Health Psychology
2008, Vol. 27, No. 6, 685–693


0278-6133/08/$12.00 DOI: 10.1037/0278-6133.27.6.685

# Diurnal Cortisol Secretion and 2-Year Changes in Older Adults' Physical Symptoms: The Moderating Roles of Negative Affect and Sleep

Carsten Wrosch
Concordia University

Gregory E. Miller
University of British Columbia

Sonia Lupien and Jens C. Pruessner
Douglas Hospital Research Center

***Objective:*** This study examined whether the association between cortisol secretion and changes in physical health symptoms would depend on other factors in a person's life. The authors expected that physical health effects would emerge particularly when cortisol disturbances co-occur in the context of high levels of trait negative affect or poor sleep. ***Design***: Physical symptoms, diurnal cortisol secretion, affective tendencies, and sleep efficiency were assessed in a 2-yr longitudinal study of 184 older adults. ***Main Outcome Measure***: Two-year changes in physical symptoms. ***Results***: High cortisol levels were associated with increases in physical symptoms, but only among participants who experienced high negative affect and poor sleep. ***Conclusion***: Elevated levels of cortisol secretion contribute to older adults' physical symptoms if they co-occur in the context of other emotional and behavioral problems. By contrast, cortisol disturbances may not influence physical symptoms among people who are emotionally well or engage in efficient sleep behaviors.

*Keywords:* cortisol, physical health, affect, sleep

Psychological models of health emphasize that cortisol secretion is an important biological process that can influence a variety of physical health problems (Cohen, Janicki-Deverts, & Miller, 2007; McEwen, 1998; Heim, Ehlert, & Hellhammer, 2000). However, the evidence linking cortisol and physical health is mixed, and some research has struggled with demonstrating that cortisol secretion predicts clinical disease outcomes (e.g., Cohen et al., 1998) or even biological intermediaries like immune functions (Miller et al., 2004). To address this issue, we examined in this study whether trait negative affect and poor sleep could moderate the association between cortisol secretion and physical health problems. We reasoned that such a process could take place because cortisol can be partially independent from trait negative affect and sleep problems (Polk et al., 2005; Steiger, 2002; van Eck, Nicolson et al., 1996). Moreover, high levels of negative affect may exacerbate the development of physical health problems through motivational and behavioral pathways (Wrosch, Schulz, & Heckhausen, 2004). In a similar vein, diminished restorative processes, such as poor sleep, may increase the likelihood of developing a physical health problem (Cacioppo et al., 2002). Thus, individuals who experience high levels of negative affect or poor sleep may be particularly vulnerable to the health-related consequences of cortisol dysregulation. By contrast, low levels of negative affect and efficient sleep patterns could buffer an adverse effect of cortisol disturbances on a person's physical health.

## Cortisol Secretion and Physical Health

Results of naturalistic and experimental studies suggest that cortisol is released into the circulation when people experience stressful events that activate their body's primary hormonal response system, the hypothalamic-pituitary-adrenocortical axis (Dickerson & Kemeny, 2004; Jacobs et al., 2007; Schaeffer & Baum, 1984; Weiner, 1992; Wrosch, Schulz, Miller, Lupien, & Dunne, 2007). Further, disturbances in cortisol secretion may influence a person's immune, metabolic, and central nervous systems (Heim, Ehlert, & Hellhammer, 2000; Lupien, Leon, & De Santi, 1998; Weiner, 1992), and thus have been implicated as a primary "suspect" in more general models of stress and disease (Cohen, Kessler, & Underwood, 1995).

However, studies examining the link between cortisol and physical health show a mixed pattern of findings. On the one hand, adverse health outcomes have been found among individuals who exhibit elevated (in the context of diabetes mellitus, cardiac disease, and breast cancer) and blunted (in the context of chronic fatigue, rheumatoid arthritis, and atopic allergies) patterns of cor-

Carsten Wrosch, Department of Psychology, Centre for Research in Human Development, Concordia University, Montreal, Quebec, Canada; Gregory Miller, Department of Psychology, University of British Columbia, Vancouver, British Columbia, Canada; Sonia Lupien and Jens Pruessner, Douglas Hospital Research Center, McGill University, Montreal, Quebec, Canada.

