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Exposure to Acute Stress is Associated with Attenuated Sweet Taste

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Abstract

This study examined the effects of stress on taste perception. Participants ($N = 38$; 21 women) completed two laboratory sessions: one stress (public speaking, math, and cold pressor) and one control rest session. The taste perception test was conducted at the end of each session and included rating the intensity and pleasantness of sweet, salty, sour, and savory solutions at suprathreshold concentrations. Cardiovascular, hormonal, and mood measures were collected throughout the sessions. Participants showed the expected changes in cardiovascular, hormonal, and mood measures in response to stress. Reported intensity of the sweet solution was significantly lower on the stress day than on the rest day. Cortisol level post stress predicted reduced intensity of salt and sour, suggesting that stress-related changes in adrenocortical activity were related to reduced taste intensity. Results indicate that acute stress may alter taste perception, and ongoing research investigates the extent to which these changes mediate effects of stress on appetite.

Keywords

Stress; sweet; taste; cortisol; negative affect

Introduction

The quality and intensity of taste has a strong influence on appetite and desire to consume food (Sorensen, Moller, Flint, Martens, & Raben, 2003). Sensory information, including smell, taste, and appearance, is one of the most important motivators for food selection and consumption (Steptoe, Pollard, & Wardle, 1995). Emotional states and environmental cues can also influence eating behavior (Zellner, Allen, Henley, & Parker, 2006; Zellner, Saito, & Gonzalez, 2007). For example, individuals may use food consumption as a coping strategy when under stress, therefore increasing the rewarding properties of food intake (Goldfield & Lumb, 2008; Mitchell & Perkins, 1998; Newman, O'Connor, & Conner, 2007).

While the importance of taste in appetite is well recognized, very little attention has been devoted to the examination of how different affective states influence taste perception (Hermanussen et al., 2008). With a few exceptions, the evaluation of the effects of stress on taste has not been directly examined. In one study (Nakagawa, Mizuma, & Inui, 1996) investigators examined effects of mood states on taste sensitivity after mental or physical stressors. Taste responses were measured using quinine sulfate (bitter), citric acid (sour), and sucrose (sweet). Findings suggested that intensity and duration of bitter, sour, and sweet taste were reduced by mental stress when compared to measures collected before the stressors within the same session. The study was limited by the lack of details on the effectiveness of the stressors in activating stress response systems, the absence of an appropriate control condition for stress (i.e., rest session on a separate day), the lack of physiological response measures, and the potential carry-over effect of conducting multiple taste protocols within the same session (i.e., before and after the brief challenges). These limitations may have weakened the effects of stress and introduced carry-over confounds into the taste protocol administered multiple times within the session.

Another study explored mood-related biological mechanisms of taste by comparing the effects of serotonin (5-HT) reuptake inhibitor, norepinephrine (NE) reuptake inhibitor, or placebo on taste functions in healthy humans (Heath, Melichar, Nutt, & Donaldson, 2006). The study showed that increased availability of 5-HT, achieved by administering the 5-HT reuptake inhibitor, was associated with reduced sweet and bitter taste thresholds. Increased availability of NE, achieved by administering the NE reuptake inhibitor, was associated with reduced bitter and sour taste thresholds. These results suggested a distinct pattern of biological pathways involved in stress reactivity with altered taste perception. They also suggest that deficiencies in these neurochemical systems may be associated with attenuated taste sensitivity. The extent to which acute adrenocortical and psychophysiological stress response influences taste perception has not been directly examined. Also, it is not known to what extent trait negative affect, such as depressed and anxious moods, interacts with effects of stress on taste perception. This leaves gaps in our understanding of how stress alters taste perception and appetite.

