J Behav Med (2008) 31:249–257
DOI 10.1007/s10865-007-9143-2

Social integration of daily activities and cortisol secretion: a laboratory based manipulation

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Accepted: November 28, 2007 / Published online: 21 December 2007

Abstract A diverse body of literature suggests that social contacts have direct regulatory influences on biological rhythms such as the diurnal cortisol decline. Although our previous prospective research has found a link between social contacts and cortisol secretion, a manipulation of social contacts is necessary to definitively evaluate causality. The current study involved a laboratory-based manipulation of daily social contacts. Fifty-three females experienced both high and low social contact conditions in the lab while collecting ambulatory data on their social contact and cortisol levels. Data were analyzed using hierarchical linear modeling, such that cortisol production on high social contact days was compared within person to cortisol production on low social contact days. Although the manipulation successfully altered daily social contacts, it had no significant effect on cortisol slope. However, cortisol slope differences were significant when participants had contact with someone whom they usually saw every day. Social relationships that provide daily contact may have the strongest influence on biological rhythms.

Keywords Social integration · Social contact · Daily activities · Diurnal cortisol slope · HPA axis

Social integration is a structural measure of social support and is an important predictor of well-being and health status. Greater social integration, in the form of more diverse social networks, has been associated with reduced disease and increased longevity (Berkman and Syme 1979; House et al. 1988). Typically in this literature, social integration is measured broadly, in terms of a person's overall number of social relationships, diversity of social ties, or strength of individual ties. This is appropriate because the health outcomes examined are broad, such as disease risk or mortality rates. However, social integration could also be measured on a day to day basis, such as social contact during routine daily activities. Conceptualizing social integration in this way would permit an examination of potential mechanisms i.e. day to day physiological processes that have known links to health.

Several explanations for the influence of social ties on health have been explored (Uchino et al. 1996; Cohen et al. 2000). According to Thoits (1983), social integration fosters a greater sense of self-worth and stronger sense of identity, as well as providing expectations for appropriate behavior. Additionally, the presence of social relationships such as a spouse has been linked to improved health behaviors such as diet and exercise that have known implications for health (Kiecolt-Glaser and Newton 2001). The idea that social ties may have a direct effect on physiology (apart from health behaviors) has been relatively unaddressed, despite the theoretical support that exists for such an effect. In the early days of life, maternal proximity and behavior regulates the activity of multiple bodily systems such as the nervous, cardiovascular and digestive systems (Polan and Hofer 1999). Just as the nature of and expectations formed from early social contacts are thought to remain throughout development as templates for future social relationships, the regulatory function of these early contacts may also be maintained as the organism develops, allowing it to be physiologically responsive to its social environment. A high level of responsiveness may benefit the organism by maximizing adaptation to social conditions.

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We have proposed that social relationships, and the daily social integration that those relationships provide, have direct regulatory influences on the rhythms of hormonal systems that are important for health. The extent to which one's social network can provide direct social contact may be an important determinant of its health effects via these regulatory effects on hormones. Although Hofer (1984) made the case that maternal social contacts have a profound influence on the infant's ability to regulate physical functioning based on animal studies, few studies have specifically examined the influence of social contact on physiological rhythms in humans. In 1971, Aschoff et al. found that social contacts were sufficient to maintain circadian rhythms (including hormone production) in a group of participants housed together in a lab without light/dark cues. While this result supports the idea that social contacts can regulate hormonal rhythms in a highly controlled lab environment, little is known about whether this is also the case when hormonal rhythms are measured in the real world. Given what is known about the health consequences of disrupted circadian rhythms (e.g. Moore-Ede and Richardson 1985), the ability of social contacts to influence the rhythms of hormone production may represent an important but unexplored pathway for the effect of social relationships on health outcomes.

