Psychoneuroendocrinology (2014) 48, 178—188

Available online at www.sciencedirect.com

SciVerse ScienceDirect

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

Interpersonal stressors predict ghrelin and leptin levels in women

Lisa M. Jaremka[a], Martha A. Belury[b], Rebecca R. Andridge[c], William B. Malarkey[a,d,e], Ronald Glaser[a,e,f], Lisa Christian[a,g,h,i], Charles F. Emery[a,d,g], Janice K. Kiecolt-Glaser[a,e,g,h,*]

[a] *Institute for Behavioral Medicine Research, The Ohio State University College of Medicine, USA*
[b] *Department of Human Sciences, The Ohio State University, USA*
[c] *College of Public Health, The Ohio State University College of Medicine, USA*
[d] *Department of Internal Medicine, The Ohio State University College of Medicine, USA*
[e] *Comprehensive Cancer Center, The Ohio State University College of Medicine, USA*
[f] *Department of Molecular Virology, Immunology and Medical Genetics, The Ohio State University College of Medicine, USA*
[g] *Department of Psychology, The Ohio State University, USA*
[h] *Department of Psychiatry, The Ohio State University College of Medicine, USA*
[i] *Department of Obstetrics and Gynecology, The Ohio State University College of Medicine, USA*

Received 14 April 2014; received in revised form 23 June 2014; accepted 23 June 2014

KEYWORDS
Ghrelin;
Leptin;
Eating;
Obesity;
Stressful events;
Interpersonal relationships

Summary
Objective: Stressful events enhance risk for weight gain and adiposity. Ghrelin and leptin, two hormones that are implicated in appetite regulation, may link stressful events to weight gain; a number of rodent studies suggest that stressors increase ghrelin production. The present study investigated the links among daily stressors, ghrelin and leptin, and dietary intake in humans.
Method: Women ($n = 50$) completed three study appointments that were scheduled at least 2 weeks apart. At each visit, women arrived fasting and ate a standardized breakfast and lunch. Blood samples were collected 45 min after each meal. Women completed a self-report version of the Daily Inventory of Stressful Events (DISE) at each appointment. Two composites were created from the DISE data, reflecting the number of stressors that did and did not involve interpersonal tension.
Results: Women who experienced more stressors involving interpersonal tension had higher ghrelin and lower leptin levels than those who experienced fewer interpersonal stressors. Furthermore, women who experienced more interpersonal stressors had a diet that was higher in

* Corresponding author at: Institute for Behavioral Medicine Research, The Ohio State University College of Medicine, 460 Medical Center Drive, Columbus, OH 43210, USA. Tel.: +1 614 293 3499.
E-mail address: Janice.Kiecolt-Glaser@osumc.edu (J.K. Kiecolt-Glaser).

http://dx.doi.org/10.1016/j.psyneuen.2014.06.018

calories, fat, carbohydrates, protein, sugar, sodium, and fiber, and marginally higher in cholesterol, vegetables (but not fruits), vitamin A, and vitamin C. Stressors that did not involve interpersonal tension were unrelated to ghrelin and leptin levels or any of the dietary components examined.

Conclusions: These data suggest that ghrelin and leptin may link daily interpersonal stressors to weight gain and obesity.

1. Introduction

Obesity contributes to a host of medical problems, including Type 2 diabetes, cardiovascular disease, and premature mortality, and is thus a major public health concern (Billington et al., 2000). Stressful events enhance risk for weight gain and adiposity (Korkeila et al., 1998; Solomon et al., 2011; Wardle et al., 2011). For example, a recent meta-analysis concluded that people who experienced more stressors gained more body fat over time than those who experienced fewer stressors (Wardle et al., 2011). However, the relationship between stressful events and weight gain is not without controversy; almost three quarters of the studies examined in the meta-analysis reported no relationship between stressful events and weight gain, whereas others demonstrated that people who experience more stressors eat less and lose weight (Torres and Nowson, 2007; Wardle et al., 2011). Accordingly, there may be contextual factors that influence the links among stressful events, eating behavior, and weight gain (see Torres and Nowson, 2007 for a related argument).

One possibility is that interpersonal stressors, such as marital disagreements, are qualitatively different from other types of stressors and thus have differential effects on appetite and eating behavior. The desire for social connection is a strong impetus behind human behavior (Leary and Cox, 2008; Maslow, 1968). The importance of the need to belong is not surprising given the significance of group living for humans' survival throughout their evolutionary past; humans were most likely to thrive when they were part of a network of people who were invested in their welfare and who looked out for their well-being (Tooby and Cosmides, 1996). Over time, this ultimately led to a fundamental need to form close and caring bonds with other people (Baumeister and Leary, 1995). Because the need for social connection is central to human nature, the failure to fulfill this need should be detrimental to mental and physical health. Moreover, the disruption of social bonds may be a uniquely potent form of stress that affects a person's appetite and eating behavior. For example, experiencing interpersonal stress should motivate people to attempt to restore their sense of social connection (Pickett and Gardner, 2005). Recent research demonstrated that eating comfort food caused people to spontaneously think about their relationships, and simply thinking about comfort food decreased loneliness (Troisi and Gabriel, 2011). Accordingly, feeling hungry and eating in response to interpersonal stressors may allow people to feel socially reconnected, suggesting a distinctive role for interpersonal stressors in eating behavior and obesity.

Ghrelin and leptin, two hormones that are implicated in appetite regulation, may link interpersonally stressful events to eating behavior and weight gain. Although a person's eating behavior is multiply determined, ghrelin and leptin provide two internal eating-related signals. Ghrelin, an appetite-stimulating hormone, is one factor that promotes food consumption (Klok et al., 2007). For example, ghrelin reliably rises before a meal and declines after eating (Cummings et al., 2001), and pre-meal rises are related to increased feelings of hunger (Cummings et al., 2004). One innovative study demonstrated that people felt hungrier and consumed more food when they received a ghrelin injection compared with saline (Wren et al., 2001). Leptin, an appetite-suppressing hormone, rises following a meal and suppresses food intake in cooperation with other peptides (Klok et al., 2007). Furthermore, fat cells are a primary source of leptin, which is elevated among overweight people (Considine et al., 1996). Consistent with its satiety-related effects, leptin-deficient medical patients who received leptin treatment were less hungry and lost considerable weight (Licinio et al., 2004).

A number of rodent studies suggest that stressors increase ghrelin and reduce leptin production. For example, a tail pinch stressor elevated ghrelin gene expression in mice (Asakawa et al., 2001). Both chronic social defeat and continuous restraint stress increased plasma ghrelin production among mice (Chuang et al., 2011; Lutter et al., 2008; Ochi et al., 2008). Rats had higher plasma ghrelin levels after a water avoidance stressor compared with pre-stress levels (Kristenssson et al., 2006). Furthermore, mice that experienced chronic social defeat stress and rats that experienced chronic restraint stress had lower leptin levels compared with no-stress controls (Chuang et al., 2010; De Oliveira et al. (2014)).

