UCD GEARY INSTITUTE DISCUSSION PAPER SERIES

The Role of Awakening Cortisol and Psychological Distress in Diurnal Variations in Affect: A Day Reconstruction Study

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Text word count: 5,270; Abstract word count: 213; References: 47; Tables: 2; Figures: 3

Abstract

People often feel unhappy in the morning but better later in the day, and this pattern may be amplified in the distressed. Past work suggests that one function of cortisol is to energize people in the mornings. In a study of 174 students we tested to see if daily affect patterns, psychological distress, and awakening cortisol levels were interlinked. Affect levels were assessed using the Day Reconstruction Method (Kahneman, Krueger, Schkade, Schwarz, & Stone, 2004) and psychological distress was measured using the Depression Anxiety Stress Scales (Antony, Bieling, Cox, Enns, & Swinson, 1998). On average positive affect increased markedly in a linear pattern across the day whilst negative affect decreased linearly. For the highly distressed this pattern was stronger for positive affect. Lower than average morning cortisol, as assessed by two saliva samples at waking and two samples 30 minutes after waking, predicted a clear increasing pattern of positive affect throughout the day. When we examined the interlinkages between affect patterns, distress, and cortisol our results showed that a pronounced linear increase in positive affect from morning through to evening occurred chiefly among distressed people with below average cortisol levels upon awakening. Psychological distress, whilst not strongly associated with morning cortisol levels, does appear to interact with cortisol levels to profoundly influence affect.

Keywords: Cortisol, Psychological Distress, Positive Affect, Diurnal Variation, Day Reconstruction Method

Introduction

For some people the morning alarm clock invokes feelings of enthusiasm, but for others feelings of apathy in the morning are commonplace. Distressed people and people with an evening preference often experience low positive affect in the morning relative to the evening (Peeters, Berkof, Delespaul, Rottenberg, & Nicolson, 2006; Jankowski & Ciarkowska, 2008). Prior research suggests a potential biological basis for morning affect patterns in cortisol, a major glucocorticoid hormone, which amongst other things functions to mobilize energy resources (Boksem & Tops, 2009). In this study, we predicted that deficient morning cortisol levels may, at least partially, explain low positive affect levels in the morning relative to the evening and why distressed people often do not feel energized towards a positive start to the day.

Diurnal Variation of Affect

Numerous studies have found positive affect to rise substantially throughout the day whereas negative affect has not yet demonstrated a robust diurnal pattern (Clark, Watson, & Leeka, 1989; Egloff, Tausch, Kohlmann, & Krohne, 1995; Hall, Spear, & Stirland, 1964; Murray, 2007; Stone, Schwarz, Schkade, Schwarz, Krueger, & Kahneman, 2006). This change in positive affect over the course of a single day has been proposed to be best represented by several models including a quadratic waveform (e.g. Murray, 2007), a bimodal pattern (Stone et al., 2006), and a linear relationship (Egloff et al., 1995). Whilst environmental factors appear to impact substantially on diurnal affect patterns (e.g. Stone et al., 2006), certain groups consistently experience more pronounced trends in affect than others and this may have a biological basis. For example, there is particularly strong evidence that the affect levels of people with depression improve substantially throughout the day (e.g. von Zerssen et al., 1985; Peeters et al., 2006). Not only do depressed people often feel worse in the morning they also tend to dislike the early hours of the day regarding themselves as evening-types (Hirata, Lima, de Bruin, Nobrega, Wenceslau, & de Bruin, 2007; Hidalgo, Caumo, Posser, Coccaro, Camozzato, & Chaves, 2009). This morning-worse pattern is characterized by poor concentration and low positive affect in the morning that transitions into greater alertness and more intense positive feelings later in the day (e.g. after 5pm) (Jankowski & Ciarkowska, 2008).

It has been suggested that such circadian rhythms are blunted in various forms of distress and in evening types, particularly rhythms which are regulated by brainstem and hypothalamic areas (Schulz & Lund, 1983; Wirz-Justice, 2008). Early morning hypoactivity of the hypothalamus–pituitary–adrenal– axis as indexed by the diminished release of cortisol may therefore be an important candidate for explaining a morning worsening pattern of affect (Fries, Hesse, Hellhammer, & Hellhammer, 2005). More precisely, if cortisol can cause an increase in feelings of energy and reinvigorate fatigued people (e.g. Tops, van Peer, Wijers, & Korf, 2006; Tops, Riese, Oldehinkel, Rijsdijk, & Ormel, 2008), then large individual differences in the volume of cortisol upon awakening may invoke divergent patterns of affect in the initial part of the day.