Our previous research provides support for the idea that social contacts regulate hormone secretion across the day (Stetler et al. 2004; Stetler and Miller 2005). In two studies we found that having higher levels of social contact was associated with either a steeper decline in cortisol production across the day (Stetler et al. 2004) or a higher morning rise in cortisol (Stetler and Miller 2005). This pattern of high morning cortisol levels with a rapid decline throughout the day reflects more normative HPA axis function and has been associated with lower disease risk factors (Matthews et al. 2006; Rosmond and Bjorntorp 2000). Most recently, we were able to refine our understanding of the relationship between daily social contacts and cortisol (Stetler and Miller submitted) by addressing the issue of directionality. Social contacts predicted cortisol secretion not only on the same (concurrent) day, but on the subsequent day as well. Cortisol slope did not predict future social contact, indicating that the direction of the relationship went from social contact to cortisol and not in the opposite direction. Results of this study support the idea that social contacts regulate cortisol secretion in a way that is likely to be health-promoting. Of interest, social contact during routine daily activities predicted cortisol where total number of daily social interactions did not. This suggests that cortisol is responsive to having others involved in one's daily activities, and not simply having large numbers of social contacts over the day.

Although the direction of the effect is consistent with our model of how social contact affects health, an experimental manipulation is necessary to convincingly eliminate alternative explanations involving third variables. For example, it is possible that dispositions such as loneliness influence (or are influenced by) both the kind of daily social contact a person has and his/her rhythm of cortisol output (Cacioppo et al. 2000). The primary goal of the current study was to develop a manipulation of daily social contacts that was informed by the results of previous research. Because our previous research demonstrated that social interaction during daily activities was the better predictor of daily cortisol secretion (above and beyond the absolute number of daily social interactions), we chose to manipulate whether a specific daily activity was done with another person or alone. The current study varied the social contact involved in eating lunch, from one day to the next. Lunch was selected as the focus of the manipulation for two reasons: Data from previous research with the sample (Stetler and Miller, submitted) suggested that the majority of participants ate lunch as a part of their daily routine, and lunch was an activity whose social context could reasonably be altered in a controlled laboratory setting.

We reasoned that if social contact regulates hormonal output in a causal fashion, days that included eating lunch with another person should be accompanied by steeper diurnal cortisol slopes, compared to days that included eating lunch alone. Finally, the current study assessed whether characteristics of the lunch partner influenced the effect of the manipulation. These characteristics included the relational identity of the lunch partner (close friend, family member, or romantic partner versus roommate or classmate/acquaintance), relationship length, frequency of contact, and level of intimacy or closeness. We reasoned that lunch partners with whom participants had longer or more intimate relationships or who saw the participants more frequently would have a greater influence on diurnal cortisol secretion compared to lunch partners that had shorter, less frequent, or less intimate relationships to the participants.

Methods

Participants

Fifty-three female participants were recruited from the student population at the University of British Columbia through flyers placed on campus. After the details of the study were explained, interested participants were scheduled for an initial lab appointment. This study's protocol was approved by the University of British Columbia's Behavioral Research Ethics Board. All participants gave

written informed consent prior to participating in the study. Next, participants completed a screening tool to determine study eligibility (modified version of the Patient Health Questionnaire module of the PRIME-MD; Spitzer et al. 1999). Potential participants were excluded from the study if they endorsed the presence of a chronic illness, acute infection, recent or current pregnancy, or use of medications that affect the HPA axis (not including oral contraceptives). Participants were also excluded from the study if they met diagnostic criteria for major depression, panic disorder, drug or alcohol abuse, generalized anxiety disorder, anorexia or bulimia based on the PRIME-MD screening. One potential participant was excluded due to these reasons. All participants were required to speak, write and understand English. Participants received monetary compensation for participating in the study.

Protocol

When eligible participants came to the laboratory for a first visit, they completed demographics and depressive symptom questionnaires and were trained on ambulatory data collection methods. Prior to the laboratory-based manipulation, participants collected baseline data: 4 days of ambulatory data collection during which they recorded information about their daily social contacts and collected saliva samples using the measures and methods described below. Data from this phase of the study have been reported elsewhere (Stetler and Miller submitted). No manipulation was employed during this baseline phase, and the data are referred to here for comparison purposes only. See Table 1 for a timeline of the data collection protocol during the manipulation.

Ambulatory data collection

Each participant was lent a Palm Pilot that served not only as an alarm to prompt saliva collections, but also as a device for data collection (Palm M100; Palm Inc., New York). During the manipulation, participants collected data on 6 days total. Each day, participants set the alarm on the computer to act as their morning alarm. They were told to maintain their normal wake-up time. Palm Pilots were programmed to sound an alarm when the participant awoke, and at 1 h, 4 h, 9 h and 14 h later. This procedure has been used in previous studies and has been shown to capture the diurnal pattern of cortisol production without placing undue burden on the participants (MacArthur Research Network on SES and Health 2000). For example, if a participant woke up at 7 AM, then the Palm Pilot was programmed to go off at 7 AM, 8 AM, 11 AM, 4 PM and 9 PM.