The rodent literature provides a useful framework for beginning to unpack the links among stressors, ghrelin, and leptin. However, humans are an ultra-social species who evolved specific cognitive skills for interpreting the social world (Herrmann et al., 2007; Pagel, 2012). Accordingly, research with human participants provides a way to delineate the importance of interpersonal versus other types of stressors. Accordingly, the goal of the current study was to fill this gap in the human literature by investigating the links among daily interpersonal and non-interpersonal stressors, ghrelin, and leptin.

2. The current study

We addressed the question of whether women who experienced more stressors involving interpersonal tension would

have higher ghrelin and lower leptin levels than women who experienced fewer interpersonal stressors. Furthermore, if interpersonal stressors are related to more ghrelin and less leptin, people experiencing more interpersonal stressors should consume more food. Accordingly, we investigated whether stressors involving interpersonal tension were related to a woman's typical diet. We also examined whether non-interpersonal stressors predicted ghrelin and leptin levels and dietary intake, allowing us to test whether the effects of stressful events were specific to interpersonal stressors. We focused on non-obese women, because obesity can alter the link between ghrelin and eating behavior (Buss et al., 2014), and obese people often develop cellular leptin resistance (Myers et al., 2010).

In order to examine our hypotheses, we conducted secondary analyses using data from a study about yoga practice and inflammation (Kiecolt-Glaser et al., 2010). Women were assessed on three separate days; we utilized 2 blood samples from each visit, both of which were collected 45 min after participants ate a standardized meal.

3. Method

3.1. Participants

Due to the nature of the parent study, we recruited women who had some form of hatha yoga experience through online ads and notices posted in yoga studios. Women were categorized as either novice ($n = 25$) or expert ($n = 25$) yoga practitioners; women with an intermediate level of expertise were excluded (Kiecolt-Glaser et al., 2010). Interested participants were ineligible if they had health problems with obvious immunological or endocrinological consequences (e.g., cancer, recent surgeries, diabetes, etc.) or were taking related medications. We also excluded women who currently smoked, used statins, beta blockers, or psychoactive drugs, consumed excessive amounts of alcohol, had a convulsive disorder, or had a BMI ≥ 30.

The final sample ($n = 50$) was primarily White ($n = 44$) and their average age was 41.32 ($SD = 10.33$, range = 30—65). Over half of the sample was married or in a domestic partnership ($n = 29$) and all participants had at least some college education. Novice and expert yoga practitioners did not differ in terms of race, age, marital status, and education level. Furthermore, all participants completed all study visits. Additional samples characteristics are listed in Table 1. The project was approved by the Ohio State University Institutional Review Board and all participants provided written informed consent before participating.

3.2. Study procedure

In this randomized cross-over study, women completed three study appointments that were scheduled at least 2 weeks apart. Each visit corresponded to a different condition that was relevant to the parent study: yoga, movement control, and video control. The order of the three conditions was randomly assigned. Every visit followed the same timeline, differing only in the condition randomized for that visit.

All participants arrived at the Clinical Research Center (CRC), a hospital research unit, at 7:30 a.m. after fasting since the previous evening. At 7:45 a.m., women ate a standardized breakfast. They were allowed to choose between one of two breakfast options that were designed to provide equivalent carbohydrates, protein, fats, and calories across individuals and study visits, and women were asked to eat the entire meal. The meals were designed and supervised by a Ph.D. level bionutritionist who was part of the CRC full-time staff.

After breakfast, each participant had a heparin well placed in one arm for subsequent blood draws. Women rested in a hospital bed for a 20-min relaxation period and then provided a blood sample 45 min after the start of breakfast. At 10:15 a.m., participants completed their assigned movement condition for that session, which took 75 min. At 12:20 p.m., women ate a standardized lunch. Similar to the breakfast, they were allowed to choose between different lunch options that were designed to be equivalent across participants and study visits, and women were asked to eat the entire meal. The second blood sample was drawn at 1:10 p.m., 50 min after the start of lunch.

3.3. Movement conditions

The three conditions used in the parent study were not the focus of current investigation and are thus only briefly summarized (see Kiecolt-Glaser et al., 2010 for details). Iyengar yoga, the form of hatha yoga used in this study, emphasizes safe and comfortable postures based on each person's body type and needs. A restorative session was selected rather than a vigorous sequence because the poses could be performed by both novice and experienced practitioners.

The first control condition consisted of walking on a treadmill at 0.5 miles per hour. This walking speed best approximated women's heart rate during the restorative yoga session. The second control condition was a video sequence about physics experiments for a high school classroom, as well as segments from two lectures on polymers and quantum mechanics.

3.4. Questionnaires

Toward the beginning of each visit, women completed the Daily Inventory of Stressful Events (DISE; Almeida et al., 2002), a commonly used measure of daily stress with good concurrent validity. Participants completed a self-report version of the DISE, indicating whether certain types of daily stressors had occurred the prior day (Mroczek et al., 2013). Accordingly, the DISE had the potential to tap into both acute and chronic stressors. For example, participants were asked ''In the last 24 h, did anything happen in your workplace or volunteer setting that most people would consider stressful?'' and ''In the last 24 h, did anything happen at home that most people would consider stressful?'' In both scenarios, a participant could report a stressor that was an ongoing chronic stressor (e.g., one of many arguments over the past few months with a spouse), or one that only happened that day, and thus was relatively more acute in nature. Following prior research, participants were also asked whether the stressor involved an argument or disagreement with another person (Almeida et al., 2002; Mroczek et al., 2013). We created two composites from the DISE, reflecting the total

Table 1 Characteristics of the 50 women included in the study analyses of ghrelin, leptin and interpersonal stressors.

Characteristic	Category/description	Number (%)	Mean (SD)
Race	White	44 (88)	—
	Black	3 (6)	—
	Other	3 (4)	—
Education	High school or below	0 (0)	—
	Some college/college graduate	26 (52)	—
	Graduate/professional training	24 (48)	—
Marital status	Single	13 (26)	—
	Married/domestic partner	29 (58)	—
	Separated/divorced/widowed	8 (16)	—
BMI (categorical)	Normal weight (<25 kg/m^2)	34 (68)	—
	Overweight (≥25 kg/m^2)	16 (32)	—
Sleep quality (PSQI—categorical)	Poor sleep quality (>5)	13 (26.0)	—
	Good sleep quality (≤5)	37 (74.0)	—
# Interpersonal stressors	0 reported across all visits	14 (29.2)	—
	At least 1 reported at 1 visit	18 (37.5)	—
	At least 1 reported at 2 visits	10 (20.8)	—
	At least 1 reported at 3 visits	6 (12.5)	—
# Non-interpersonal stressors	0 reported across all visits	13 (27.1)	—
	At least 1 reported at 1 visit	16 (33.3)	—
	At least 1 reported at 2 visits	11 (22.9)	—
	At least 1 reported at 3 visits	8 (16.7)	—
BMI (continuous)	N/A	—	23.21 (2.77)
Sleep quality (PSQI—continuous)	N/A	—	4.24 (2.18)
Age	N/A	—	41.32 (10.33)
Ghrelin levels at T1 (pg/ml)	Averaged across all 3 visits	—	1053.06 (332.71)
Ghrelin levels at T2 (pg/ml)	Averaged across all 3 visits	—	1161.89 (378.35)
Leptin levels at T1 (ng/ml)	Averaged across all 3 visits	—	9.25 (5.37)
Leptin levels at T2 (ng/ml)	Averaged across all 3 visits	—	8.99 (5.20)

Note: $n = 50$, except for number of stressors ($n = 48$). T1 refers to the blood draw after breakfast whereas T2 is after lunch. Both ghrelin and leptin levels represent untransformed values.

number of stressors that did and did not involve interpersonal tension on the day before each visit (Almeida et al., 2002); both composites were based on stressors that participants self-identified as involving interpersonal tension or not.