The present study directly examined effects of acute stress on taste perception and examined the associations of the stress response measures, with trait negative affect and taste perception controlling for many of the confounding factors discussed above. For example, the study included a control session conducted on a separate day to control for effects of time, familiarity with experimental settings, and diurnal fluctuations. The study included a carefully developed and executed protocol to assess effects of stress using multiple hormonal, cardiovascular, and subjective measures and included multiple taste solutions. The study also included and accounted for multiple background trait measures relevant to stress responses including negative affect and perceived stress. Our hypothesis was that acute stress reduces taste perception (intensity and pleasantness), and that taste perception may be associated with affective, adrenocortical, and cardiovascular responses to stress. This hypothesis was based on disparate studies showing that acute stress may alter taste (Heath et al., 2006; Nakagawa et al., 1996) and that cortisol may be associated with attenuated taste detection acuity (Fehm-Wolfsdorf, Scheible, Zenz, Born, & Fehm, 1989).

Method

Participants

Participants were recruited through flyers posted around campus and through an online recruiting system. Potential participants completed a phone-screening questionnaire that assessed their eligibility for the study; if they passed the phone screening, they were invited to participate in an onsite health screening protocol. Participants were included in the study

if they were at least 18 years of age, were not taking any medication (with the exception of birth control), and had no history of any major medical or psychiatric disorders. Participants signed a consent form approved by the Institutional Review Board of the University of Minnesota. Then, participants were given a questionnaire packet which contained forms to assess medical history, health habits, the Profile of Mood State questionnaire (POMS; McNair et al., 1992), and the Perceived Stress Scale (PSS; Cohen et al, 1983). Thirty-eight participants (21 female) were eligible and completed the study.

Measures

During the screening, participants completed a measure of mood disturbance that includes subscales for depression and anxiety (McNair, Lorr, & Droppleman, 1992) and perceived stress (Cohen et al, 1983) to assess levels of psychological stress over the previous week. In the laboratory sessions, distress and positive affect was assessed using the Revised Subjective States Questionnaire (SSQ; Lundberg & Frankenhaeuser, 1980). The Distress factor included items of anxiety, irritability, impatience, and restlessness. Positive affect was assessed using items of cheerfulness, content, calmness, controllability, and interest. Each item referenced an 8-point scale anchored by the end points, "Not at All" and "Very Strong." Instructions on the SSQ asked participants to report on how they felt over the preceding 30 minutes. The scale has previously been shown to have strong psychometric properties (al'Absi, Wittmers, Erickson, Hatsukami, & Crouse, 2003).

Saliva samples were collected using a commercially available collection device (Salivette®, Sartstedt, Germany). Samples were stored at -70° C until assay. Cortisol in saliva was measured using a solid phase enzyme-linked immunosorbent assay kit based on competitive cortisol binding (IBL America, Minneapolis MN). The assay range is between 0-80 ng/mL, with a minimum sensitivity of 0.54 ng/mL. Inter-assay coefficient of variation was <15% and the intra-assay coefficient of variation < 5%, as measured using an internal standard. Absorbance was determined by the Spectramax Plus (Molecular Devices, Sunnyvale, CA) microtiter plate reader at 450 nm and analyzed using Soft Max Pro software (Molecular Devices, Sunnyvale, CA). Systolic and diastolic blood pressure (SBP, DBP) and heart rate (HR) were measured using an automated Dynamap oscillometric blood pressure monitor (Critikon, Tampa, FL).

Taste intensity was rated using a modified version of Green and colleagues' Labeled Magnitude Scale (LMS; Green et al., 1996). LMS uses a quasi-logarithmic spacing of its verbal labels and has been shown to provide psychophysical functions equivalent to magnitude estimation (Green et al., 1996). This scale ranges from 0 defined as "barely detectable" to the upper boundary of 100 defined as the "strongest imaginable taste". Pleasantness was verbally rated from 0 (dislike extremely) to 100 (like extremely) with the halfway point (50) corresponding to either like or dislike. The two scales were placed side by side on the wall next to the participant. Time to expectoration was also measured during the taste protocol by recording the time, in seconds, it took for the participant to fully taste the solution, or from sip to expectoration. Participants rated the intensity and pleasantness of each solution twice; the average of those two ratings was used in the data analyses.