The computer alarm prompted participants to collect a saliva sample using a Salivette (Sartstedt Inc, Germany), a cotton dental roll within a sterile plastic tube. Participants placed the cotton roll in their mouths for approximately one minute in order to saturate it with saliva. The cotton roll was then returned to the plastic tube. The tube was capped tightly until returned to the lab. One tube was used at each saliva collection. It has been established that salivary cortisol concentrations are stable at room temperature (Clements and Parker 1998). The handheld computer also briefly displayed a unique 3-digit code that the participant was instructed to record. Proper recording of this code indicated that the saliva collection was done at the correct time. The Palm Pilot also stored the time that participants responded to each code. This time was used to determine the actual number of minutes since awakening that the saliva sample was obtained and thus served as a useful way to evaluate participant compliance with the sampling protocol.

Total daily social contact

On each of the six study days, at 1 h, 4 h, 9 h and 14 h after waking up, participants were asked to report whether or not they had a social interaction (defined as an important social exchange usually lasting at least several minutes) in the previous hour or since responding to the Palm Pilot, and if so, how many interactions occurred. This information was used to calculate the total number of social interactions that occurred each day. We left it up to participants to determine what constituted an important interaction, although we did suggest to them that it would typically have some sort of influence on them (i.e. more that just buying a cup of coffee and getting the change).

Table 1 Timeline of study protocol

	Experimental manipulation phase (counterbalanced order)					
	Friend condition			Alone condition		
	Day 1	Day 2	Day 3	Day 9	Day 10	Day 11
Lunch in lab	X	X		X	X	
Social Rhythm Metric	X	X	X	X	X	X
Salivary cortisol samples	X	X	X	X	X	X

X = participant performed/ completed this activity

Social integration of daily activities

In order to assess the level of social integration in each participant's daily activities, participants completed the Social Rhythm Metric (SRM; (Monk et al. 1990) at the final time point (14 h after waking) each day. The SRM assesses whether or not each of 14 given activities occurred for them that day (e.g. eating lunch, going to work/school, exercising, watching TV), and whether or not other people were present or involved when the activity occurred. For each day's activities, the level of social integration was calculated based on the ratio of activities done with other people to total activities done each day. Scores on this index could range from 0 to 1, with higher scores indicating more socially integrated daily activities.

Experimental manipulation of daily social contacts

Participants were asked to eat lunch in the lab, either by themselves (two consecutive days) or with another person (two consecutive days). Participants continued to collect saliva samples and information about their social interactions and daily activities as described above. Conditions were separated by a minimum of 5 days. Lunches were generally scheduled between 10 AM and 3 PM each day; the exact time varied according to participants' availability. Ambulatory data collection occurred on all four "lunch in the lab" days, and on the one day immediately following each condition, for a total of 6 days (see Table 1).

During one condition (labeled *friend condition*), participants were asked to bring someone in to the lab to eat lunch with them (a friend, romantic partner, roommate or relative). Participants could bring anyone they chose but were asked to bring the same person each day. Under the other condition (labeled *alone condition*), participants were asked to eat lunch in the lab alone. Conditions were scheduled in counterbalanced order across participants. At each appointment, participants (and their lunch partners, where applicable) were seated in a quiet lab room and offered something to eat and drink. While meal contents were not identical across participants or across days, low-protein meals such as vegetable soup and crackers or pastries stuffed with vegetables were offered at each visit. Meals high in protein have been shown to cause an acute increase in cortisol levels (Slag et al. 1981) which could have been inadvertently captured by one of the daily salivary cortisol samples. The door to the room was then closed, and participants (and lunch partners, when present) remained in the room for 1 h. Participants were asked not to use cell phones, email, or IM/text messaging devices during the lunches.