To assess women's typical diet, we administered the Food Frequency Questionnaire (FFQ) at an initial screening visit. Taken from the National Cancer Institute's Health Habits and History Questionnaire, the FFQ assessed participant's typical intake of select foods and nutrients (Patterson et al., 1999). The FFQ is widely used among different populations and shows convergent validity with other dietary measures (Subar et al., 2001). Women reported the type, frequency, and quantity of foods and beverages they consumed in the past 90 days. Software from the National Cancer Institute allowed us to calculate dietary intake of key food groups (Kristal et al., 1999).

During their screening visit, women also completed the Pittsburgh Sleep Quality Index, assessing sleep quality over the past month via a combination of subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medications, and daytime dysfunction (PSQI; Buysse et al., 1989). The PSQI has good internal consistency and can distinguish between people with and without sleep disturbances, indicating acceptable discriminant validity (Buysse et al., 1989; Carpenter and Andrykowski, 1998). At each visit, participants were asked how many hours they slept the night before and how rested they felt when they woke up that morning. The sleep measures provided a way to assess the links among interpersonal stressors, ghrelin, and leptin independent of sleep, which can influence both hormones (Knutson et al., 2007; Taheri et al., 2004).

3.5. Endocrine assays

All blood samples for a participant were collected via a catheter, frozen after collection, and analyzed within the same assay run. Determinations for leptin and total ghrelin

were made using their respective RIA kits per kit instructions (Millipore Corporation, St. Charles, MO 63304). For leptin, the intra-assay coefficient of variation (CV) was 4.2% and inter-assay CV was 4.5%; sensitivity was 0.5 ng/ml as previously reported (Kiecolt-Glaser et al., 2012). For total ghrelin, the intra-assay CV was 6.4% and inter-assay CV was 16.3%; sensitivity was .09 ng/ml.

3.6. Data analytic strategy

The hormone data were moderately skewed. Accordingly, each measure was square root transformed prior to analyses. Linear mixed models were used to account for the correlations within a participant, both within and across conditions. A random subject-specific effect captured the within-subject correlations across conditions (yoga vs. movement vs. video) and also across sample times (after breakfast vs. after lunch). All analyses were conducted in SPSS version 19.0 (IBM, New York).

We investigated whether stressors involving interpersonal tension predicted ghrelin and leptin levels. Specifically, we conducted an analysis with the number of interpersonal stressors at each visit as the predictor and either ghrelin or leptin levels as the outcome. First, we investigated a model with no covariates. Next, we added a series of control variables (described below) and the fixed effects for the 3-way interpersonal stressor by condition by sample time interaction, and all corresponding 2-way interactions. This allowed us to test whether condition or sample time modified the effects of interpersonal stressors. Due to the complexity of the analytic model and our limited sample size, higher order interactions that were not significant or marginally significant were dropped (p values > .10). Remaining significant interactions were decomposed using simple slopes tests. We followed the same data analytic strategy using the number of non-interpersonal stressors at each visit as the predictor.

We conducted two sets of ancillary analyses. For both sets, we examined whether stressors involving interpersonal tension predicted participants' dietary intake. Our diet measure assessed women's food intake over a 90 day period prior to the study. Accordingly, we created an interpersonal stressor composite by averaging the number of interpersonal stressors each woman reported across visits. This composite provided a window into a participant's typical day by serving as an index of how many stressors she would experience on an average day.

For the first set of ancillary analyses, we conducted a set of linear regressions examining whether the average number of interpersonal stressors across visits predicted women's typical diet in terms of quantity of foods consumed. Specifically, we examined calories, three macronutrients (fat, carbohydrates, and protein), and several other dietary components (cholesterol, sugar, sodium, fiber, fruits, vegetables, vitamin A, and vitamin C). We followed the same data analytic strategy for non-interpersonal stressors.

In the second set of auxiliary analyses, we conducted a set of linear regressions testing whether the average number of interpersonal stressors across visits predicted the percentage of calories due to fat, carbohydrates, and protein. We followed the same data analytic strategy for non-interpersonal stressors. These accompanying analyses allowed us to investigate whether interpersonal stressors were linked to the overall quantity of macronutrients women were consuming (which would be supported by ancillary analysis #1) versus the type of macronutrients people were consuming (which would be supported by ancillary analysis #2).

Potential confounds were selected based on their theoretical and empirical relationships to stressful events, ghrelin, and leptin (Haqq et al., 2003; Kiecolt-Glaser et al., 2012; Knutson et al., 2007; Shiiya et al., 2002; Taheri et al., 2004). Every model adjusted for age, body mass index (BMI: kg/m^2), sleep, and prior yoga experience (novice vs. expert). We had multiple sleep measures available. In the primary analyses, feeling rested in the morning (or the lack thereof) was more strongly related to ghrelin and leptin levels than hours of sleep the night before, perhaps because people vary in their usual waking time and the amount of sleep they typically need (Van Dongen et al., 2005). Accordingly, the feeling rested item was used as a covariate in our primary analyses. In the secondary analyses investigating women's diets over a 3-month period, we used the PSQI, measuring longer-term sleep quality.

In sum, the primary analyses focused on relationships between the number of stressors the day before each visit (as a continuous predictor) and ghrelin or leptin levels at each visit. The ancillary analyses examined the link between average number of stressors reported across all three visits (as a continuous predictor) and women's typical dietary intake. Furthermore, the ghrelin, leptin, and dietary analyses all included the same covariates, although the sleep measure differed based on the timeframe of the corresponding dependent measure. Degrees of freedom vary slightly from analysis to analysis because of small amounts of missing data.

4. Results

4.1. Preliminary analyses

Number of stressors within each visit: Within the video condition visit, 59.6% of women reported 0 stressors involving interpersonal tension, 31.9% reported 1 interpersonal stressor, 6.4% reported 2 interpersonal stressors, and 2.1% reported 3 interpersonal stressors. The corresponding breakdowns within the movement control condition were 59.6%, 23.4%, 17.0%, and 0%. Within the yoga condition, the frequencies were 62.5%, 27.1%, 10.4%, and 0%.