Laboratory Session Procedures

Prior to each laboratory session participants were instructed to refrain from alcohol for at least 24 hours, caffeine and/or nicotine for at least 4 hours, and any medication (with the exception of birth control) for 72 hours. Participants were asked to have a light healthy meal (e.g., cereals, fresh fruit) 1-2 hours before their scheduled lab session. Also, they were asked to avoid consuming fatty foods (e.g., fried foods, meat with high-fat content) or prepared and processed food with oil or fat during the 24 hours prior to each session. A list that

included suggested dietary items was provided to participants prior to each session. All the study sessions (stress and rest) were conducted between noon and 2 pm to control for diurnal effects on cortisol. Upon arrival to the first laboratory session, participants reviewed the informed consent document and were trained on how to perform the taste perception protocol using water samples.

Participants were randomly assigned to the stress or rest condition for the first lab session. Participants were asked when they last ate anything and what they ate at that time. In addition, they were asked to provide details on what they ate the previous 24 hours. After the placement of blood pressure cuff, the participant sat quietly while watching a nature film. During this 15 min baseline period, SBP, DBP, and HR were taken every 3 min. Two saliva samples were collected at 10 min and after 15 minutes of rest. The SSQ was completed at the end of the baseline rest period.

Following baseline measures, participants either performed the acute stressors or continued to rest for 30 minutes. The stressors included public speaking (4 minutes of speech preparation and 4 minutes of delivery), mental arithmetic task (8 minutes), and a cold pressor test (CPT; immersion of non-dominant hand in ice water for 90 seconds). These tasks have been previously described and shown to be effective in producing reliable cardiovascular and adrenocortical responses (e.g., al'Absi, Buchanan, & Lovallo, 1996; al'Absi et al., 1997). Throughout the stress tasks, cardiovascular measures were taken approximately every 2 to 3 minutes. On the rest day, the participant relaxed while watching the nature film, during which cardiovascular measures were obtained every 3 min. A saliva sample and SSQ were collected at the end of this stress (or rest) period.

Following stress or rest, the taste protocol was administered. The participant was randomly assigned to one of five presentation orders. Four solutions plus water as a control were each given twice for a total of 10 trials presented to each participant. The four solutions included sweet (sucrose, 1M), salty (sodium chloride, 1M), sour (citric acid, .032M), savory (monosodium glutamate; MSG; 0.1M) in addition to the deionized water control. These concentration levels have been used in previous psychophysical studies (Small & Apkarian, 2006; Small, Zatorre, & Jones-Gotman, 2001) and were found to be suitable for the purpose of this study in pilot testing. The participant was instructed to sip the solution and hold it for 5 to 10 seconds until he or she fully tasted it. The researcher timed how long the participant held the solution in their mouth. After expectoration, the participant verbally rated the intensity and pleasantness of that solution, and rinsed with water. A new solution was presented 45 seconds after the previous solution was expectorated. A saliva sample for cortisol measurement was collected when the taste test was over.

The taste perception task was followed by a 50-min recovery period including a “snack time.” During the first 10 min, cardiovascular measures (every 3 min), a saliva sample, and SSQ were collected. Then, the participant was offered a snack tray that included two salty and two sweet snacks: one high fat and one low fat in each category. Thus, the snacks offered were one serving each of grapes (92.0 g), M&M candy (47.9 g), pretzels (28.0 g), and potato chips (28.3 g). The participant was told that we offer a snack because we did not want them to get too hungry, and if the participant wanted more, they were told they could ask for more. During the last 10 min of the recovery, cardiovascular measures were evaluated (every 3 min) and the final saliva sample and SSQ were obtained. Snacks were weighed prior to being offered to participants and following the “snack time.”