Lunch partner characteristics

At the end of the hour on one of the friend condition days, participants completed a brief questionnaire about their lunch partner. This questionnaire asked how long the participant had known the person accompanying her, how many times during an average week the participant had contact with this person, and how long the average contact lasted. Participants were also asked to classify the person accompanying them as one of the following: friend, best friend, roommate, romantic partner, sibling, classmate/coworker, or acquaintance. Finally, participants answered five items regarding the level of closeness/intimacy in the relationship. An example of an item is "How much do you confide in this person?" Items were answered on a 1–7 scale, with higher scores indicating more intimacy/closeness in the relationship. Cronbach's alpha for these five items in the current sample was $\alpha = 0.80$.

Cortisol samples

After they were returned to the laboratory, saliva collection containers were centrifuged for five minutes at $750 \times g$ until a clear, low-viscosity supernatant emerged. The supernatants were then collected and frozen at –30°C until the end of the data-collection sequence. Cortisol assays were performed in duplicate using a commercially available chemiluminescence assay (IBL, Hamburg, Germany). This assay has a sensitivity of 0.16 ng/ml. The intra-assay coefficient of variation was 4.74%; the inter-assay coefficient of variation was 6.56%. Levels of cortisol in saliva have been shown to be highly correlated with levels in plasma (Kirschbaum and Hellhammer 1989) and represent a better measure of the biologically active cortisol available in the body compared to cortisol levels in plasma (Vining et al. 1983).

Assessing HPA axis function

Each day's data was used to create an index that represents the change in cortisol secretion across the day. The diurnal pattern of cortisol secretion was computed as a linear slope measure, with salivary cortisol values at each timepoint regressed on the number of hours since awakening. In order to better model the curvilinear diurnal rhythm as a linear slope, we computed slopes based on log transformed cortisol values. Five (log-transformed) cortisol values per day were regressed on the actual time since waking (in hours) that the sample was collected according to the Palm Pilot codes. Higher (less negative) values indicate a flatter diurnal cortisol slope, while lower (more negative) values indicate a steeper diurnal cortisol slope.

Data analysis[1]

Estimates of the within-person association between each manipulation condition and cortisol slope were generated using hierarchical linear modeling (HLM; Bryk and Raudenbush 1992). HLM is appropriate for handling nested data such as ours and is able to deal with repeated-measures designs and to efficiently model missing data. Because measurements collected from the same individual at different points in time are often correlated and have correlated error terms (thus violating the assumption of independence), we took advantage of HLM's ability to model dependence in the data. We conducted our analyses two ways: using an autoregressive error structure (meaning that data on day 1 were correlated most highly with data from day 2, less strongly with data from day 3, even less from day 4, and so forth) and using the standard homogenous error structure (meaning that data are correlated consistently across days). We performed the analyses using both types of error structures, and obtained identical results for the variables of interest. Thus, we report below outcomes with the simpler homogenous structure.

Assessing effect of social rhythm manipulation

Manipulation check

Each measure of social contacts (number of social interactions or social integration of daily activities) was modeled as a function of manipulation condition using planned contrasts (see below). Social contact scores should be higher during the 'high social contact' condition compared to the 'low social contact' condition. Social contact scores during each of these conditions were also compared to the social contact scores during the pre-manipulation baseline phase in order to determine which condition represented a change for the participant. That is, either the high social contact condition represented an increase from baseline for a given participant, or the low social contact represented a decrease from baseline. Validity of the manipulation was supported if social contact scores are greater during the high social contact condition compared to the low social contact condition, and if either of those conditions represents a change from social contact scores across the baseline phase.

[1] We repeated our analyses using a 3-level HLM. The results were unchanged: cortisol slope was not significantly different between manipulation conditions, while daily contact remained a significant moderator of the manipulation's effect ($P < 0.05$). Because diurnal cortisol slope, and not cortisol level at any one particular point in time is the outcome of interest, and because a 2-level model is a more parsimonious way to model the data (i.e. requires fewer parameter estimates), we chose to report results from the 2-level model.

$$\text{Level one: } Y_{ij}\,(\text{Socialcontacts}) = \beta_{0j} + \beta_{1j}\,(\text{Condition contrast code}) + \varepsilon_{ij}$$

$$\text{Level two: } \beta_{0j} = \gamma_{00} + \upsilon_{0j}$$
$$\beta_{1j} = \gamma_{10} + \upsilon_{1j}$$