Within the video condition, 51.1% of women reported 0 non-interpersonal stressors, 42.6% reported 1 non-interpersonal stressor, 6.4% reported 2 non-interpersonal stressors, and 0% reported 3 non-interpersonal stressors. The corresponding breakdowns within the movement control condition were 61.7%, 23.4%, 10.6%, and 4.3%. Within the yoga condition, the frequencies were 56.3%, 31.3%, and 12.5%.

Number of stressors averaged across visits: Approximately 12.5% of women reported one or more stressors involving interpersonal tension at all 3 assessments, 20.8% during at least 2 assessments, 37.5% at only one assessment, and 29.2% did not report any interpersonal stressors.

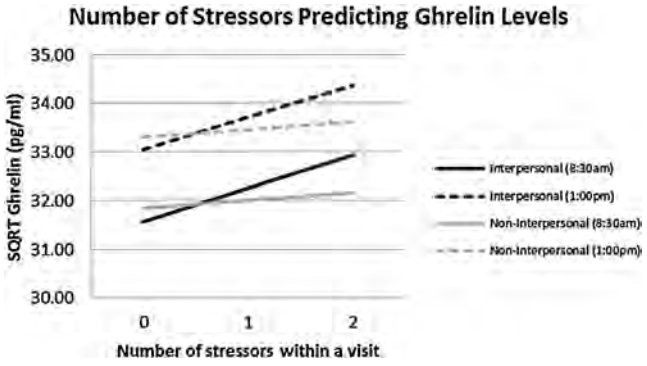

Figure 1 Number of stressors predicting ghrelin values. Note. $n = 47$. Estimated marginal means were calculated from two mixed models, one predicting ghrelin levels (SQRT) from number of interpersonal stressors at each visit, controlling for BMI, age, sleep, and yoga experience, and the other with non-interpersonal stressors as the key predictor.

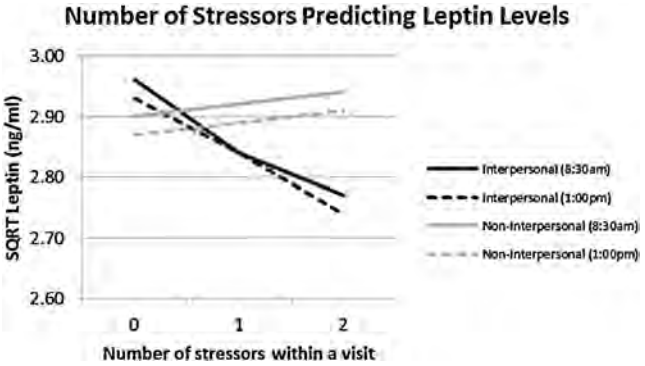

Figure 2 Number of stressors and leptin values. Note. $n = 47$. Estimated marginal means were calculated from two mixed models, one predicting leptin levels (SQRT) from number of interpersonal stressors at each visit, controlling for BMI, age, sleep, and yoga experience, and the other with non-interpersonal stressors as the key predictor.

The corresponding breakdowns for non-interpersonal stressors were 16.7%, 22.9%, 33.3%, and 27.1% respectively. All reported coefficients are unstandardized.

4.2. Primary analyses

First, we examined an unadjusted model with the number of interpersonal stressors at each visit as the predictor and ghrelin levels as the outcome. Women who experienced more stressors involving interpersonal tension had higher ghrelin levels than those who experienced fewer interpersonal stressors, $b = .68$, $F(1,204) = 3.35$, $p = .068$, although this effect was only marginally significant. Next, we added our a priori selected covariates and also tested whether the interpersonal stressor effect was moderated by condition or time of day. Ghrelin levels broken down by type of stressor, number of stressors at each visit, and time of day are graphed in Fig. 1. As predicted, women who experienced more stressors involving interpersonal tension had higher ghrelin levels than those who experienced fewer interpersonal stressors, $b = .67$, $F(1,201) = 3.97$, $p = .048$. Women also had higher ghrelin levels later in the day compared with earlier, $b = 1.45$, $F(1,192) = 11.26$, $p = .001$. However, none of the interactions with sample time or condition were significant, indicating that the strength of the relationship between interpersonal stressors and ghrelin was the same across conditions (i.e., visits) and at both sampling time points, all p values >.366. Non-interpersonal stressors were unrelated to ghrelin levels, except there was a significant non-interpersonal stressor by time by condition interaction predicting ghrelin levels, $F(1,109) = 3.85$, $p = .024$. This interaction was driven by higher ghrelin levels later in the day compared to earlier for everyone except women experiencing more non-interpersonal stressors in the video condition. This interaction was not replicated with the leptin data and is thus not discussed further.

Next, we examined an unadjusted model with the number of interpersonal stressors at each visit as the predictor and leptin levels as the outcome. Women who experienced more stressors involving interpersonal tension had lower leptin than those who experienced fewer interpersonal stressors, $b = -.12$, $F(1,191) = 3.90$, $p = .050$. Next, we added our a priori selected covariates and also tested whether the interpersonal stressor effect was moderated by condition or time of day. Leptin levels broken down by type of stressor, number of stressors at each visit, and time of day are graphed in Fig. 2. As expected, women who experienced more stressors involving interpersonal tension had lower leptin than those who experienced fewer interpersonal stressors, $b = -.10$, $F(1,184) = 4.20$, $p = .042$. Time of day was unrelated to leptin levels, $b = -.03$, $F(1,180) = 0.22$, $p = .641$. Furthermore, none of the interactions with condition or sampling time were significant, indicating that the strength of the relationship between interpersonal stressors and leptin was the same across conditions and at both sampling time points, all p values >.105. Non-interpersonal stressors were unrelated to leptin levels in either the unadjusted or adjusted models, p values >.434.

4.3. Ancillary analyses

First, we examined women's diet in terms of overall quantities of food consumed. Women who experienced more stressors involving interpersonal tension across all three visits had a typical diet that was higher in calories, fat, carbohydrates, protein, sugar, sodium, and fiber compared with those who experienced fewer interpersonal stressors (see Table 2). Their diet also included more cholesterol, vegetables (but not fruits), vitamin A, and vitamin C, although these effects were only marginally significant. Non-interpersonal stressors were unrelated to any of the dietary components examined (see Table 3).

Next, we investigated the percentage of calories in a woman's diet due to three macronutrients: fat, carbohydrates, and protein. Both interpersonal stressors and non-interpersonal were unrelated to percentage of calories due to all three macronutrients, p values >.112.

5. Discussion

The current study demonstrated that women who experienced more stressors involving interpersonal tension had

Table 2 Fully adjusted regression analyses: average number of stressors across visits involving interpersonal tension predicting dietary outcomes.