Data Preparation and Analysis

The primary dependent variables were ratings of intensity, pleasantness, and time until expectoration of each taste solution. To test our hypothesis addressing effects of stress on

taste perception, we conducted 2 (Gender) $\times$ 2 (Session: stress, rest) analysis of variance (ANOVA) for each taste variable, with gender as a between-subject factor and session as a within-subject factor. To examine effects of stress on cardiovascular measures (HR, SBP, and DBP), we conducted repeated measures ANOVA with gender as a between-subject factor and session and time (baseline, during stress/rest, the first 10 minutes of the recovery, and the last 10 min of the recovery period) as within-subject factors. Subjective measures (distress and positive affect on SSQ) were analyzed by a repeated measure ANOVA with gender as a between-subject factor and session and time (baseline, post stress/rest, final recovery at 10 min, and at the end of the final recovery) as within-subject factors. For cortisol, we conducted a repeated measure ANOVA with gender as a between-subject factor and session and time (baseline, post stress/rest, post taste test, final recovery at 10 min, and at the end of the final recovery) as within-subject factors. Cortisol values were log transformed to meet the normality assumption. The Greenhouse-Geisser correction was used when sphericity assumption was violated.

The relationship between psychophysiological measures, acute stress, and taste perception was also examined using multiple regression analysis with subjective or physiological measures (e.g., distress, cortisol) and gender included as predictors. The separate ratings of taste intensity and pleasantness were the dependent measures. In addition, we examined the extent to which trait negative mood (i.e., total mood disturbance as assessed by the POMS or psychosocial stress as measured by the PSS) moderated effects of acute stress on taste perception using multiple regression analysis. The analysis specifically focused on the interaction term between the trait mood measures by the physiological or mood state measures after including the main effect of the trait measure and the stress response measure. Separate regression models were conducted for distress, positive affect, SBP, DBP, HR, and cortisol stress response by each of the two trait measures. Intensity of each of the tastes (i.e., salt, sour, sweet, and MSG) were the dependent measures.

Results

Sample Characteristics

Table 1 shows participants' demographic information. Participants were relatively young (average age $\pm$ SEM = 20.3 $\pm$ 0.3) and predominantly Caucasians.

Effects of Stress on Physiological Activity

As illustrated in Figure 1, stress increased HR, SBP, and DBP as shown by significant Session $\times$ Time interactions (F s (2, 73) $>$ 51, p s $<$.001, $\eta^2 >$.16). Analysis of change scores (the mean value during the baseline was subtracted from the mean value during stress (or rest) revealed that HR, SBP, and DBP responses were greater on the stress day than the rest day (F s (1, 37) $>$ 150, p $<$.001, $\eta^2 >$.80), reflecting significant cardiovascular responses to the acute stressors. Also, men had higher SBP than women (F (1, 36) = 11.2, p $<$.01, $\eta^2 = .23$). Similarly, there was a significant Session $\times$ Time interaction (F (3, 106) = 8.19, p $<$.001, $\eta^2 = .06$) in cortisol concentrations. Differences in cortisol activity using area under the curve (AUC; calculated using the Trapezoidal rule) also revealed that overall cortisol concentrations were higher on the stress day than the rest day (F (1, 35) = 16.6, p $<$.001, $\eta^2 = .25$). In addition, analysis of change scores (the mean cortisol value of 2 samples during the baseline subtracted from the mean value of 2 post stress samples) revealed that cortisol responses were greater on the stress day than the rest day (F (1, 35) = 16.4, p $<$.001, $\eta^2 = .30$), indicating significant adrenocortical responses to the acute stressors.

Measures of distress and positive affect also changed in response to acute stress, as evidenced by significant Session $\times$ Time interactions (F s (3, 90.) $>$ 13, p s $<$.001, $\eta^2 = .10$;

see Figure 2). Analysis of change scores (the value during the baseline subtracted from the value immediately after stress) indicated greater levels of increase in distress and decrease in positive affect on the stress day compared to that observed on the rest day ($F_s(1, 37) > 18$, $ps < .001$, $\eta^2 > .33$). There were no gender differences in these measures ($F_s(1, 36) < 1.7$, $ps > .20$).