Preparation of this article was supported in part by grants and awards from Canadian Institutes of Health Research, Social Sciences and Humanities Research Council of Canada, Michael Smith Foundation for Health Research, Heart and Stroke Foundation of Canada, and National Alliance for Research on Schizophrenia and Depression.

Correspondence concerning this article should be addressed to Carsten Wrosch, Department of Psychology, Centre for Research in Human Development, Concordia University, 7141 Sherbrooke St. West, Montreal, QC H4B 1R6, Canada. E-Mail: carsten.wrosch@concordia.ca

tisol secretion (Heim et al., 2000; McEwen, 1998; Smith et al., 2005; Weiner, 1992). In addition, elevated levels of cortisol secretion during the day and evening hours predicted mortality in a cohort of patients with breast cancer (Sephton, Sapolsky, Kraemer, & Spiegel, 2000). On the other hand, research also suggests that cortisol level is not always related to physical health problems, and often does not explain linkages between stressful events and emotions, biological intermediaries, and disease outcomes (e.g., Cohen et al., 1998; Miller, Chen, & Zhou, 2007). Consistent with these findings, our previous research showed that although challenge-related negative emotions predicted both, high cortisol levels and physical health symptoms, cortisol was not associated with physical symptoms (Wrosch, Bauer, Miller, & Lupien, 2007).

## Moderators of the Association Between Cortisol and Physical Health

We think that there may be a reason why cortisol secretion is not always associated with indicators of physical health. In particular, we argue that emotional experiences and behavioral patterns may determine whether increased levels of cortisol forecast declines in physical health. To further explore this possibility, we postulate that elevated levels of cortisol secretion are particularly likely to influence physical health problems when they co-occur in the context of high trait negative affect and inefficient sleep.

There are several arguments that support the idea that adverse health effects of cortisol secretion may depend on a person's affective tendencies and sleep patterns. First, although it has been shown that emotions and sleep can be associated with cortisol (Kirschbaum & Hellhammer, 1989; Steiger, 2003), they can also be conceptualized as partially independent from cortisol secretion. For example, personality theories suggest that there are stable individual differences in people's tendencies to experience emotions (Watson, Clark, & Tellegen, 1988). Thus, given that individuals can be confronted with stressful life events, whether they are emotionally well or not, trait affect is likely to have only a modest association with a person's cortisol secretion. In support of this argument, research suggests that trait affect is not always associated with cortisol (Polk et al., 2005; van Eck, Nicolson et al., 1996), and that there is considerable variability across studies in the strength of the association between various indicators of emotional distress and cortisol (Cacioppo et al., 2002; Dickerson & Kemeny, 2004; Miller et al., 2004, 2007; Pressman et al., 2005).

In a similar vein, there is substantial variability in the strength of the cortisol-sleep association across studies, and cortisol does not always predict sleeping problems (Steiger, 2002). In this regard, it has been argued that cortisol may be associated with only some sleep disorders (Shaver, Johnston, Lentz, & Landis, 2002), and it may exert a synergetic effect in conjunction with other biological factors rather than being the primary cause of sleeping problems (Buckley & Schatzberg, 2005; Steiger, 2003). This makes it possible that sleep problems and trait affect are partially independent from cortisol, and permits us to conceptualize interaction effects between sleep, affect, and cortisol on physical health outcomes.