Cortisol and Diurnal Variation in Affect

The diurnal pattern of cortisol release is a well-documented biological process with an established circadian component. Cortisol declines steeply throughout the day and is then regenerated during sleep so waking levels are raised substantially and then increase further, by 40-75% in the next half hour, to a daily peak (de Weerth & Buitelaar, 2005). The cortisol awakening response is assessed primarily with two metrics: the increase in cortisol from waking and the total integrated volume of cortisol released in the period immediately after waking (e.g. Chida & Steptoe, 2009; Pruessner, Kirschbaum, Meinlschmid, & Hellhammer, 2003). The former, cortisol increase from waking, has been well-examined and is thought to be a distinct component of the cortisol cycle (e.g. Clow, Thorn, Evans, & Hucklebridge, 2004). The awakening increase is responsive to psychosocial factors potentially signaling the effect of anticipation of the upcoming challenges of the day (e.g. Edwards et al., 2001; Fries, Dettenborn, & Kirschbaum, 2009).

The less studied overall volume of awakening cortisol is closely linked to the circadian cortisol cycle and does not appear to be strongly related to psychosocial factors (e.g. Chida & Steptoe, 2009). The total volume of cortisol released over the waking period may be relatively unaffected by psychosocial factors but yet interact with such factors to explain morning affect levels. For instance, for some people, with high levels of psychosocial resources, low levels of morning cortisol may have little impact on their affect levels. In contrast, low morning cortisol levels may act to compound the already lethargic and negative state of the distressed.

Several recent studies show partial support for this idea. Healthy people with a morning preference have been shown to have higher cortisol levels in the first hour after waking than evening types (Kudielka, Federenko, Hellhammer, & Wust, 2006; Kudielka, Bellingrath, & Hellhammer, 2007; Bailey & Heitkemper, 1991). In other research, people with diminished wakeup cortisol levels have been shown to experience fatigue at waking and later in the day (Dahlgren, Kecklund, Theorell, & Akerstedt, 2009; Adam, Hawkley, Kudielka, & Cacioppo, 2006). Further evidence suggests that the effects of reduced morning cortisol levels may be most pronounced in the distressed. For instance, cortisol levels over the wakeup period have been shown to be reduced in people with chronic fatigue and burnout (Fries et al., 2005), those with post-traumatic stress disorders (Chida & Steptoe, 2009; Rohleder, Joksimovic, Wolf, & Kirschbaum, 2004), people with mild to moderate depression (Bhattacharyya, Molloy, & Steptoe, 2008), major depression (e.g. Posener, DeBattista, Williams, Kraemer, Kalehzan, & Schatzberg, 2000) and in anxious people and suicide attemptors (Sjogren, Leanderson, & Kristenson, 2006; Lindqvist, Isaksson, Traskman-Bendz, & Brundin, 2008).

The Present Investigation

In the present study, we therefore assessed people‘s psychological distress using the

Depression Anxiety Stress Scales (DASS-21) (Brown, Chorpita, Korotitsch, & Barlow, 1997; Antony, Bieling, Cox, Enns, & Swinson, 1998). We also measured the total volume of cortisol each person released over the waking period on a work day (e.g Pruessner et al., 2003), and we comprehensively assessed affect and activity patterns throughout the same day using the Day Reconstruction Method (Kahneman, Krueger, Schkade, Schwarz, & Stone, 2004). Using multilevel regression we firstly sought to identify how best to model the temporal relation between time of day and affect (e.g. linear, quadratic, cubic). Next, we investigated whether people with higher levels of psychological distress would modify the link between time of day and affect so as that the more distressed experience a steeper increase in positive affect during the day than those with lower distress scores. Although existing research does not appear to generate robust predictions regarding diurnal patterns of negative affect, we tested to see if it followed the opposite trend to positive affect (i.e. increased in the morning among the distressed with a subsequent decrease). Specifically, we expected that DASS-21 scores would predict the relationship between time of day and affect.

We next examined the possibility that cortisol levels in the first half hour after waking may predict the relationship between time of day and affect. We expected that those with lower cortisol levels in the first half hour from waking would show a greater increase in positive affect and potentially a larger decrease in negative affect throughout the day than those with higher cortisol levels. Finally, we sought to link our two initial hypotheses by testing to see if people with higher psychological distress and lower morning cortisol levels are particularly likely to experience a pattern of increasing positive affect and decreasing negative affect over the course of the day.

Method

Participants

One hundred and seventy four (59 males, 115 females) students participated in the study for course credit or 25 euro. The participants ranged in age from 18 to 49 (M = 23, SD = 5.7) and

10.05% of the sample indicated they had a chronic medical condition. On the first day of the study participants received verbal and written instructions detailing what the study entailed and provided informed consent. They then completed baseline physiological tests administered by trained research nurses and received instruction detailing the cortisol sampling procedure. On the next day participants provided cortisol samples at waking and thirty minutes after waking. Cortisol levels were examined solely on work days as morning cortisol levels have been shown to be systematically more pronounced on work days than at the weekend (e.g. Kunz-Ebrecht, Kirschbaum, Marmot & Steptoe, 2004). On the third day of the study the participants completed a day reconstruction survey (Kahneman et al., 2004), a measure of psychological distress, and a series of questions about their health behavior.