Effects of Stress on Taste Perception and Food Consumption

Intensity of sweetness was lower after the stressors on the stress day than the rest day ($F(1, 35) = 10.3$, $p < .01$, $\eta^2 = .23$; see Figure 3). Time until expectoration for MSG was longer on the stress day than the rest day ($F(1, 36) = 4.87$, $p < .05$, $\eta^2 = .12$). A similar, albeit not significant, trend was found for the salt solution ($F(1, 36) = 2.76$, $p = .11$, $\eta^2 = .07$). Women reported lower pleasantness ratings and shorter time until expectoration in response to salt and MSG tastes than men ($F_s > 4.7$, $ps < .05$, $\eta^2 > .12$). They also tended to report greater intensity rating of MSG taste than men on the rest day, as reflected by a Gender $\times$ Session interaction trend ($F(1, 36) > 3.89$, $p = .06$, $\eta^2 = .10$).

Total food consumption (in grams) of 4 food items (grapes, M&Ms, pretzels, chips) on the stress day (mean grams $\pm$ SEM: 142 ± 6.3) and the rest day (mean grams $\pm$ SEM: 143 ± 6.9) were comparable ($p > .90$). Total caloric consumption across all four food items did not differ between the two conditions (means $\pm$ SEM = 343 ± 23 on stress day and 353 ± 22 on rest day; $F(1, 36) < 1$), but there was a gender difference, with men consuming more calories than women (402 ± 31 for men and 294 ± 28 for women; $F(1, 36) = 6.60$, $p < .05$).

Multiple regression analysis was conducted to examine the extent to which stress-related affective and physiological measures were associated with taste perception. Gender was included as a covariate since it did not moderate the relationship between stress and taste variables in most of the previous analysis. The regression models were conducted separately for stress and rest sessions. On the stress day, cortisol levels immediately after stress predicted intensity of sour ($\beta = -.43$, $t = -2.75$, $p < .01$) and salt ($\beta = -.35$, $t = -2.11$, $p < .05$). Reported distress immediately after stress was predictive of intensity of sour ($\beta = .48$, $t = 3.38$, $p < .01$) and MSG ($\beta = .34$, $t = 2.21$, $p < .05$), and there was a trend of association between distress after stress and salt intensity ($\beta = .28$, $t = 1.75$, $p = .09$). Distress post-stress also predicted pleasantness of sour ($\beta = -.32$, $t = -2.00$, $p = .05$) and salt ($\beta = -.45$, $t = -3.25$, $p < .01$). In contrast, these findings were diminished on the rest day. Cortisol levels during the rest condition predicted intensity of sour ($\beta = -.35$, $t = -2.12$, $p < .05$) and distress predicted MSG intensity ($\beta = .36$, $t = 2.51$, $p < .05$) and pleasantness ($\beta = -.28$, $t = -2.04$, $p < .05$).

Multiple regression analysis was also conducted on food consumption variables. On the stress day, cortisol levels immediately after stress predicted consumption (in grams) of grapes ($\beta = .37$, $t = 2.22$, $p = .05$) and pretzels ($\beta = -.30$, $t = 1.99$, $p < .05$). None of the stress-related subjective or physiological measures predicted total calorie consumption ($ps > .1$).