Effect on cortisol rhythms

These models are similar to those for the manipulation check except that now cortisol slope is the dependent variable. Cortisol slope was modeled as a function of social contact condition (a within-subjects variable) using planned contrasts. Two sets of contrasts were made. First, cortisol during the high social contact condition was compared to cortisol during the low social contact condition. We expected that during the high social contact condition, cortisol slopes will be steeper (more negative) compared to the low social contact condition.

$$\text{Level one: } Yij\,(\text{Cortisol slope}) = \beta_{0j} + \beta_{1j}\,(\text{Condition contrast code}) + \varepsilon_{ij}$$

$$\text{Level two: } \beta_{0j} = \gamma_{00} + \upsilon_{0j}$$
$$\beta_{1j} = \gamma_{10} + \upsilon_{1j}$$

Here β_{1j} is the difference in cortisol slope between manipulation conditions for participant j. Each of the three days of each condition are coded the same and thus averaged within participant. Meanwhile, ε_{ij} represents the within-person residual parameter (i.e., the difference between an individual's own mean slope across all other days and their cortisol slope during that condition). A significant β_1 term indicates that the difference in cortisol slope between manipulation conditions is non-zero. Subsequent models using dummy codes are then computed to examine the cortisol slope means for each condition. We predicted that cortisol slope should be significantly steeper (more negative) during the high social contact condition compared to the low social contact condition.

We also conducted lagged analyses, where we modeled the relationship between social contact condition and the following day's cortisol slope. We expected that on the day following the high social contact condition, cortisol slope will be steeper (more negative) compared to the day following the low social contact condition.

Characteristics of the lunch partner

Participants were free to bring in whomever they liked in to the lab during the high social rhythm condition. We modeled whether differences in lunch partners across

participants moderates the effect of the manipulation by including type of relationship, duration, frequency of contact or level of closeness in Level 2 of the model.

$$\text{Level one: } Y_{ij}\,(\text{Cortisol slope}) = \beta_{0j} + \beta_{1j}\,(\text{Condition contrast code}) + \varepsilon_{ij}$$

$$\text{Level two: } \beta_{0j} = \gamma_{00} + \gamma_{01}\,(\text{Duration}) + \upsilon_{0j}$$
$$\beta_{1j} = \gamma_{10} + \gamma_{11}\,(\text{Duration}) + \upsilon_{1j}$$

Results

Manipulation check

Given the results of previous studies (Stetler and Miller submitted), we intended the manipulation to alter social integration of daily activities, but not necessarily the total number of social interactions each day. We hypothesized that daily social integration scores would be higher during the friend condition compared to the alone condition, confirming that the manipulation of social involvement in daily activities did indeed work. Social integration scores did vary by condition. Participants reported an average daily social integration score of .50 (SE = 0.03) during the alone condition and .59 (0.03) during the friend condition. Contrast analyses indicate that the average difference in social integration between alone and friend condition days was 4% (SE = 0.009, $t(513) = 4.56$, $p < 0.001$). This small but significant difference is consistent with a manipulation that attempted to alter social integration during one (lunch) of many possible daily activities. The manipulation did not significantly influence the total number of daily social interactions that participants reported ($p > 0.17$).

We were interested in exactly how the manipulation altered social integration, i.e. whether having lunch with a friend was an increase relative to usual baseline or if having lunch alone was a decrease relative to usual baseline (data collected prior to manipulation). Comparing social integration scores during the friend and alone conditions to social integration scores across three baseline days allowed us to examine this question. Across all three baseline days of data collection prior to the manipulation phase, the average social integration score was 0.57 (0.03), which is not significantly different from social integration during the friend condition (0.59, $p > 0.6$). However, social integration during baseline was significantly different compared to the alone condition (average difference 3% (SE = 0.01, $t(513) = 2.67$, $p < 0.01$). Overall, asking participants to eat lunch alone seemed to take away a social interaction that would usually occur, while asking them to eat lunch with a friend maintained their usual pattern of social contact. However, each participant experienced the manipulation differently; for some it was an increase in social contacts relative to normal, for others, a decrease. Because we are primarily interested in within-subjects effects, we do not distinguish the direction of the change in social integration scores.