Measures

Online Day Reconstruction

On the day after providing the saliva samples participants completed a computer-assisted reconstruction of the objective details and affective experiences of the previous day. As in the original pen-and-paper day reconstruction survey (Kahneman et al., 2004) the online day reconstruction survey follows a fixed format in order to reduce recall bias. Participants firstly complete a diary by breaking their day into morning, afternoon, and evening stages and then recalling and labeling each episode from their day. Participants are instructed to consider their day as a film and episodes as scenes from that film, with the transition to each new episode representing a significant change (e.g. change of place, activity), and with each episode typically lasting between 20 minutes and 2 hours (Stone et al., 2006).

As both cortisol and affect patterns can be affected by environmental factors such as one's location (e.g. home, at work), activities (e.g. commuting, exercising) and social interactions, participants provided specific information about each of these factors during each episode reported.

For each episode participants also rated how much they felt positive affect (happy, calm, comfortable, affectionate, interested, confident) and negative affect (impatient, depressed, stressed, irritated), on a scale from 0 (not at all) to 6 (very much). Prior research suggests that the affect levels identified using the day reconstruction method appear to approximate those assessed using experience sampling (Kahneman et al., 2004). Average levels of positive ($M = 3.6$, $SD = 1.1$) and negative ($M = 1.4$, $SD = 1.2$) affect were then converted to standardized Z-scores for the subsequent regression analyses. As is typical, positive and negative affect scores were found to be related ($r = -.5$, $p < .001$) but sufficiently separable to be considered distinguishable.

Psychological Distress

Psychological distress was assessed using the short-form version of the Depression Anxiety Stress Scales (DASS-21) (Brown et al., 1997; Antony et al., 1998), a brief 21-item instrument which has been shown to yield a general factor dimension representing psychological distress (Henry & Crawford, 2005). The DASS-21 is composed of three 7-item self-report scales from the extended version of the DASS. Each item refers to a particular symptom and participants rate the extent to which the symptoms applied to them in the past week on a scale from 0 (did not apply) to 3 (applied to me very much or most of the time). Possible scores on the DASS-21 range from 0 to 63. In the present study two participants were found to score over 50 and were considered statistical outliers and not included in subsequent analyses. The DASS-21 scores of the remaining participants ranged from 0 to 42, ($M = 14.4$, $SD = 9.6$).

Health and Health Behavior

An array of baseline health variables and health behaviors were assessed primarily to ensure that the cortisol analyses were not confounded by individual differences in health, behavior or consumption which have been shown to influence diurnal cortisol cycles and/or affect levels. For instance, prior research has linked a high body mass index to both diminished cortisol levels and low levels of positive affect (Daniel et al., 2006; Oswald & Powdthavee, 2007). Conversely, it is possible that engaging in exercise would increase both morning cortisol levels and positive affect (e.g. exercise, Mason, Hartley, Kotchen, Mougey, Ricketts, & Jones, 1973; Stone et al., 2006). Thus, during the baseline medical assessment trained research nurses assessed several aspects of participant‘s physiological functioning that may link to their cortisol and affect levels. More precisely, the nurses measured each participant's body mass index (M = 23 kg/m2, SD = 3.3), body fat (M = 29%, SD = 8.2), lung capacity (M = 402.1 liters/minute, SD = 117), and systolic (M =121mmHg, SD = 13.5) and diastolic (M = 68.2 mmHg, SD = 9.4) blood pressure. In addition, as part of the questionnaire component of the study the participants responded to items related to their health behavior. Participants rated how often they exercise (from 0 = Never to 4 = 4 or more times a month), (M = 3.31, SD = 1.29). Twelve percent of the sample indicated they were current smokers and 9% were currently on a diet. The frequency of alcohol consumption was rated on scale from 0 (Never) to 5 (Four or more times a week), (M = 3.31, SD = 1.29). Finally, we inquired as to if the participants consumed alcohol on the day prior to the monitoring day (25% drank) and also if they drank during the monitoring day (24% drank).

Salivary Cortisol Sampling

A total of four salivary cortisol samples were collected from each participant using a Salivette collection device (Sarstedt, 51582 Numbrecht, Germany). Two samples were taken immediately at waking and then two samples 30 minutes after waking. The participants received detailed verbal instruction as well as a written protocol relating how to collect the saliva samples. Participants were requested not to eat, drink beverages, smoke, or brush/floss their teeth during the 30 minute period from waking to when they had collected their fourth sample. Participants completed an adherence monitoring form upon which they detailed the scheduled times when their samples were to be collected and the actual time each sample was provided at. Six participants indicated that they collected one or more of their samples at times greater than 10 minutes from when scheduled and were thus not included in the final sample for this study (i.e. N = 174). The samples were returned to the laboratory the day after collection and frozen at -80 oC and subsequently assayed. The two samples at waking yielded highly consistent results ($r = .93$, $p < .001$) as did the later two samples at 30 minutes post-waking ($r = .91$, $p < .001$). We converted awakening and 30-minute cortisol levels using log transformation to reduce skewness as is typical. The total integrated volume of cortisol over the awakening period was calculated as the total area under the curve (relative to zero) between the waking and 30-minutes post-waking samples (e.g. Pruessner et al., 2003; Chida & Steptoe, 2009).