To further explore the results across both conditions, we calculated a stress-related change scores accounting for baseline and rest day measures using the following step: 1) for each session, a mean value was calculated for baseline and for the stress period (or rest in the control day condition); 2) the mean value during the baseline was subtracted from the mean value for the stress period (or rest in the control day condition); 3) the change score on the rest day was subtracted from the change score on the stress day. We then conducted multiple regression analysis using this reactivity score as a predictor and taste perception on the stress day as a dependent measure, with gender as a covariate. We found that cortisol response predicted intensity of sour ($\beta = -.50$, $t = -3.35$, $p < .01$) and salt ($\beta = -.34$, $t = -2.05$, $p < .05$), and pleasantness of MSG ($\beta = .48$, $t = 3.18$, $p < .01$). SBP response predicted pleasantness of

sour ($\beta = -.34, t = -2.12, p < .05$) and MSG ($\beta = .36, t = 2.34, p < .05$), and DBP response predicted pleasantness of MSG ($\beta = .31, t = 2.05, p < .05$). These results suggest that hormonal and blood pressure reactivity was inversely associated with perception of salt and sour but was positively related to pleasantness of MSG.

Distress predicted intensity of sour ($\beta = .48, t = 3.42, p < .01$), salt ($\beta = .40, t = 2.59, p < .05$), and MSG ($\beta = .39, t = 2.57, p < .05$) as well as pleasantness of salt ($\beta = -.48, t = -3.49, p < .01$). Distress also predicted time until expectoration of sour ($\beta = -.37, t = -2.61, p < .05$) and salt ($\beta = -.34, t = -2.27, p < .05$). These results indicate that distress in response to stress was positively associated with intensity and negatively associated with pleasantness ratings and time until expectoration of the taste solutions. In all, findings paralleled previous results using absolute values.

Trait Negative Affect, Stress Response, and Taste Perception

Results from regression analysis that included mood disturbance (as measured by the POMS) and stress response measures indicated that the associations between psychophysiological stress reactivity and attenuated taste perception were pronounced among individuals high in mood disturbance. As shown in Table 2, mood disturbance interacted with distress ($\beta = -.51, t = -2.63, p < .05$) and DBP ($\beta = -1.10, t = -2.56, p < .05$) in predicting intensity of sweet. Mood disturbance also moderated the association between DBP and intensity of salt ($\beta = -1.03, t = -2.30, p < .05$).

Similarly, results from regression analysis that included perceived stress (measured by the PSS) indicated that the associations between psychophysiological stress reactivity and attenuated taste perception were pronounced among individuals high in perceived stress. As shown in Table 2, there were significant perceived stress $\times$ distress ($\beta = -1.94, t = -2.38, p < .05$) and perceived stress $\times$ DBP ($\beta = -1.93, t = -2.85, p < .01$) interactions on intensity of sweet taste. Also, a perceived stress $\times$ SBP interaction was found in intensity of salt ($\beta = -2.05, t = -2.92, p < .01$) and sour ($\beta = -1.55, t = -2.09, p < .05$). In addition, a perceived stress $\times$ DBP response was observed in intensity of salt ($\beta = -1.66, t = -2.46, p < .05$), sour ($\beta = -1.73, t = -2.57, p < .05$) and MSG ($\beta = -1.93, t = -2.82, p < .01$).

Discussion

This study obtained interesting and novel results indicating that acute stress was associated with reduced sweet taste perception, and that this attenuation was stronger in participants with high trait negative affect. The results also showed that increased cortisol concentrations following exposure to stress were associated with diminished taste intensity of salty and sour solutions. Consistent results were found when considering the length of time it took for the participant to fully taste the solutions. Time to expectoration was longer for MSG on the stress day than the rest day. The results demonstrated the effectiveness of the stress tasks in producing significant adrenocortical and cardiovascular changes and in increasing reported distress.

Patterns of association between stress-related measures and taste observed in this study suggest a possible central mechanism. This is supported in part by findings showing that levels of hypothalamic-pituitary-adrenocortical (HPA) response to stress and increased distress were associated with changes in taste perception and food consumption. Increased cortisol release after stress exposure was associated with attenuated intensity of sour. Also, cortisol levels after stress were associated with increased consumption of grapes. Although these results were based on exploratory analysis, they suggest that reduced taste perception led to a compensatory consumption behavior reflected by increased food intake, similar to

previously observed patterns (Curtis, Krause, & Contreras, 2001; Tepper, 1999; Keller, Steinmann, Nurse, & Tepper, 2002).