In addition, negative affect and poor sleep may exacerbate cortisol effects on physical health problems through different pathways. For example, emotional problems can contribute to a reduced motivation to address physical problems, maladaptive coping with health threats, or health-compromising behaviors (e.g., smoking, drinking, or eating less healthy food) (Bruce, 2000; Griffin, Friend, Eitel, & Lobel, 1993; Wrosch, Schulz, & Heckhausen, 2002). Moreover, it has been argued that diminished restorative processes, such as inefficient sleep problems, may exert adverse effects on physical health (e.g., Cacioppo et al., 2002). Poor sleep may trigger problems in a person's immune, endocrine, or metabolic systems (Irwin, Wang, Campomayor, Collado-Hidalgo, & Cole, 2006; Spiegel, Leproult, & Van Cauter, 1999) and has been linked with morbidity and mortality (Dew et al., 2003; Jennings, Muldoon, Hall, Buysse, & Manuck, 2007). An important implication of this argument is that individuals who tend to experience high levels of negative affect or exhibit poor sleep patterns may be particularly vulnerable to the health-related consequences of cortisol dysregulation. By contrast, beneficial health effects of low levels of negative affect and adaptive sleep patterns may buffer the adverse consequences of cortisol disturbances on physical health.

## The Present Study

To examine physical health effects of cortisol, trait affect, and sleep, we predicted 2-yr changes in physical symptoms (e.g., difficulty breathing, joint, leg, or chest pain) in a longitudinal sample of older adults. We predicted physical symptoms because our sample of older adults was relatively healthy at baseline, and physical symptoms may be a sign of a variety of developing or underlying diseases (Wrosch & Schulz, 2008). Thus, we reasoned that there may be a higher likelihood of capturing health effects of cortisol dysregulation if we predict symptoms that can be associated with a variety of health problems. In addition, we focused in our analyses on the overall output of diurnal cortisol, averaged across 3 days, because we reasoned that such reliable measures of cumulative concentration of cortisol may be particularly likely to predict physical health outcomes.

We hypothesized that elevated levels of diurnal cortisol secretion would be associated with increases in physical symptoms, but only among older adults who tend to experience high levels of negative affect or exhibit inefficient sleep patterns. By contrast, we did not expect an association between cortisol level and changes in physical symptoms to emerge among participants who experience low levels of negative affect or engage in efficient sleep patterns. In addition, we explored whether cortisol level would exert a particularly strong effect on increases in physical symptoms among participants who experience both, high levels of negative affect and poor sleep. By contrast, it would be possible that efficient sleep could ameliorate the adverse effect of negative affect (and vice versa) on the association between cortisol level and physical symptoms. Moreover, given that recent work has implicated positive emotions in the development of physical problems (Pressman & Cohen, 2005), we also explored whether positive affect would play a role in the association between cortisol secretion and changes in physical symptoms.

Finally, we addressed the possibility that cortisol is not the starting point, but levels of physical symptoms, affect, or sleep could contribute to dysregulation of cortisol output (e.g., Wrosch et al., 2007). To examine this alternative pathway, we also conducted a reversed analysis, predicting changes in cortisol level by baseline levels of physical symptoms, affect, and sleep.

## Method

### Participants

The present study is based on longitudinal data from the *Montreal Aging and Health Study* (Wrosch et al., 2007). We recruited a heterogeneous sample of 215 older adults in 2004 via newspaper advertisements. The only inclusion criterion was that participants had to be older than 60 years because we were interested in examining a normative sample of older adults. After contacting the laboratory, participants were invited for an initial appointment. Participants who were unable to visit the lab were assessed in their homes. During the initial appointment, they were instructed to complete a questionnaire, to collect saliva samples over the course of three nonconsecutive typical days, and to respond to a short questionnaire at the end of each of the three days. Participants were asked not to chose days that included unusual events (e.g., visit to a physician or dentist) and the assessment was typically completed over the course of 4 to 5 days ($M_{T1} = 4.17$, $SD_{T1} = .91$; $M_{T2} = 4.08$, $SD_{T2} = .48$). After finishing the study, all materials were collected, and participants received $50 for participating in the study.

We completed a second wave of data collection in 2006, approximately 2 years after the initial interview (*range* = 1.73 to 2.13 years) by applying the same procedures that were used in the initial assessment. Of the 215 initial participants, 184 participated in the longitudinal follow-up. At baseline, participants in the longitudinal follow-up were on average 72.27 years old ($SD$ = 5.79), 94 were female (51.10%), and 60 participants (32.60%) had attained an undergraduate university degree or a higher education. Study attrition was not significantly associated with baseline measures of the reported study variables.