Statistical Analysis

There were 1,886 episodes reported in total (on average 10.77 per person) in the day reconstruction survey. To assist in the interpretation and presentation of the results we focused on episodes for which the temporal mid-point of their duration was between 8am and 12pm (1,821 episodes). We applied multilevel analyses to examine most of the study questions. Multilevel analysis was particularly suited to the nested structure of the data in the current study and the uneven number of repeated assessments at the episode-level (Stone et al., 2006). In this study, we had two levels of nesting: the episode level at which the affect and other day reconstruction data (e.g. location & activity information) was recorded (Level 1), and the person level at which the demographic, health and health behavior, psychological distress and cortisol metrics were assessed (Level 2).

We firstly aimed to identify if the relation between time of day and affect levels that produced the best fit was linear, quadratic, or cubic. Then we aimed to examine the extent to which the temporal patterning of affect was linked to (i) psychological distress, (ii) awakening cortisol levels, and (iii) the interaction between distress and cortisol levels. In order to graphically examine these relations we separated the sample into those with above or below average psychological distress levels and those with cortisol levels which were above/below the mean. To test for differences in the diurnal pattern of affect between these groups we examined the slope of the affect levels and the associated confidence interval for each group.

[Table 1 about here]

Results

We firstly produced an unadjusted multilevel regression model testing the link between time of day, time-squared and time-cubed and affect levels. Time of day was linearly linked to positive affect levels ($t = 6.67$, $p < .005$; $R^2 = .0203$). Incorporating time-squared or time-cubed into the model failed to substantially increase the variance explained by the model ($time^2$: $R^2 = .0204$; $time^3$: $R^2 = .0223$). Negative affect demonstrated a linear decrease over the course of the day ($t = -4.13$, $p < .005$; $R^2 = .008$). The inclusion of time-squared or time-cubed into the model produced a small increase in the variance in negative affect levels explained by the model ($time^2$: $R^2 = .0098$; $time^3$: $R^2 = .0102$). Overall, a linear model appeared to produce the best fit of the relationship between time of day and affect levels in the current data. We therefore examined the linear models linking time of day with positive and negative affect and how psychological distress and morning cortisol levels modify these linkages. The control variables included were activity patterns, social interactions and location details at the episode level as well as demographic factors, baseline health and health behavior variables at the level of the individual. Age and father‘s education were largely unrelated to affect. Females were found to experience more positive affect than males, as shown in Table 1. In line with previous studies (e.g. Stone et al., 2006), positive affect increased across the course of the day whilst negative affect declined markedly. Distressed participants experienced high levels of negative affect and low positive affect as anticipated. Morning cortisol levels were not significantly related to affect. In additional analyses, we showed that morning cortisol levels and psychological distress were unrelated ($r = -.04$, $p = .56$).

[Figure 1 about here]

Following this, we tested the three interaction effects that corresponded to the main hypotheses of the study. Demographic variables and control variables were included in each analysis as were lower order interaction effects for the three-way interaction analyses. Firstly, we examined the relation between psychological distress and diurnal rhythms of affect. Participants with high levels of psychological distress were found to demonstrate a clear pattern of lower positive affect in the morning than the evening (i.e. *psychological distress* × *time of day* interaction), as shown in Table 2, and illustrated in Figure 1. Tests for the simple slopes suggested that the relationship between time of day and an increase in positive affect was stronger for those with above average psychological distress, (B = .031, SE = .006, t = 5.31, $p < .0005$), than for those with below average levels of distress, (B = .011, SE = .004, t = 2.54, $p < .05$). Confidence intervals for the simple slopes confirmed that the slope for positive affect across the course of the day was steeper for those with high psychological distress (.031 ± .012) than for participants with low psychological distress (.011 ± .008). The large differences in positive affect between distressed and non-distressed participants early in the day diminished as the day progressed and converged in the evening, as anticipated. Distress also interacted with time of day to predict negative affect. Distressed people showed a significant decrease in negative affect from morning through evening (B = -.014, SE = .007, t = -2.15, $p < .05$) whereas the non-distressed did not (B = -.007, SE = .005, t = -1.43, p = .15). However, the confidence intervals for the simple slopes of those with high distress (-.014 ± .013) and those with low distress (-.007 ± .01) overlapped substantially indicated that the two slopes were not different.