In contrast, there was a statistical trend indicating that reported distress post stress was associated with increased intensity and decreased pleasantness of salt. There was also a negative association between distress and consumption of pretzels. Findings on cortisol and distress seemed somewhat contradictory; however, it should be noted that lag time in terms of stress effects on these measures may vary depending on the method used (hormonal versus subjective response). Another possibility is that different components of the stress response may be associated with different food selections under stress. For example, high cortisol reactors may exhibit stronger attenuation in certain tastes when stressed and therefore choose different types of food compared to low cortisol reactors (Adam & Epel, 2007). Nevertheless, the patterns of the results reported here suggest an association between stress-related changes, possibly due to central modulations, including enhanced activation of multiple neurobiological pathways involved in stress, appetite regulation, and sensory processing.

The present results support work indicating that stress hormonal activation and other reward-related circuitry may be involved in increasing consumption of food items that are high in calories (Adam & Epel, 2007). One of the proposed mechanisms to explain these effects of stress is the enhanced activity of the HPA (Dallman et al., 2003) and the endogenous opioid system (Mathes, Brownley, Mo, & Bulik, 2009). Research has shown that participants who exhibited enhanced cortisol response to acute stress consumed more calories compared to low cortisol responders under the same stress, although the two groups consumed similar amounts of food on another control rest day (Epel et al., 2001). There was more preference for sweet items in high reactors than low reactors. Also, higher intensity and number of daily hassles were associated with increased snack intake among high cortisol reactors (Newman et al., 2007). Self-report stress eaters gained more weight and exhibited increased nocturnal insulin, cortisol, and total cholesterol to high density lipoprotein ratio during stressful periods (Epel et al., 2004). Experimental studies have shown that administration of glucocorticoids (cortisol) is associated with increase in ad-lib food intake (Tataranni et al., 1996). In addition, both stress and palatable food stimulate endogenous opioid release (Adam & Epel, 2007; Kuta, Bryant, Zabik, & Yim, 1984; Vaswani, Tejwani, & Mousa, 1983) and reactivity to stress increases the relative reinforcing value of food in binge eaters (Goldfield, Adamo, Rutherford, & Legg, 2008; Goldfield & Lumb, 2008). The extent to which stress-related activation in the HPA and opioid systems modulate taste perception and food intake should be addressed in future research.

The current study found moderating effects of trait negative affect on stress-related attenuation in sweet and MSG taste. Reduced sweet and MSG intensity in response to stress was stronger in participants who were high in negative mood. Trait negative affect has been reported to be associated with increased food intake in obese individuals (Schneider, Appelhans, Whited, Oleski, & Pagoto, 2010) or individuals under stress (Pollard, Steptoe, Canaan, Davies, & Wardle, 1995). Although preliminary, these results support the possibility that negative affect amplifies stress-related alterations in taste perception that may influence food intake in certain groups of people. Individual differences may play an important role in stress-induced desensitization (or sensitization) in taste perception and therefore appetite regulation. This hypothesis remains to be tested prospectively in future research.

This study was limited by the small sample size and the relative homogeneity of the sample in terms of weight, age, and racial background. The use of a single concentration of the testants may have limited the sensitivity to measure the hedonic effects of these solutions.

There was also a concern about the limited quantities of the snack food items offered to participants, which may have reduced chances for documenting effects of stress. Future research may benefit from additional information on appetite-related measures in determining effects of stress on taste and appetite regulation. Although specific instructions were provided to participants about diet prior to each session, future research may benefit from ongoing monitoring by the participant of their dietary behaviors on the day prior to participation. Nevertheless, the study had several strengths including the careful, structured assessment of stress, the use of multiple measures of the stress response (hormonal, cardiovascular, and subjective measures), the inclusion of multiple taste solutions, the inclusion of background trait measures relevant to stress responses, and the control for various confounding factors. The inclusion of a control session in the context of evaluating effects of stress provides a strong approach to evaluate and interpret stress-related changes in the collected measures controlling for time, familiarity with experimental settings, and diurnal fluctuations.