Predictor: average number of stressors involving interpersonal tension				
Outcome	Unstandardized beta coefficient (*b*)	Standard error	*t*	*p*
Calories (kcal)	652.45	170.20	3.83	<.001
Fat (g)	20.39	7.38	2.76	.009
Carbohydrates (g)	77.21	23.97	3.22	.003
Protein (g)	35.32	8.13	4.35	<.001
Cholesterol (mg)	89.19	47.69	1.87	.069
Sugars (g)	32.32	12.32	2.62	.012
Sodium (mg)	1287.70	332.57	3.87	<.001
Fiber (g)	8.48	2.85	2.98	.005
Fruit (#/day)	0.20	0.51	0.38	.705
Vegetables (#/day)	0.87	0.51	1.69	.099
Vitamin A (IU)	5117.15	3088.64	1.66	.105
Vitamin C (mg)	38.11	22.18	1.72	.093

Note: $n = 46$. All analyses controlled for age, BMI, sleep quality, and yoga experience.

higher ghrelin and lower leptin levels than those who experienced fewer interpersonal stressors. Furthermore, women who experienced more interpersonal stressors had a typical diet that was significantly higher in calories, fat, carbohydrates, protein, sugar, sodium, and fiber, and marginally higher in cholesterol, vegetables (but not fruits), vitamin A, and vitamin C. However, the percentage of calories in a woman's diet due to fat, carbohydrates, and protein was unrelated to interpersonally stressful events. Furthermore, stressors that did not involve interpersonal tension were unrelated to ghrelin and leptin levels or any of the dietary components examined.

A number of rodent studies have demonstrated that stressors increase ghrelin production (Asakawa et al., 2001; Chuang et al., 2011; Kristenssson et al., 2006; Lutter et al., 2008; Ochi et al., 2008). Although these studies provide a useful foundation to build upon, humans are an ultra-social species who evolved specific cognitive skills for interpreting the social world (Herrmann et al., 2007; Pagel, 2012). Accordingly, the present results fill an important gap in the human literature by investigating the relationships between daily stressors and both ghrelin and leptin. Furthermore, the current research distinguished between interpersonal and non-interpersonal stressors, demonstrating that only stressors involving interpersonal tension were related to ghrelin and leptin levels and dietary intake. These data suggest that interpersonal stressors are qualitatively different than other types of stressors in terms of their effect on two appetite-relevant hormones and a person's typical diet.

The present data demonstrated that women who experienced more interpersonal stressors had a typical diet that was higher in all three macronutrients (i.e., fat, carbohydrates, and protein) and a variety of micronutrients. However, the percentage of calories in women's diets due to fat, carbohydrates, and protein was similar between women experiencing more or fewer interpersonal stressors.

Table 3 Fully adjusted regression analyses: average number of stressors across visits not involving interpersonal tension predicting dietary outcomes.

Predictor: average number of stressors not involving interpersonal tension				
Outcome	Unstandardized beta coefficient (*b*)	Standard error	*t*	*p*
Calories (kcal)	14.94	193.20	0.08	.939
Fat (g)	0.87	7.82	0.11	.912
Carbohydrates (g)	−2.31	26.11	−0.09	.930
Protein (g)	1.54	9.57	0.16	.873
Cholesterol (mg)	30.32	48.04	0.63	.532
Sugars (g)	10.28	12.85	0.80	.428
Sodium (mg)	−194.34	377.32	−0.52	.609
Fiber (g)	−3.48	3.00	−1.16	.254
Fruit (#/day)	−0.17	0.50	−0.35	.731
Vegetables (#/day)	−0.24	0.51	−0.46	.648
Vitamin A (IU)	−1877.00	3085.44	−0.61	.546
Vitamin C (mg)	−24.24	21.98	−1.10	.277

Note: $n = 46$. All analyses controlled for age, BMI, sleep, and yoga experience.

Accordingly, interpersonally stressed women were eating more macronutrients without altering the proportion of their diet that came from these macronutrients. Taken together, the hormone and dietary data add to the burgeoning literature about ghrelin, leptin, and eating behavior. For example, a growing body of research suggests that ghrelin increases consumption of hedonically pleasant food, such as food high in sugar and fat, among non-obese rodents and humans (Buss et al., 2014; Disse et al., 2010; Perello et al., 2010). The current study raises the possibility that interpersonally stressful events may also be a determining factor that shapes the links among ghrelin, leptin, and eating behavior. Accordingly, an excellent target for future research is examining the effects of interpersonal stressors on ghrelin, leptin, and actual food consumption.

Women in the current study had higher ghrelin levels later in their visit compared with earlier. However, leptin did not change based on time of day. Prior work examining diurnal changes in ghrelin and leptin has revealed inconsistent patterns (Birketvedt et al., 2012; Bodosi et al., 2004; Sánchez et al., 2004). This variation may be due to differences in macronutrient consumption and sample timing across studies; ghrelin levels largely depend on macronutrient consumption (Koliaki et al., 2010), which may obfuscate any diurnal patterns. Taken together, prior research and the present data begin to paint a picture about timing and macronutrient-related factors that influence ghrelin and leptin levels.

Obesity contributes to a host of medical problems and is thus a major public health concern (Billington et al., 2000). The current data suggest that ghrelin and leptin may link interpersonally stressful events to overeating and weight gain. However, eating behavior is multiply determined. Accordingly, other physiological and psychological mechanisms may work independently or in tandem with changes in ghrelin and leptin levels to influence eating behavior. For example, sleep deprivation is linked to increased food consumption (Knutson et al., 2007). In addition, environmental factors, such as food package size and lighting conditions, alter dietary intake (Wansink, 2004). The stringent exclusion criteria used in this study and the use of standardized meals helped rule out potential confounding factors that might explain the links among interpersonal stressors, ghrelin, and leptin. In addition, the current results were independent of participants' age, BMI, sleep, and yoga experience. Consequently, interpersonal stressors were related to ghrelin and leptin levels and dietary intake independent of participants' demographic characteristics, health, and health behaviors.

We excluded interested participants with a BMI $\geq 30\,kg/m^2$, and thus none of the women in our sample were obese (Centers for Disease Control and Prevention, 2014). Obesity is related to cellular leptin resistance, although it remains unclear whether obesity causes this resistance or vice versa (Myers et al., 2010). One interesting extension of the present research would be testing whether the relationships among interpersonal stressors, ghrelin, and leptin generalize to obese individuals. In fact, a recent study demonstrated that ghrelin was linked to caloric intake and hedonic eating among overweight but not obese people (Buss et al., 2014), suggesting potential differential effects of interpersonal stressors among obese people. Along similar lines, prior research indicates that the links among acute stressors, ghrelin, and food consumption may be altered by eating-related problems, such as binge eating disorder or emotional eating (Raspopow et al., 2014, 2010; Rouach et al., 2007), suggesting another possible extension of the current findings.

One critical avenue for additional research is exploring mechanisms that link interpersonal stressors to elevated ghrelin and leptin. One rodent study demonstrated that a β_3-adrenergic antagonist attenuated the effects of chronic social defeat on leptin production (Chuang et al., 2010). In addition, direct stimulation of the sympathetic nervous system in rats elevated ghrelin levels (Mundinger, 2006). Accordingly, one promising mechanism is sympathetic nervous system activation. However, the research examining the links among stressors, ghrelin, and leptin is in its infancy, particularly among humans.