[Table 2 about here]

Next, we tested to see if people with low morning cortisol levels experience low positive and high negative affect levels in the morning relative to the evening (i.e. *cortisol* × *time of day* interaction). As expected the positive affect levels of those with low morning cortisol were low in the morning and then subsequently converged with people with high morning cortisol in the evening, as shown in Table 2 and illustrated in Figure 2. More precisely, the relationship between time of day and positive affect was positive and highly significant for those with below average levels of morning cortisol (*B* = .039, SE = .006, t = 6.03, $p < .0005$) but non-significant for those with above average levels of morning cortisol (*B* = .006, SE = .004, t = 1.48, p = .14). Morning cortisol also interacted significantly with time of day to predict negative affect. Whilst the interaction effect identified was not easily interpretable from an inspection of the graph (Figure 2b), those with low morning cortisol levels did appear to experience a decrease in negative affect throughout the day (*B* = -.021, SE = .0066, t = -3.12, $p < .005$) whereas those with high morning cortisol did not (*B* = -.005, SE = .005, t = -.94, p = .35). To summarize, the initial interaction analyses clearly showed that low levels of positive affect in the morning were predicted by both high psychological distress and low cortisol levels upon waking. There was also some tentative evidence that those with high psychological distress and low morning cortisol experience high negative affect in the mornings that diminishes as the day progresses.

[Figure 2 about here]

Finally, we sought to show that the results from our initial two interaction effects were interlinked. More precisely, we expected that people with high psychological distress and low morning cortisol would experience the steepest increase in positive affect and potentially decrease in negative affect during the day (i.e. *psychological distress* × *cortisol* × *time of day* interaction). As expected, participants with above average levels of distress and with lower than average morning cortisol levels were the only group to experience a highly significant trend towards low positive affect early in the day followed by a sharp rise in positive affect (*B* = .052, SE = .009, t = 5.4 p < .0005), as shown in Table 2 and illustrated in Figure 3a. A comparison of the simple slopes and confidence intervals showed that the increase in positive affect for those with below average cortisol levels and above average distress levels (*B* = .052, SE = .009, t = 5.4 p < .0005), was more rapid than for those with above average distress alone (*B* = .031, SE = .006, t = 5.31, p < .0005) and marginally more rapid than for those with below average cortisol alone (*B* = .039, SE = .006, t = 6.03, p < .0005).

Those with both lower than average psychological distress and morning cortisol were the only other group for which there was a statistically significant relationship between time of day and positive affect (*B* = .018, SE = .008, t = 2.1p < .05), as illustrated in Figure 3b. However, the slope of the relationship between time of day and positive affect was stronger for those with low morning cortisol and high psychological distress (.052 ± .018) than for those with both low psychological distress and morning cortisol (.018 ± .016) as hypothesized.

Apparently low awakening cortisol levels predict a particularly low trough in positive affect levels for the distressed in the mornings. But this group subsequently goes on to feel more positive as the day progresses and may even surpass the positive affect levels of distressed people with high morning cortisol by the evening. Non-distressed people with low morning cortisol did experience a rise in positive affect during the day, but this increase was smaller in magnitude than the increase in the low cortisol - high distress group. No such three-way interaction was identified for negative affect.

[Figure 3 about here]

Discussion

The present results indicate that there are predictable patterns in diurnal rhythms of affect that can be explained by both psychological and biological factors. Consistent with previous reports, in the sample as a whole we found that positive affect increased considerably throughout the day and negative affect declined slightly (Stone et al., 2006). However, although these patterns have been identified in healthy people and appear to be robust, average changes in affect may mask the effect of important individual differences that could explain emotional fluctuations.

Although it is clear that distressed people are likely to feel worse than the non-distressed throughout a given day, the diurnal trend in the emotions of the distressed is perhaps less obvious. Using a measure of psychological distress composed of depression, anxiety, and stress scores we showed that more distressed people experienced a clear trend towards low positive affect and to some extent high negative affect in the mornings relative to the evenings. It could therefore be the case that the diurnal changes in affect observed across numerous studies (e.g. Murray, 2007; Stone et al., 2006; Peeters et al., 2006), may be a direct result of large fluctuations in affect among certain groups such as the distressed. Moreover, prior observations of morning-worst affect in distressed people have lead commentators to suggest that such changes in affect may have a physiological basis grounded in systems that follow a circadian rhythm (Axelsson, Akerstedt, Kecklund, Lindqvist, & Atterfors, 2003).

Cortisol, Affect Patterns, and Distress

The present study also found that morning cortisol was of crucial importance to affect levels early in the day. We analyzed the total cortisol output in the first half hour after waking, an important marker of neuroendocrine functioning (e.g. Chida & Steptoe, 2009; Pruessner et al., 2003). People with a below average level of cortisol output in the first half hour after waking had lower positive affect and higher negative affect in the morning which improved substantially over the course of the day, converging with those with an above average volume of morning cortisol late in the evening. This result links well with earlier findings showing that people who prefer the morning to evening typically feel better during the initial hours after waking and have higher wakeup cortisol levels than those who prefer evenings (Jankowski & Ciarkowska, 2008; Bailey & Heitkemper, 1991; Kudielka et al., 2007). In addition, the strong association between low levels of awakening cortisol and diminished positive affect identified in the current study is consistent with research showing that groups with generally diminished energy (e.g. chronic fatigue, burnout) and low mood levels (e.g. post-traumatic stress, melancholic depression) tend to have reduced cortisol levels in the period after waking (Boksem & Tops, 2009). Furthermore, our analyses suggest that the divergent diurnal patterns of affect predicted by morning cortisol levels were unlikely to be explained by activity patterns, environmental changes or baseline health or health behavior differences.