Influence of manipulation on cortisol secretion

We next asked whether cortisol slope would vary by manipulation condition. The hypothesis was that there would be a significant difference in cortisol slope between the friend and alone conditions, such that cortisol slope would be steeper (more negative) during the friend condition compared to the alone condition. The average cortisol slope during the friend condition was –0.11 (0.01), while the average slope during the alone condition was also –0.11 (0.01). This was not a significant difference ($p > 0.7$). Thus, although the manipulation successfully altered social integration, it did not have an effect on that day's cortisol slope.[2] Furthermore, the manipulation did not predict the following day's cortsiol slope after controlling for current day's cortisol ($\beta_{1j} = -0.002$, SE = 0.01, $t(52) = -0.20$, $p = 0.84$). Another possibility is that the effect of the manipulation may not be fully realized for a while, so including the first day's cortisol slope as an outcome may be diluting the social contact effect. Even when this day was removed from analyses, however, there were still no differences in cortisol slope between the friend and alone conditions ($\beta_{1j} = -0.005$, SE = 0.01, $t(52) = -0.61$, $p = .55$).[3]

Lunch partner characteristics

Participants were free to choose their lunch partner during the friend condition. Because we were interested in whether one's choice of lunch partner during the friend condition influenced cortisol slope, we assessed whether differences in the type of relationship that the participants

[2] Although less consistent with our overall hypothesis about the regulatory effect of social contacts on the diurnal rhythm of cortisol secretion, we also examined the effect of the manipulation on total daily cortisol production and daily area under the curve. Those analyses did not yield any significant effects.

[3] Because previous studies have shown that daily social contact and cortisol output rhythms become uncoupled in episodes of clinical depression (Stetler et al. 2004; Stetler and Miller 2005), we wondered if high levels of depressive symptoms may have muted the effect of our manipulation. The data did not support this explanation: the severity of depression symptoms (CESD score) did not predict cortisol responses to the manipulation ($\gamma_{1j} = -0.001$, SE = 0.001, $t(50) = -1.00$, $p = 0.32$).

had with their lunch partners moderated the effect of the manipulation on cortisol slope.

The majority of participants (n = 28) brought someone they classified as a friend in to the lab for lunch. Eight participants brought a sibling, six participants brought a best friend, four brought a roommate, four brought a romantic partner, and one brought a classmate/coworker. Because there were insufficient numbers in each category to perform specific contrasts, we grouped the participants into two groups based on their lunch partner; participants who brought in lunch partners that were closer relationships such as best friends, siblings or romantic partners (n = 18) were compared to participants who brought in partners who were perhaps more distant such as friends, roommates or classmates (n = 33). When the difference in diurnal cortisol slopes between the alone and friend conditions were compared for each group, no significant differences were found (γ_{1j} = –0.011, SE = 0.015, t(48) = –0.72, p = 0.48). The type of relationship that participants had with their lunch partners did not influence cortisol slope, based on this crude grouping of relationship categories.

Participants varied widely in the number of months they had known their lunch partners. The average participant had known her lunch partner for 40.9 (SD = 60.2) months, but relationships ranged from 1 to 252 months old. Because this variable was not normally distributed, it was natural log-transformed prior to analysis. The length of relationship was not a significant moderator of the manipulation's effect on cortisol slope (γ_{1j} = 0.003, SE = 0.005, t(48) = 0.69, p = .50).

Participants were also asked how often they saw their lunch partners in an average week. Answers ranged from 0 to 30 times per week, with an average rate of 6.12 (SD = 5.13) times per week. Because this variable was not normally distributed, it was natural log-transformed prior to analysis. Although the amount of weekly contact was not a significant moderator of the manipulation's influence on cortisol slope (γ_{1j} = –0.001, SE = 0.0009, t(47) = –1.57, p = 0.12), whether or not the participant reported daily contact with the lunch partner was (γ_{1j} = –0.027, SE = 0.014, t(48) = –1.95, p = 0.05). That is, participants who had daily contact with their lunch partners had steeper slopes in the friend condition (–0.13) compared to the alone condition (–0.10), while participants who did not see their lunch partners on a daily basis had steeper slopes during the alone condition (–0.12) compared to the friend condition (–0.09) (see Fig. 1).