Another intriguing avenue for future research is understanding why stressors involving interpersonal tension, but not other stressors, were related to ghrelin and leptin. One possibility is that feeling hungry in response to interpersonal stress is socially adaptive. The need for social connection is fundamental to human nature. Consequently, experiencing interpersonal stressors should motivate people to try and connect with others in order to restore their sense of belonging. Furthermore, eating and social connection are intricately linked; eating was a highly social activity throughout human evolution (Wrangham, 2010), and people still often eat around other people. In addition, recent research demonstrated that eating comfort food caused people to spontaneously think about their relationships, and simply thinking about comfort food decreased loneliness (Troisi and Gabriel, 2011). Consequently, people may feel hungrier when they experience interpersonal stressors because they have either implicitly or explicitly learned that eating either helps them feel socially connected and/or provides them with an opportunity for social connection.

The current sample consisted of women who were primarily white, one limitation of the present results. The study hypotheses were also designed and tested after data collection for the study was complete. Accordingly, researchers should design additional studies to a priori test the relationships among interpersonal stressors, ghrelin and leptin, and dietary intake in more diverse samples. In the present study, it is possible that some participants did not completely finish their standardized meals, another limitation. However, none of the women were obese, they were allowed to choose from multiple standardized meal options, and they were instructed to eat the entire meal, making this possibility less likely. Nonetheless, given the influence of calorie consumption on ghrelin levels (Le Roux et al., 2005), an important direction for additional research is to examine actual food consumption and whether this differs from self-reported dietary intake. Although all participants were given standardized meals, no pre-meal blood samples were obtained. Accordingly, the results evident in this study may be due to specific meal responses, more chronic hormone dysregulation, or a combination of the two. In addition, the inventory of stressful events utilized in this study captures stressful events that occurred within the prior 24 h. Accordingly, these events could reflect daily stressors that represent a chronic source of distress and those that are acute one-time occurrences. Understanding the relationships among acute

versus chronic stressors, ghrelin, and leptin both before and after a meal is an important direction for future research. Another key question is to determine whether more recent stressors have a stronger effect on appetite-regulation than those that are less recent.

The ghrelin assay used in this study was based on total levels, and thus it is unclear how active ghrelin may be related to interpersonal stressors. However, previous research demonstrated that overweight women with higher total ghrelin levels consumed more calories, particularly hedonically pleasant food, than those with lower levels, supporting the importance of total ghrelin in eating behavior (Buss et al., 2014).

In sum, women who experienced more stressors involving interpersonal tension had higher ghrelin and lower leptin levels and reported consuming more food than those who experienced fewer interpersonal stressors. These data suggest that ghrelin and leptin, two hormones that are implicated in appetite regulation, may link daily interpersonal stressors to weight gain and obesity.

Role of the funding sources

Work on this project was supported in part by NIH grants R21 AT002971, K05 CA172296, R21 CA158868, P30 CA016058, and UL1RR025755, as well as American Cancer Society Postdoctoral Fellowship Grant 121911-PF-12-040-01-CPPB and a Pelotonia Postdoctoral Fellowship from the Ohio State University Comprehensive Cancer Center.

Conflict of interest

All authors declare that there are no financial conflicts of interest.

Acknowledgements

None.

References

Almeida, D.M., Wethington, E., Kessler, R.C., 2002. The daily inventory of stressful events: an interview-based approach for measuring daily stressors. Assessment 9, 41—55, http://dx.doi.org/10.1177/1073191102091006.

Asakawa, A., Inui, A., Kaga, T., Yuzuriha, H., Nagata, T., Fujimiya, M., Katsuura, G., Makino, S., Fujino, M.A., Kasuga, M., 2001. A role of ghrelin in neuroendocrine and behavioral responses to stress in mice. Neuroendocrinology 74, 143—147, http://dx.doi.org/10.1159/000054680.

Baumeister, R.F., Leary, M.R., 1995. The need to belong: desire for interpersonal attachments as a fundamental human motivation. Psychol. Bull. 117, 497—529, http://dx.doi.org/10.1037/0033-2909.117.3.497.

Billington, C.J., Epstein, L.H., Goodwin, N.J., Hill, J.O., Pi-Sunyer, F.X., Rolls, B.J., Stern, J., Wadden, T.A., Weinsier, R.L., Wilson, G.T., Wing, R.R., Yanovski, S.Z., Hubbard, V.S., Hoofnagle, J.H., Everhart, J., Harrison, B., 2000. Overweight, obesity, and health risk. Arch. Intern. Med. 160, 898—904.

Birketvedt, G.S., Geliebter, A., Kristiansen, I., Firgenschau, Y., Goll, R., Florholmen, J.R., 2012. Diurnal secretion of ghrelin, growth hormone, insulin binding proteins, and prolactin in normal weight and overweight subjects with and without the night eating syndrome. Appetite 59, 688—692, http://dx.doi.org/10.1016/j.appet.2012.07.015.

Bodosi, B., Gardi, J., Hajdu, I., Szentirmai, E.F., Obal, J., Krueger, J.M., 2004. Rhythms of ghrelin, leptin, and sleep in rats: effects of the normal diurnal cycle, restricted feeding, and sleep deprivation. Am. J. Physiol. Regul. Integr. Comp. Physiol. 287, R1071—R1079, http://dx.doi.org/10.1152/ajpregu.00294.2004.

Buss, J., Havel, P.J., Epel, E., Lin, J., Blackburn, E., Daubenmier, J., 2014. Associations of ghrelin with eating behaviors, stress, metabolic factors, and telomere length among overweight and obese women: preliminary evidence of attenuated ghrelin effects in obesity? Appetite 76, 84—94, http://dx.doi.org/10.1016/j. appet.2014.01.011.

Buysse, D.J., Reynolds 3rd, C.F., Monk, T.H., Berman, S.R., Kupfer, D.J., 1989. The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research. Psychiatry Res. 28, 193—213.

Carpenter, J.S., Andrykowski, M.A., 1998. Psychometric evaluation of the Pittsburgh sleep quality index. J. Psychosom. Res. 45, 5—13, http://dx.doi.org/10.1016/S0022-3999(97)00298-5.

Centers for Disease Control and Prevention, 2014. Overweight and Obesity [WWW Document], http://www.cdc.gov/obesity/adult/defining.html (accessed 04.02.14).

Chuang, J.-C., Krishnan, V., Yu, H.G., Mason, B., Cui, H., Wilkinson, M.B., Zigman, J.M., Elmquist, J.K., Nestler, E.J., Lutter, M., 2010. A β3-adrenergic-leptin-melanocortin circuit regulates behavioral and metabolic changes induced by chronic stress. Biol. Psychiatry 67, 1075—1082, http://dx.doi.org/10.1016/j.biopsych.2009.12.003.

Chuang, J.-C., Perello, M., Sakata, I., Osborne-Lawrence, S., Savitt, J.M., Lutter, M., Zigman, J.M., 2011. Ghrelin mediates stress-induced food-reward behavior in mice. J. Clin. Invest. 121, 2684—2692, http://dx.doi.org/10.1172/JCI57660.