Perhaps most important, we found that psychological distress, morning cortisol, and affect patterns were interlinked. We showed a clear shift in positive affect from reduced morning levels to a much improved evening state among distressed people with below average cortisol levels in the period after waking. This finding draws together two parallel streams of research: the first demonstrating that distressed people are likely to experience a steeply increasing pattern of positive affect during the day (Murray, 2007; Peeters et al., 2006) and the second showing that reduced volumes of morning cortisol are linked to a dislike of the initial hours of the day (e.g. Kudielka et al., 2006) and to clinical conditions characterized by low energy and mood (e.g. Fries et al., 2005). We suggested that psychological distress whilst not strongly associated with morning cortisol levels may interact with cortisol levels to profoundly influence affect. In line with this idea, the distressed appear to be particularly vulnerable to a physiological susceptibility to low positive affect early in the day, as indexed by diminished awakening cortisol levels.

If the finding from the current study can be replicated they will have several implications. For instance, distressed people who experience a marked evening improvement in mood on a daily basis may postpone seeking treatment, as has been noted to occur in morning-worse depression (Carpenter, Kupfer, & Ellen, 1986). It is possible that the exogenous administration of cortisol to those with deficient morning levels, may stimulate an enhancement of positive mood (e.g. Tops et al., 2006) and reduce negative affect (e.g. Putman, Hermans, Koppeschaar, van Schijndel, & van Honk, 2007). The growing field of chronotherapeutics is likely to offer numerous non-pharmaceutical treatments to normalize disruptions in affective rhythms, such as light therapy and manipulations of the sleep-wake cycle (e.g. sleep deprivation) which may assist in normalizing the cortisol cycle (Wirz-Justice, 2006; Monteleone & Maj, 2009).

Limitations

Three central limitations of this study should be noted. Firstly, the day reconstruction method protocol constrains the data collected in several ways. Participants are requested to only report episodes that are at least 20 minutes in length, meaning that more abrupt but potentially meaningful experiences may be omitted. The day reconstruction survey also restricts the reporting of activities, locations and interactions to a non-exhaustive set of common response options. Furthermore, it is possible that experience sampling techniques for the ambulatory assessment of affect that permit the open-ended reporting of a wide-array of activities and interactions, may yield more high frequency and potentially more accurate results than the day reconstruction survey. However, as the day reconstruction survey is designed to measure be exogenous to the period under scrutiny and to minimize recall bias by carefully evoking contextual information we felt it represented the optimal trade-off between respondent burden and ecological validity.

Secondly, as the survey reporting period was restricted to the participants chosen period of wakefulness this meant that affect patterns across broader time horizons (e.g. 24 hours)were not examined. Incorporating a sleep deprivation protocol in order to test affect rhythms over lengthy time-periods, whilst potentially less ecologically valid than naturalistic monitoring of the waking hours, may have assisted in identifying the curvilinear, quadratic or cubic circadian rhythm in affect shown in prior studies (e.g. Murray et al., 2007; Peeters et al., 2006). Thirdly, whilst we took measures to ensure compliance with the saliva sampling protocol, we relied on the accuracy of the participants self-reports which may overestimate actual compliance (Broderick, Arnold, Kudielka, & Kirschbaum, 2004). Finally, it is unclear that the present data can be generalized to representative samples or indeed clinical conditions. For example, as the activity of the hypothalamus–pituitary–adrenal–axis varies substantially over the life-course (e.g. Saxbe, 2008), the results of this study may not be generalizable to older adults. Also, groups such as hospitalized psychiatric patients may differ qualitatively in their affective and psychobiological functioning from healthy people with mild or moderate affective disturbances (Stetler & Miller, 2005).

Conclusions

Despite these limitations, the current data provide strong evidence linking several existing strands of research. We replicated research showing a morning-worse affect pattern to be a prominent feature of psychological distress. In addition, we found that people with higher morning cortisol levels tend to be happier in the morning than those with diminished waking cortisol levels. We extended this finding to psychological distress, showing that distress did not influence morning cortisol levels but instead interacted with cortisol output to predict positive affect. More precisely, distressed people with below average morning cortisol started off the day with especially diminished positive affect that subsequently increased quickly. Future research should examine the role of genetic factors in predicting how people respond to interventions which aim to modify the psychological and biological factors underlying diurnal rhythms of affect. This research will yield potentially critical insights into the understanding everyday rhythms of affect in both healthy people and those with affective disorders.