### Materials

The main study variables were assessed at T1 and T2 and consisted of measures of participants' physical symptoms, diurnal cortisol secretion, positive and negative affect, and sleep efficiency. Table 1 presents means, standard deviations, and zero-order correlations of the main variables.[1] In addition, we included sociodemographic characteristics into the analyses (age, sex, and socioeconomic status).

*Physical symptoms.* We asked the participants to report at the end of each of three nonconsecutive typical days whether or not they had experienced 12 physical health symptoms during the day (e.g., chest, back, or joint pain, headaches, shortness of breath). This list of symptoms was derived from the PRIME MD patient questionnaire screener (Spitzer et al., 1994). To obtain global indicators of physical symptoms, we counted the total number of physical symptoms experienced across the three days at T1 and T2. Daily measures of physical symptoms were significantly correlated with each other ($rs_{T1} = .65$ to .74, $ps_{T1} < .01$; $rs_{T2} = .61$ to .76, $ps_{T2} < .01$). In addition, we computed a measure of changes in physical symptoms by predicting in a regression analysis the T2 indicator from the T1 indicator of physical symptoms, and saving the standardized residuals for further analysis.

*Diurnal cortisol secretion.* Participants collected saliva samples as they engaged in their normal daily activities. On each of the 3 days, participants collected five saliva samples (by using Salivettes) at specific times of the day: awakening, 30 minutes after awakening, 2 p.m., 4 p.m., and before bedtime. They were further asked not to eat or brush their teeth immediately before saliva collection to prevent contamination with food or blood. Participants were provided with a timer that they had to set to 30 minutes at the time they collected their first saliva sample after awakening. To ensure compliance concerning the collection of the afternoon and evening samples, participants were called at 2 p.m. and 4 p.m. They were further instructed to collect the last sample of the day by themselves at the time they went to bed. The actual time of day was recorded by the participants for all of the collected saliva samples.

The saliva samples were stored in participants' home refrigerators until they were returned to the lab 2 to 3 days after collection was completed (for stability of cortisol concentrations in these conditions, see Clements & Parker, 1998), and they were subsequently frozen until the completion of the study. Cortisol analysis was performed at the University of Trier in duplicate, using a time-resolved fluorescence immunoassay with a cortisol-biotin conjugate as a tracer (Kirschbaum, Kudielka, Gaab, Schommer, & Hellhammer, 1999). The intraassay coefficient of variation was less than 5%; the interassay variability has been found to be routinely below 10%.

Across both assessments, we obtained typical patterns of cortisol secretion over the three days, demonstrating high levels at awakening ($M$s = 12.01 to 15.02, $SD$s = 7.53 to 8.84), peaking 30 minutes after awakening ($M$s = 15.41 to 20.64, $SD$s = 10.15 to 13.36), and continuously decreasing over the later part of the day (2 p.m.: $M$s = 5.34 to 6.77, $SD$s = 3.55 to 4.48; 4 p.m.: $M$s = 4.78 to 5.63, $SD$s = 3.20 to 4.20; and bedtime: $M$s = 3.15 to 3.89, $SD$s = 3.11 to 5.15). To compute measures of participants' level of diurnal cortisol secretion, we calculated the area-under-the-curve (AUC) of cortisol secretion for each day separately, using the trapezoidal method (based on hours after awakening). Given that some saliva samples may have been contaminated with blood or food, we excluded all samples that deviated more than three $SD$s from the mean cortisol secretion for the time of day. In addition, we calculated AUC only if the participants provided at least four out of five samples for a specific day. In cases where a single saliva sample was missing, we replaced the missing value with the sample mean before calculating AUC. Single day measures of AUC were significantly correlated, $rs_{T1} = .51$ to .63, $rs_{T2} = .42$ to .45, all $ps < .01$, and were averaged to obtain stable indicators of cortisol secretion at T1 and T2. We computed a measure of changes in cortisol level over time by predicting T2 levels from T1 levels of cortisol (AUC) and saving the standardized residuals.