Considine, R.V., Sinha, M.K., Heiman, M.L., Kriauciunas, A., Stephens, T.W., Nyce, M.R., Ohannesian, J.P., Marco, C.C., McKee, L.J., Bauer, T.L., 1996. Serum immunoreactive-leptin concentrations in normal-weight and obese humans. N. Engl. J. Med. 334, 292—295, http://dx.doi.org/10.1056/NEJM199602013340503.

Cummings, D.E., Frayo, R.S., Marmonier, C., Aubert, R., Chapelot, D., 2004. Plasma ghrelin levels and hunger scores in humans initiating meals voluntarily without time- and food-related cues. Am. J. Physiol. — Endocrinol. Metabol. 287, E297—E304, http://dx.doi.org/10.1152/ajpendo.00582.2003.

Cummings, D.E., Purnell, J.Q., Frayo, R.S., Schmidova, K., Wisse, B.E., Weigle, D.S., 2001. A preprandial rise in plasma ghrelin levels suggests a role in meal initiation in humans. Diabetes 50, 1714—1719, http://dx.doi.org/10.2337/diabetes.50.8.1714.

De Oliveira, C., Scarabelot, V.L., Souza, A., de Oliveira, C.M., de Medeiros, L.F., Macedo, I.C., de Marques Filho, P.R., Cioato, S.G., Caumo, W., Torres, I.L.S., 2014. Obesity and chronic stress are able to desynchronize the temporal pattern of serum levels of leptin and triglycerides. Peptides 51, 46—53, http://dx.doi.org/10.1016/j.peptides.2013.10.024.

Disse, E., Bussier, A.-L., Veyrat-Durebex, C., Deblon, N., Pfluger, P.T., Tschöp, M.H., Laville, M., Rohner-Jeanrenaud, F., 2010. Peripheral ghrelin enhances sweet taste food consumption and preference, regardless of its caloric content. Physiol. Behav. 101, 277—281, http://dx.doi.org/10.1016/j.physbeh.2010.05.017.

Haqq, A.M., Farooqi, I.S., O'Rahilly, S., Stadler, D.D., Rosenfeld, R.G., Pratt, K.L., LaFranchi, S.H., Purnell, J.Q., 2003. Serum ghrelin levels are inversely correlated with body mass index, age, and insulin concentrations in normal children and

are markedly increased in Prader-Willi Syndrome. JCEM 88, 174—178, http://dx.doi.org/10.1210/jc.2002-021052.

Herrmann, E., Call, J., Hernàndez-Lloreda, M.V., Hare, B., Tomasello, M., 2007. Humans have evolved specialized skills of social cognition: the cultural intelligence hypothesis. Science 317, 1360—1366, http://dx.doi.org/10.1126/science.1146282.

Kiecolt-Glaser, J.K., Christian, L., Preston, H., Houts, C.R., Malarkey, W.B., Emery, C.F., Glaser, R., 2010. Stress, inflammation, and yoga practice. Psychosom. Med. 72, 113—121, http://dx.doi.org/10.1097/PSY.0b013e3181cb9377.

Kiecolt-Glaser, J.K., Christian, L.M., Andridge, R., Hwang, B.S., Malarkey, W.B., Belury, M.A., Emery, C.F., Glaser, R., 2012. Adiponectin, leptin, and yoga practice. Physiol. Behav. 107, 809—813, http://dx.doi.org/10.1016/j.physbeh.2012.01.016.

Klok, M.D., Jakobsdottir, S., Drent, M.L., 2007. The role of leptin and ghrelin in the regulation of food intake and body weight in humans: a review. Obes. Rev. 8, 21—34, http://dx.doi.org/10.1111/j.1467-789X.2006.00270.x.

Knutson, K.L., Spiegel, K., Penev, P., Van Cauter, E., 2007. The metabolic consequences of sleep deprivation. Sleep Med. Rev. 11, 163—178, http://dx.doi.org/10.1016/j.smrv.2007.01.002.

Koliaki, C., Kokkinos, A., Tentolouris, N., Katsilambros, N., 2010. The effect of ingested macronutrients on postprandial ghrelin response: a critical review of existing literature data. Int. J. Pept. 2010, e710852, http://dx.doi.org/10.1155/2010/710852.

Korkeila, M., Kaprio, J., Rissanen, A., Koskenvuo, M., Sorensen, T.I.A., 1998. Predictors of major weight gain in adult Finns: stress, life satisfaction and personality traits. Int. J. Obes. 22, 949—957, http://dx.doi.org/10.1038/sj.ijo.0800694.

Kristal, A.R., Patterson, R.E., Shattuck, A., Vizenor, N.C., 1999. Nutrient databases for food frequency questionnaires. In: Presented at the National Nutrient Databank Conference.

Kristenssson, E., Sundqvist, M., Astin, M., Kjerling, M., Mattsson, H., Dornonville de la Cour, C., Håkanson, R., Lindström, E., 2006. Acute psychological stress raises plasma ghrelin in the rat. Regul. Pept. 134, 114—117, http://dx.doi.org/10.1016/j.regpep.2006.02.003.

Le Roux, C.W., Patterson, M., Vincent, R.P., Hunt, C., Ghatei, M.A., Bloom, S.R., 2005. Postprandial plasma ghrelin is suppressed proportional to meal calorie content in normal-weight but not obese subjects. J. Clin. Endocrinol. Metab. 90, 1068—1071, http://dx.doi.org/10.1210/jc.2004-1216.

Leary, M.R., Cox, C.B., 2008. Belongingness motivation: a mainspring of social action. In: Gardner, W.L., Shah, J.Y. (Eds.), Handbook of Motivation Science. Guilford Press, New York, NY, pp. 27—40.

Licinio, J., Caglayan, S., Ozata, M., Yildiz, B.O., Miranda, P.B., de O'Kirwan, F., Whitby, R., Liang, L., Cohen, P., Bhasin, S., Krauss, R.M., Veldhuis, J.D., Wagner, A.J., DePaoli, A.M., McCann, S.M., Wong, M.-L., 2004. Phenotypic effects of leptin replacement on morbid obesity, diabetes mellitus, hypogonadism, and behavior in leptin-deficient adults. PNAS 101, 4531—4536, http://dx.doi.org/10.1073/pnas.0308767101.

Lutter, M., Sakata, I., Osborne-Lawrence, S., Rovinsky, S.A., Anderson, J.G., Jung, S., Birnbaum, S., Yanagisawa, M., Elmquist, J.K., Nestler, E.J., Zigman, J.M., 2008. The orexigenic hormone ghrelin defends against depressive symptoms of chronic stress. Nat. Neurosci. 11, 752—753, http://dx.doi.org/10.1038/nn.2139.

Maslow, A.H., 1968. Toward a Psychology of Being, 2nd ed. D. Van Nostrand, Oxford, England.