Participants also rated the level of closeness or intimacy present in their relationship with their lunch partner. The average score on this five-item measure was 27.2 (SD = 4.8; range: 16–34). Level of closeness was not a significant predictor of the manipulation's effect on cortisol

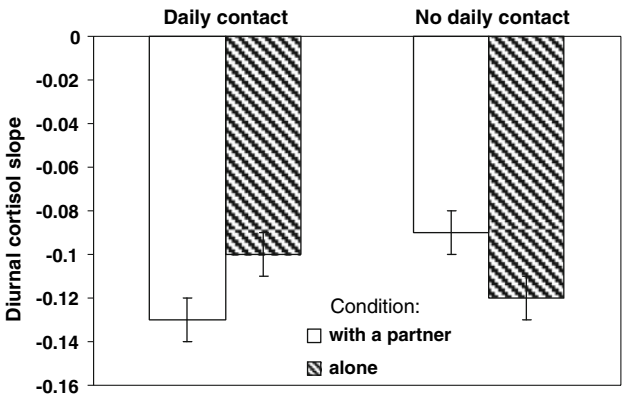

Fig. 1 Mean diurnal cortisol slope during each manipulation condition is moderated by daily contact with lunch partner (yes/no)

(γ_{1j} = –0.001, SE = 0.002, t(47) = –0.57, p = 0.57). Thus, participants who reported a higher-than-average degree of closeness with their lunch partners did not have any greater change in their cortisol slopes during the friend condition compared to participants who reported lower-than-average levels of closeness. Including level of closeness in the model with relationship length and daily contact did not change this result. It appears that quantitative aspects of the relationship such as level of contact were more predictive of changes in cortisol slope than qualitative aspects of the relationship, such as level of closeness or intimacy.

Discussion

The goal of the current study was to develop and evaluate a manipulation of daily social contact, so we could determine whether it has a causal influence on the rhythms of cortisol secretion. Although the manipulation was not associated with a change in the diurnal pattern of cortisol secretion, we did learn potentially important information about what types of social contact might have the greatest capacity to act in such a regulatory fashion. Lunch partners with whom participants typically have daily contact were associated with the biggest changes in cortisol slope across manipulation conditions.

Manipulation of social contact

In designing the manipulation of social contact, we attempted to balance the need for control over the manipulation with the desire to make the manipulation mimic participants' daily lives as much as possible. Thus, we continued to use ambulatory methods of data collection while asking participants to take part in a lab-based manipulation. We wanted to make the manipulation as minimally disruptive as possible, in order to maximize

subject participation, while maintaining as powerful a manipulation as we could. Thus we chose to manipulate the social environment in which participants consumed their lunches. Of all the daily activities assessed with the daily diary measures, lunch seemed the most feasible to re-create in a laboratory setting given our sample of university students.

The results suggest that we were successful in altering the level of social integration of our participants' daily activities. Social integration scores were significantly greater on days when participants ate lunch in the lab with another person compared to days when they ate lunch alone. The small but statistically significant change in social integration score is consistent with the fact that the manipulation changed only 1 out of 14 daily activities assessed by our inventory. Notably, the total amount of daily social contact was not altered by the manipulation. The fact that this variable was not affected by the manipulation may indicate that when participants ate lunch by themselves, they moved their usual lunch-time social interactions to other times during the day. As there were no significant differences in the number of daily social contacts on usual baseline days and days when participants ate lunch in the lab by themselves, we suspect that participants were able to maintain their normal levels of social contact despite eating lunch alone in a lab.

Effect of laboratory manipulation on cortisol production

Because we were able to show that the manipulation altered at least one measure of social contact (social integration score), we then tested whether the manipulation influenced cortisol secretion. We hypothesized that diurnal cortisol slopes would be steeper on days when participants ate lunch with a friend and flatter on days when they ate lunch by themselves. However, we found no significant differences in cortisol slope between manipulation conditions. Neither did we find differences when we looked at cortisol slope on the days after each manipulation condition.

We do not believe that these null findings reflect a lack of statistical power, as associations between similar variables were detected with data from the baseline phase, which included approximately the same number of participants and fewer total days of data collection (Stetler and Miller submitted). Measurement unreliability is not a likely cause of the null findings here. Associations among these variables measured in the same manner have been shown in previous studies as well as in the baseline phase of the study (Stetler and Miller submitted). Although previous research (Stetler et al. 2004; Stetler and Miller 2005) showed that higher levels of depressive symptoms reduced the association between social contacts and cortisol production, including participants with some amount of depressive symptoms does not appear to be the reason why our manipulation of social contacts had no significant effect on cortisol slope.