*Positive and negative affect* was assessed by administering the Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988). Participants were asked to indicate the extent to which they experienced 10 positive emotions (e.g., interested, excited, or active) and 10 negative emotions (e.g., distressed,

[1] The analyses for testing the hypotheses are based on 177 subjects. Seven subjects were excluded because they had missing data at baseline for cortisol secretion (4) and emotional experiences (3). Replacing missing data with the sample mean would not have changed the observed pattern of findings. In addition, we obtained missing data at T2 with respect to cortisol secretion (2), sleep efficiency (5), and emotional experiences (4). These subjects were excluded from the respective correlation and regression analyses.

Table 1
*Means, SDs, and Zero-Order Correlations of the Main Study Variables*

| | *M* (*SD*)[a] | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. Physical symptoms (T2) | 2.97 (3.44) | | | | | | | | | |
| 2. Physical symptoms (T1) | 2.50 (3.12) | .53** | | | | | | | | |
| 3. Diurnal cortisol (AUC) (T2) | 136.52 (58.57)** | −.11 | −.17* | | | | | | | |
| 4. Diurnal cortisol (AUC) (T1) | 119.03 (53.91) | .03 | .01 | .33** | | | | | | |
| 5. Positive affect (T2) | 3.43 (.69) | −.22** | −.14 | .10 | .00 | | | | | |
| 6. Positive affect (T1) | 3.41 (.66) | −.15* | −.09 | .10 | .04 | .69** | | | | |
| 7. Negative affect (T2) | 1.83 (.67) | .20** | .22** | −.05 | −.03 | −.23** | −.13 | | | |
| 8. Negative affect (T1) | 1.88 (.67) | .34** | .27** | −.09 | −.02 | −.24** | −.11 | .63** | | |
| 9. Sleep efficiency (T2) | .83 (.12) | −.21** | −.15* | .03 | .02 | .12 | .12 | −.15* | −.18* | |
| 10. Sleep efficiency (T1) | .82 (.13) | −.18* | −.09 | .03 | .00 | .15* | .21** | −.09 | −.27** | .48** |

[a]Asterisks represent significant mean level changes over time.
* $p \leq .05$. ** $p \leq .01$.

guilty, or afraid) over the past year, by using 5-point Likert-type scales, with the endpoints 1 = *very slightly or not at all* to 5 = *extremely*. This measure has been shown to exhibit trait-like stability in previous research (Watson et al., 1988). For both assessments, we computed separate scores for positive affect and negative affect by averaging the 10 positive emotions ($\alpha_{T1} = .88$, $\alpha_{T2} = .89$), and the 10 negative emotions, respectively ($\alpha_{T1} = .88$, $\alpha_{T2} = .89$).

*Sleep efficiency* was measured by administering the Brief Pittsburgh Sleep Quality Index (Buysse, Reynolds, Monk, Berman, & Kupfer, 1989). Participants were asked to report for the majority of recent days and nights during the past month (a) the time they usually laid down to go to sleep, (b) the time they usually got out of bed in the morning, (c) how long it took them to fall asleep after they had laid down to go to sleep, (d) how many minutes of sleep they had lost because they woke up in the middle of the night, and (e) how many minutes of sleep they had lost because they woke up earlier than their usual time to get up. Sleep efficiency was operationalized by computing an index representing the time that the participants spent in bed during the night sleeping, relative to the overall time that they spent in bed. At baseline, participants spent on average 8.15 hours in bed ($SD = 1.09$), of which 1.42 hours ($SD = 1.09$) were spent without sleeping ($M_{T2} = 8.21$ hours [$SD_{T2} = 1.03$] in bed; $M_{T2} = 1.37$ hours [$SD_{T2} = .98$] without sleeping).