Mroczek, D.K., Stawski, R.S., Turiano, N.A., Chan, W., Almeida, D.M., Neupert, S.D., Spiro, A., 2013. Emotional reactivity and mortality: longitudinal findings from the VA normative aging study. J. Gerontol. B: Psychol. Sci. Soc. Sci., http://dx.doi.org/10.1093/geronb/gbt107.

Mundinger, T.O., 2006. Direct stimulation of ghrelin secretion by sympathetic nerves. Endocrinology 147, 2893—2901, http://dx.doi.org/10.1210/en.2005-1182.

Myers, M.G., Leibel, R.L., Seeley, R.J., Schwartz, M.W., 2010. Obesity and leptin resistance: distinguishing cause from effect. Trends Endocrinol. Metab. 21, 643—651, http://dx.doi.org/10.1016/j.tem.2010.08.002.

Ochi, M., Tominaga, K., Tanaka, F., Tanigawa, T., Shiba, M., Watanabe, T., Fujiwara, Y., Oshitani, N., Higuchi, K., Arakawa, T., 2008. Effect of chronic stress on gastric emptying and plasma ghrelin levels in rats. Life Sci. 82, 862—868, http://dx.doi.org/10.1016/j.lfs.2008.01.020.

Pagel, M., 2012. Evolution: adapted to culture. Nature 482, 297—299, http://dx.doi.org/10.1038/482297a.

Patterson, R.E., Kristal, A.R., Tinker, L.F., Carter, R.A., Bolton, M.P., Agurs-Collins, T., 1999. Measurement characteristics of the Women's Health Initiative food frequency questionnaire. Ann. Epidemiol. 9, 178—187, http://dx.doi.org/10.1016/S1047-2797(98)00055-6.

Perello, M., Sakata, I., Birnbaum, S., Chuang, J.-C., Osborne-Lawrence, S., Rovinsky, S.A., Woloszyn, J., Yanagisawa, M., Lutter, M., Zigman, J.M., 2010. Ghrelin increases the rewarding value of high-fat diet in an orexin-dependent manner. Biol. Psychiatry 67, 880—886, http://dx.doi.org/10.1016/j.biopsych.2009.10.030.

Pickett, C.L., Gardner, W.L., 2005. The social monitoring system: enhanced sensitivity to social cues as an adaptive response to social exclusion. In: Williams, K.D., Forgas, J., von Hippel, W. (Eds.), The Social Outcast: Ostracism, Social Exclusion, Rejection, and Bullying. Psychology Press, New York, pp. 213—225.

Raspopow, K., Abizaid, A., Matheson, K., Anisman, H., 2010. Psychosocial stressor effects on cortisol and ghrelin in emotional and non-emotional eaters: influence of anger and shame. Horm. Behav. 58, 677—684, http://dx.doi.org/10.1016/j.yhbeh.2010.06.003.

Raspopow, K., Abizaid, A., Matheson, K., Anisman, H., 2014. Anticipation of a psychosocial stressor differentially influences ghrelin, cortisol and food intake among emotional and non-emotional eaters. Appetite 74, 35—43, http://dx.doi.org/10.1016/j.appet.2013.11.018.

Rouach, V., Bloch, M., Rosenberg, N., Gilad, S., Limor, R., Stern, N., Greenman, Y., 2007. The acute ghrelin response to a psychological stress challenge does not predict the post-stress urge to eat. Psychoneuroendocrinology 32, 693—702, http://dx.doi.org/10.1016/j.psyneuen.2007.04.010.

Sánchez, J., Oliver, P., Picó, C., Palou, A., 2004. Diurnal rhythms of leptin and ghrelin in the systemic circulation and in the gastric mucosa are related to food intake in rats. Pflugers Arch — Eur. J. Physiol. 448, 500—506, http://dx.doi.org/10.1007/s00424-004-1283-4.

Shiiya, T., Nakazato, M., Mizuta, M., Date, Y., Mondal, M.S., Tanaka, M., Nozoe, S.-I., Hosoda, H., Kangawa, K., Matsukura, S., 2002. Plasma ghrelin levels in lean and obese humans and the effect of glucose on ghrelin secretion. JCEM 87, 240—244, http://dx.doi.org/10.1210/jc.87.1.240.

Solomon, M.B., Jankord, R., Flak, J.N., Herman, J.P., 2011. Chronic stress, energy balance and adiposity in female rats. Physiol. Behav. 102, 84—90, http://dx.doi.org/10.1016/j.physbeh.2010.09.024.

Subar, A.F., Thompson, F.E., Kipnis, V., Midthune, D., Hurwitz, P., McNutt, S., McIntosh, A., Rosenfeld, S., 2001. Comparative validation of the Block Willett, and National Cancer Institute food frequency questionnaires: the Eating at America's Table Study. Am. J. Epidemiol. 154, 1089—1099, http://dx.doi.org/10.1093/aje/154.12.1089.

Taheri, S., Lin, L., Austin, D., Young, T., Mignot, E., 2004. Short sleep duration is associated with reduced leptin, elevated

ghrelin, and increased body mass index. PLoS Med 1, e62, http://dx.doi.org/10.1371/journal.pmed.0010062.

Tooby, J., Cosmides, L., 1996. Friendship and the banker's paradox: other pathways to the evolution of adaptations for altruism. In: Runciman, W.G., Smith, J.M., Dunbar, R.I.M. (Eds.), Evolution of Social Behaviour Patterns in Primates and Man. Oxford University Press, New York, NY, pp. 119—143.

Torres, S.J., Nowson, C.A., 2007. Relationship between stress, eating behavior, and obesity. Nutrition 23, 887—894, http://dx.doi.org/10.1016/j.nut.2007.08.008.

Troisi, J.D., Gabriel, S., 2011. Chicken soup really is good for the soul: ''Comfort food'' fulfills the need to belong. Psychol. Sci. 22, 747—753, http://dx.doi.org/10.1177/0956797611407931.

Van Dongen, H.P.A., Vitellaro, K.M., Dinges, D.F., 2005. Individual differences in adult human sleep and wakefulness: Leitmotif for a research agenda. Sleep 28, 479—496.

Wansink, B., 2004. Environmental factors that increase the food intake and consumption volume of unknowing consumers. Annu. Rev. Nutr. 24, 455—479, http://dx.doi.org/10.1146/annurev.nutr.24.012003.132140.

Wardle, J., Chida, Y., Gibson, E.L., Whitaker, K.L., Steptoe, A., 2011. Stress and adiposity: a meta-analysis of longitudinal studies. Obesity 19, 771—778, http://dx.doi.org/10.1038/oby.2010.241.

Wrangham, R., 2010. Catching Fire: How Cooking Made us Human. Basic Books.

Wren, A.M., Seal, L.J., Cohen, M.A., Brynes, A.E., Frost, G.S., Murphy, K.G., Dhillo, W.S., Ghatei, M.A., Bloom, S.R., 2001. Ghrelin enhances appetite and increases food intake in humans. JCEM 86, 5992, http://dx.doi.org/10.1210/jc.86.12.5992.