The manipulation's effect on cortisol was strongest when participants chose a lunch partner with whom they had daily contact. When a participant chose an individual whom they see on a daily basis as a lunch partner, their cortisol slopes were steeper during friend condition and flatter during alone condition. Given our conceptualization of steeper cortisol slopes as indicating better HPA axis function compared to flatter cortisol slopes, this finding lends support to the hypothesis that daily social contacts to some extent drive daily cortisol secretion. When an individual whom a participant normally sees every day is removed (during the alone condition), cortisol slope flattens, suggesting weaker HPA axis regulation. These findings suggest that contact with the same person every day stabilizes biological rhythms; that is, regular social contacts act as zeitgebers that entrain healthy patterns of cortisol output. A zeitgeber is a factor in the external environment that helps to synchronize endogenous circadian processes. These results should be interpreted with caution, however, because we were unable to replicate the effect when frequency of contact was measured continuously rather than dichotomously. Although we acknowledge that this finding could be an artifact of artificially dichotomizing a continuous variable, conceptual reasons for such a dichotomy exist. In order to act as zeitgebers, social contact with a given person needs to occur at least once a day, but above that threshold, additional contact with the same person may not enhance the zeitgeber function. That is, stabilization of biological rhythms may be finite, such that additional zeitgebers (such as social contact) do not result in additional stabilization.

When a participant chose to eat lunch with someone whom she did not typically see every day, the effects on cortisol slope were reversed. Slopes were steeper when participants ate lunch alone in the lab, and flatter when they ate lunch with a partner. This could reflect a stress response from the novelty of spending time with someone not seen recently. We do not think this effect is likely for two reasons. First, the order of the manipulation conditions was counterbalanced across participants. Second, although having lunch with a person of one's choice may be physiologically stimulating in a positive way, we do not believe it would be accurately described as stressful. We would not expect participants to invite someone to lunch who they did not enjoy spending time with. A recent meta-analysis of the cortisol and acute stress literature (Dickerson and Kemeny 2004) found that situations involving motivated performance, social-evaluative threat and uncontrollability produced the largest, most reliable increases in cortisol. We do not believe that our manipulation included any of those

components. Nonetheless, this "new" person was a change in the participant's usual routine and thus may have perturbed the participant's cortisol slope, working against any stabilizing influence that the social contact during lunch offered. Future studies could assess which individual(s) a participant sees every day (or most frequently) and compare cortisol slope on days when the participant sees this person and days when s/he does not. Those studies could then manipulate contact with that particular person in order to maximize the power of a similar manipulation.

Another way to increase the potency of the manipulation would be to extend its duration. One limitation of the study's manipulation was that participants were only exposed to each condition for one hour a day for two days. This may not have been long enough to produce immediate changes in cortisol slope. In addition, when participants ate lunch by themselves in the lab, they may have compensated for that missed social interaction by seeking social involvement in other daily activities. A manipulation of social contact involving more if not all of one's daily activities would be more likely to produce an effect on cortisol. This would be easily accomplished by isolating participants in a lab during the day, but that would reduce the ecological validity of the manipulation. Future studies should continue to undertake the challenge of designing a well-controlled manipulation that is representative of normal daily experiences yet powerful enough to affect physiology.

In order to conclusively examine the issue of causality and extend previous research, we conducted a manipulation of daily social environment that proved to be of some success. We were able to produce changes in social integration of daily activities. Although these changes in social integration were not associated with changes in diurnal cortisol slope for all participants, we did succeed in altering cortisol production in some people. These people were those who brought in a lunch partner that they had regular daily contact with. This finding gives us some insight in to what relationships are most important for cortisol production and offers some exciting ideas for future studies.

Acknowledgements Preparation of this manuscript was made possible by NIH Grant Number P20 RR–016461 from the National Center for Research Resources (CAS). The authors would like to acknowledge financial support from the Human Early Learning Partnership at UBC (CAS, GEM) and the Canadian Institute of Health Research (GEM). We would also like to thank Nicolas Rohleder, Jane Woo, Adeline Sawsurachai, Jennifer Munch, Shivani Nair, Khrystyna Savchuk, Erica Bennett and Kim Johnson for their assistance on the project.

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