*Sociodemographic characteristics* were assessed in the baseline questionnaire and included participants' age, sex, and socioeconomic status (SES). SES was measured with three variables: highest education level completed (0 = no education, 1 = high school, 2 = college, 3 = BA, 4 = MA or PhD; $M = 2.08$, $SD = 1.05$), yearly family income (0 = less than \$17,000, 1 = up to \$34,000, 2 = up to \$51,000, 3 = up to \$68,000, 4 = up to \$85,000, 5 = more than \$85,000; $M = 1.52$, $SD = 1.29$), and perceived SES (Adler, Epel, Castellazzo, & Ickovics, 2000; $M = 6.15$, $SD = 1.80$). To obtain a global measure of SES, we averaged the standardized scores of the three single SES variables ($M = .01$, $SD = .83$, $\alpha = .70$).

## Results

The description of results is divided into two sections. In the first section, we report analyses testing our hypotheses about effects of cortisol, affect, and sleep efficiency on changes in physical symptoms over time. Given that physical symptoms, affect, and sleep could also influence cortisol secretion, we describe in the second section results from a reversed analysis, predicting changes in diurnal cortisol secretion by baseline levels of physical symptoms, affect, and sleep.

### *Effects on Changes in Physical Symptoms*

We had predicted that affective tendencies and sleep problems could moderate the association between diurnal cortisol secretion and changes in physical problems. To test this hypothesis, we conducted a hierarchical multiple regression analysis, predicting changes in physical symptoms (using residualized scores) as the outcome variable. In the first step of the analysis, we entered sociodemographic characteristics (age, sex, and SES) in addition to baseline levels of positive affect, negative affect, sleep efficiency, and the area-under-the-curve (AUC) measure of diurnal cortisol secretion into the regression equation. In the second step of the analysis, we tested the two-way interactions between positive affect and cortisol level, negative affect and cortisol level, and sleep efficiency and cortisol level separately for significance. In the third step of the analyses, we entered the three-way interactions between affect (for positive and negative affect separately), sleep efficiency, and cortisol level into the regression equation (controlling for the two-way interactions among the three predictors). All predictor variables were centered before conducting the regression analysis.

The results of the analysis are reported in Table 2. None of the sociodemographic characteristics exerted a significant effect on changes in physical symptoms, $Fs(1, 169) < .14$, $R^2s = .00$, $ps > .05$. In addition, the main effects of positive affect, sleep efficiency, and level of diurnal cortisol secretion were not significantly associated with changes in physical symptoms, $Fs(1, 169) < 1.37$, $ps > .05$. However, negative affect significantly predicted changes in physical symptoms, $F(1, 169) = 6.23$, $p < .05$. Participants who reported high levels of negative affect experienced larger increases in physical symptoms over time, as compared to their counterparts who reported low levels of negative affect.

Of importance, the second step of the analysis demonstrated significant two-way interactions between negative affect and cortisol level, $F(1, 168) = 9.34$, $p < .01$, and sleep efficiency and cortisol level, $F(1, 168) = 8.56$, $p < .01$, on changes in physical symptoms over time. No significant effect was obtained for the

Table 2
*Hierarchical Regression Analysis Predicting 2-Yr Changes in Physical Symptoms Over Time by Positive Affect, Negative Affect, Sleep Efficiency, and Diurnal Cortisol Secretion (AUC)*

| | ΔPhysical symptoms | |
|---|---|---|
| Predictors (T1)[a] | $R^2$ | *Beta* |
| Main effects | | |
| Positive affect (PA) | .00 | −.07 |
| Negative affect (NA) | .03* | .20* |
| Sleep efficiency (SE) | .01 | −.09 |
| Diurnal cortisol secretion (AUC) | .00 | .03 |
| Two-way interactions | | |
| AUC X PA | .00 | −.06 |
| AUC X NA | .05** | .23** |
| AUC X *SE* | .04** | −.22** |
| Three-way interactions | | |
| AUC X PA X *SE* | .00 | .03 |
| AUC X NA X *SE* | .02* | −.19* |

[a]The analysis was controlled for age, sex, and socioeconomic status.
* $p < .05$. ** $p < .01$.