In summary, this study provides evidence that acute stress is associated with attenuated sweet taste perception. Patterns of association between stress-related measures and taste perception measures suggest that these associations may be particularly pronounced in individuals with high levels of trait negative affect. Also, cortisol levels in response to stress were related to reduced intensity of salt and sour. The results have implications in understanding the role of stress in regulating taste and appetite.

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Figure 1.

Mean cardiovascular and cortisol measures during the laboratory session. Line bars indicate standard error of the mean. Note. For cardiovascular measures, Recovery A includes data collected during the first 10 minutes of the recovery period; Recovery B includes data collected during the last 10 minutes of recovery. For cortisol, Recovery A sample was collected after 10 minutes of recovery and Recovery B sample was collected at the end of recovery.

Figure 2.

Mean subjective measures during the laboratory sessions. Line bars indicate standard error of the mean. Recovery A measure was collected after 10 minutes of recovery and Recovery B measure was collected at the end of recovery.

Figure 3.

Mean taste perception measures. Line bars indicate standard error of the mean. Note. The numerical position of the verbal rating for the intensity scale (the Labeled Magnitude Scale; Green et al., 1996) was: 1.4 (barely detectable); 6.1 (weak); 17.2 (moderate); 35.4 (strong), 53.3 (very strong); 100 (strongest imaginable). * $p < .05$.

Table 1

Sample characteristics

	ALL SUBJECTS	WOMEN	MEN
Age (years)	20.1 (0.3)	19.9 (0.4)	20.4 (0.4)
BMI (kg/m ²)	23.1 (0.5)	22.6 (0.6)	23.8 (0.7)
Education (years)	14.4 (0.2)	14.1 (0.3)	14.8 (0.3)
Exercise (hours/week)	6.0 (0.7)	5.1 (0.9)	7.1 (1.0)
Average Sleep (hours/night)	7.5 (0.1)	7.5 (0.2)	7.5 (0.2)
Ethnicity (% of Caucasian)	92.1	95.2	88.2
Tobacco Use (%)	5.3	0	11.8
Supplement Use (%)	23.7	23.8	23.5
Vegetarian (%)	2.6	4.8	0

Note. Entries show mean (standard error) or percentage of the study sample; BMI: body mass index.

Table 2

Predicting taste perception: The interaction of mood disturbance and perceived stress with stress response measures

Intensity of taste perception on the stress day				
	Salt	Sour	Sweet	MSG
Mood disturbance				
Distress	-.25	-.21	-.51**	-.22
Positive affect	.16	.35*	.40**	.49**
Systolic BP	-.91*	-.50	-.52	-.42
Diastolic DBP	-1.03**	-.84*	-1.10**	-.87*
Heart rate	-.41	.37	-.26	.11
Cortisol	.21	.14	.29	.11
Perceived stress				
Distress	-.47	-.48	-1.94**	-1.38*
Positive affect	-1.00	.57	1.08	2.12**
Systolic BP	-2.05***	-1.55**	-1.26	-1.30
Diastolic DBP	-1.66***	-1.73**	-1.93***	-1.93***
Heart rate	-.77	.19	-.33	-.51
Cortisol	.86	-.35	1.21	-.28

Entries show standardized coefficients beta derived from the interaction terms within the multiple regression model that examined the relationship between psychophysiological responses to stress and taste perception. Results show the interaction term of mood disturbance (measured using the Profile of Mood State) and perceived stress (measured using the Perceived Stress Scale) with each of the stress responses measures (distress, positive affect, systolic BP, diastolic BP, heart rate, and cortisol; as described in the text).

Note.

*
 $p < .1$,

**
 $p \leq .05$,

 $p < .01$.