus sucrose but also were prevented from contributing to error variability by our balanced design.

Although the CPT duration data analyses show support for the previously established phenomenon of sucrose-induced analgesia, the participant gLMS ratings for cold pain intensity did not show a difference between the sucrose solution and water conditions. This inconsistency between the duration and rating data may be a side effect of testing, as each person was instructed to leave their hands in water "as long as possible.". This interpretation is consistent with other studies that showed similar effects (Lewkowski et al. 2003; Prescott and Wilkie 2007).

The results of this experiment suggest that taste qualities, probably due to their values as a signal for nutrition, are responsible for mediating cold pain tolerance. Although it is possible that chocolate in other forms may do so, the present study demonstrates that cocoa added to sucrose does not increase cold pain tolerance due to its bitter taste.

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