two-way interaction between positive affect and cortisol level, $F(1, 168) = .61$, $p > .05$. Finally, the third step of the analysis demonstrated a significant three-way interaction involving negative affect, sleep efficiency, and cortisol level, $F(1, 165) = 4.80$, $p < .05$. The three-way interaction between positive affect, sleep efficiency, and cortisol level did not predict significant changes in physical symptoms over time, $F(1, 165) = .30$, $p > .05$.[2]

To illustrate the significant two-way interactions, we plotted in Figure 1 the associations between cortisol level (1 *SD* above and below the sample mean) and changes in physical symptoms, separately for participants who experienced high (+1 *SD*) and low (−1 *SD*) levels of negative affect (left panel), and participants who reported efficient sleep (+1 *SD*) and poor sleep (−1 *SD*, right panel, see Aiken & West, 1991). The observed pattern of findings suggests that increased levels of physical health problems were found only among participants who secreted high levels of diurnal cortisol and experienced high levels of negative affect (left panel) or poor sleep (right panel). Analyses of the simple slopes supported this interpretation of the data. Cortisol level was significantly associated with increases in health problems over time among participants who experienced high levels of negative affect, +1 *SD*: $\beta = .31$, $p < .01$, or poor sleep, −1 *SD*: $\beta = .30$, $p < .01$, but not among participants with low levels of negative affect or efficient sleep, βs: −.17 to −.19, *p*s > .05. Conversely, negative affect, +1 *SD*: $\beta = .47$, $p < .01$, and poor sleep, −1 *SD*: $\beta = .32$, $p < .01$, significantly predicted increases in physical symptoms over time among participants who secreted elevated levels of cortisol, but not among participants with low levels of cortisol secretion, βs: .03 to −.17, *p*s > .05. These findings support our hypotheses by demonstrating that the more negative affect participants experienced or the less efficient their sleep was, the stronger was the association between cortisol level and increases in physical health problems.

Figure 2 illustrates the obtained three-way interaction by plotting the two-way interactions between cortisol level and negative affect on changes in physical symptoms (1 *SD* above and below the sample means of these variables), separately for participants with poor sleep efficiency (upper panel) and efficient sleep (lower panel) (using a median split of the sleep variable).[3] The observed pattern of findings qualifies the previously reported two-way interactions by demonstrating that high levels of cortisol were associated with increases in physical symptoms only among participants who experienced high levels of negative affect and inefficient sleep. Analyses of the simple slopes support this interpretation by showing that cortisol level was significantly associated with increases in physical symptoms among participants with high levels of negative affect and poor sleep, $\beta = .51$, $p < .01$. By contrast, no significant associations between cortisol level and changes in physical symptoms were found among participants with low levels of negative affect (for both, participants with poor sleep, $\beta = -.10$, $p > .05$, and efficient sleep, $\beta = -.12$, $p > .05$) and participants who experienced high levels of negative affect and efficient sleep, $\beta = -.33$, $p > .05$.

### *Effects on Changes in Cortisol Level*

Given that physical symptoms, affect, and sleep could also influence changes in cortisol secretions, we conducted another regression analysis to obtain additional information needed for interpreting the direction of effects. In this analysis, we predicted changes in diurnal cortisol secretion (AUC) as the outcome variable (using residualized scores), and incorporated baseline levels of affect, sleep efficiency, and physical symptoms as predictor variables (controlling for sociodemographics).

The results of the analysis showed that none of the sociodemographic control variables predicted changes in cortisol level over time, *F*s(1, 167) < 1.36, $R^2$s < .01, *p*s > .05. In addition, baseline levels of positive affect, $F(1, 167) = .86$, $R^2 = .00$, $\beta = .07$, $p > .05$, negative affect, $F(1, 167) = .14$, $R^2 = .00$, $\beta = -.03$, $p > .05$, sleep efficiency, $F(1, 167) = .12$, $R^2 = .00$, $\beta = -.03$, $p > .05$, and physical symptoms, $F(1, 167) = 3.41$, $R^2 = .02$, $\beta = -.15$, $p > .05$, were not significantly associated with changes in cortisol secretion.[4] These results suggest that baseline levels of physical symptoms, affect, or sleep did not contribute to changes in diurnal cortisol secretion over time.