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Table 1. Summary of Multilevel Models Testing the Association of Demographic Factors and Core Study Variables with Positive and Negative Affect Adjusting for Covariates

	Dependent Variable			
	Positive Affect		Negative Affect	
Variable	B (SE)	t	B (SE)	t
Intercept	-.467 (.54)	.87	-.289 (.443)	-.65
Age	.005 (.01)	.6	-.012 (.007)	-1.57
Male [b]	-.67(.19)	-3.46**	.097 (.156)	.62
Fathers Education	-.037 (.06)	-.62	-.055 (.05)	-1.15
Time of Day (linear)	.021 (.004)	5.49***	-.012 (.004)	-2.93**
Psychological Distress	-.027 (.005)	-5.27***	.37 (.004)	9***
Morning Cortisol Levels	.147 (.08)	1.83	-.042 (.065)	-.65

[a] Analyses are adjusted for activity patterns, social interaction, and location at Level 1 and health (body mass index, body fat, lung capacity, blood pressure), and health behaviour (exercise, smoking, alcohol consumption, dieting) at Level 2. [b] ‘Female’ is coded as 1. ** $p < .01$, *** $p < .001$.

Table 2. Summary of Multilevel Models Testing Study Hypotheses Relating to the Association of Time of Day, Psychological Distress, and Cortisol Levels with Positive and Negative Affect Adjusting for Covariates

	Dependent Variable			
	Positive Affect		Negative Affect	
Hypothesized Interaction [a]	B (SE)	t	B (SE)	t
1. Psychological Distress × Time of Day (linear)	.002 (.0004)	4.56***	-.001(.0004)	-2.79**
2. Morning Cortisol × Time of Day (linear)	-.0205 (.005)	-3.74***	.02 (.006)	3.29***
3. Psychological Distress × Morning Cortisol × Time of Day (linear) [b]	-.002 (.0006)	-3.42***	.001 (.001)	1.15

[a] Analyses are adjusted for time of episode, social interaction, activity patterns and location at Level 1 and psychological distress, morning cortisol levels, demographic factors (age, gender, fathers education), health (body mass index, body fat, lung capacity, blood pressure), and health behaviour (exercise, smoking, alcohol consumption, dieting) at Level 2.

[b] Analyses are adjusted for two-way interaction effects in addition to control variables.

**** $p < .01$, *** $< .005$**

Figure Caption

Figure 1. Standardized (a) positive and (b) negative affect as a function of time of day for participants with low and high psychological distress.

(a) **(b)**

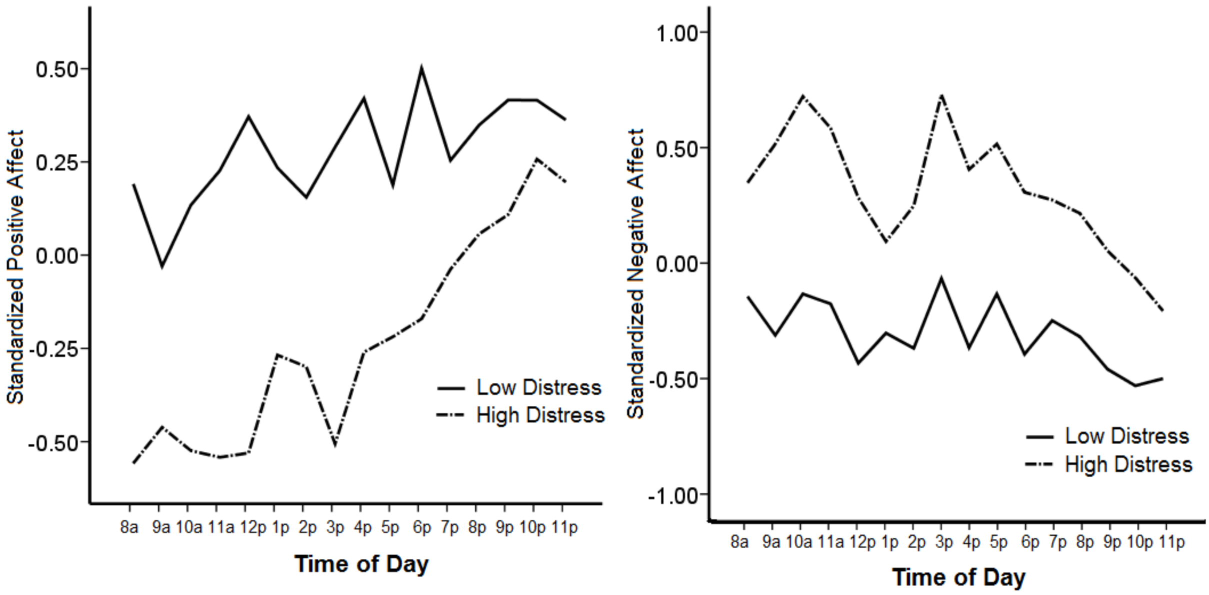


Figure Caption

Figure 2. Standardized (a) positive and (b) negative affect as a function of time of day for participants with high and low morning cortisol levels.

(a) **(b)**

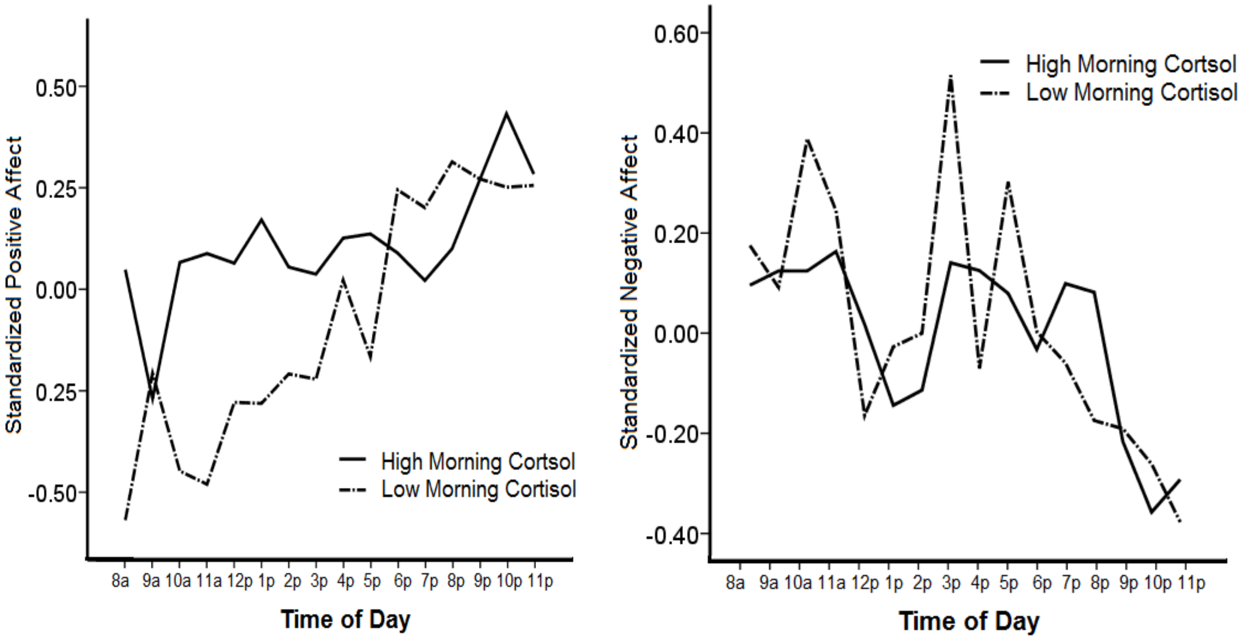
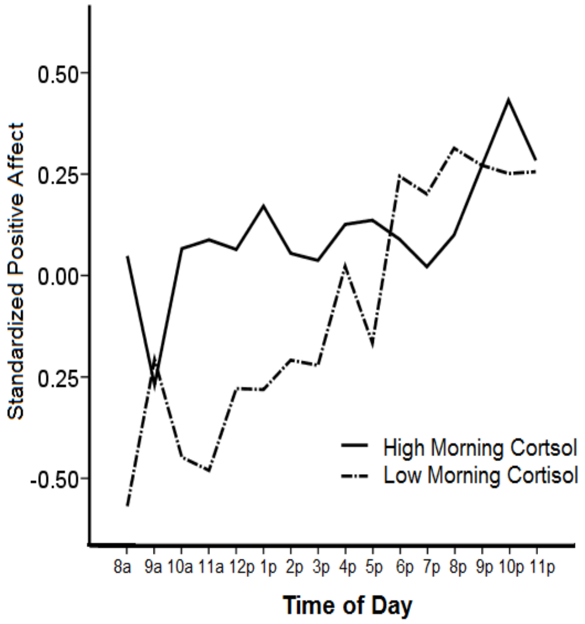


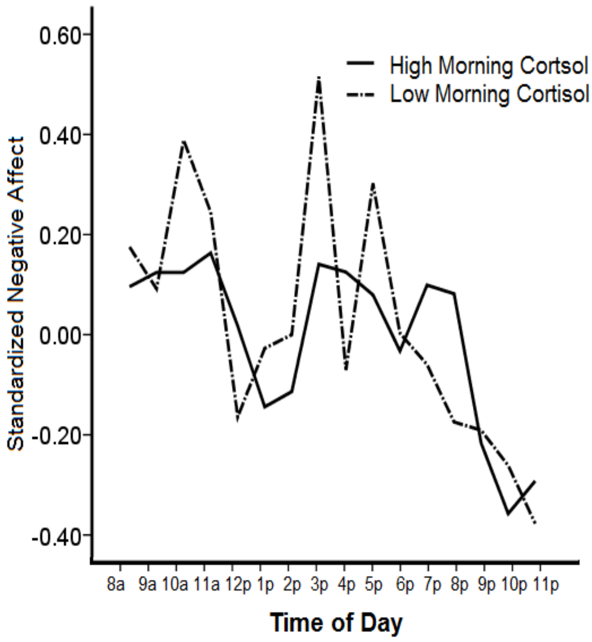
Figure Caption

Figure 3. Standardized (a) positive and (b) negative affect as a function of time of day for participants with high and low morning cortisol levels

(a)



(b)



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