[2] Given that there are different ways of operationalizing an analysis of change, we note that we obtained identical interaction effects if we predicted T2 levels of physical symptoms that were controlled for baseline levels of physical symptoms, all *F*s > 5.97, *p*s < .02. In addition, we could replicate the interactions if we predicted T2 levels of physical symptoms that were not controlled for baseline levels of physical symptoms, all *F*s > 8.26, *p*s < .01, but not if we predicted baseline levels of physical symptoms, *F*s < 2.21, *p*s > .05.

[3] Follow-up analyses showed a significant interaction effect between cortisol level and negative affect for participants with poor sleep, $F(1, 81) = 7.90$, $R^2 = .08$, $\beta = .31$, $p < .01$, but not for participants with efficient sleep, $F(1, 80) = .54$, $R^2 = .01$, $\beta = -.10$, $p > .10$.

[4] We also conducted another set of analyses, predicting changes in affect and sleep over time by baseline levels of physical symptoms, affect, sleep, and cortisol. In these analyses, baseline levels of the predictor variables were largely unrelated to the outcome variables, except for baseline levels of negative affect, which predicted a decline in positive affect over time, $F(1, 165) = 4.86$, $p < .05$.

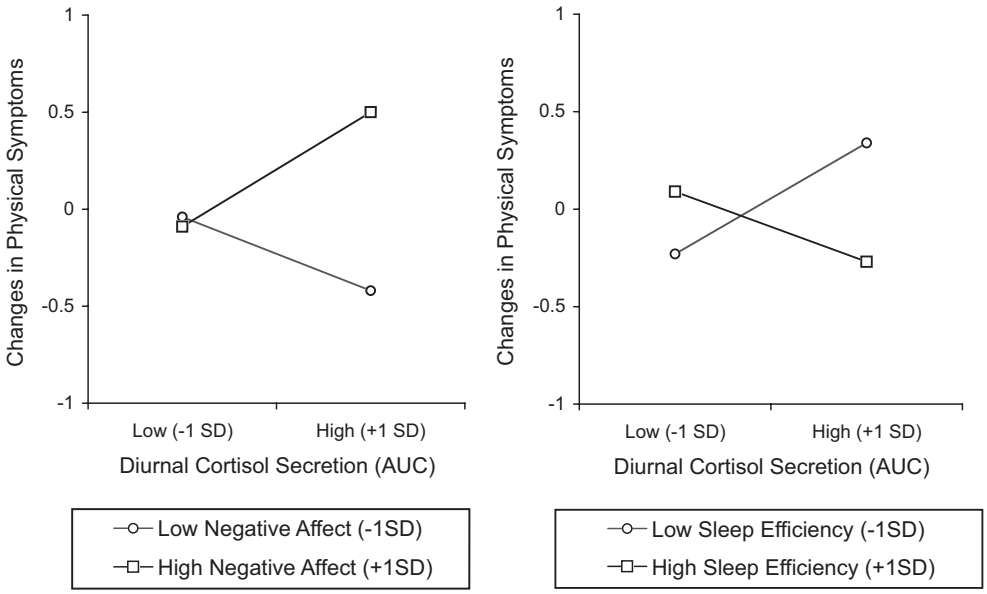


*Figure 1.* Associations between level of diurnal cortisol secretion (AUC) and 2-yr changes in physical symptoms among participants with high versus low levels of negative affect (left panel) and high versus low levels of sleep efficiency (right panel).

## Discussion

The results of the present study support the theoretical claim that high levels of diurnal cortisol secretion can influence older adults' physical health problems if they co-occur in the context of trait negative affect and inefficient sleep. More specifically, the findings from the reported two-way interaction analyses suggest that elevated secretion of diurnal cortisol can be associated with an increase in physical symptoms over time among older adults who experience high levels of negative affect or exhibit poor sleep, but not among older adults who experience low levels of negative affect or efficient sleep. However, the emergence of a significant three-way interaction implies that these effects need to be qualified. In this regard, the reported findings demonstrate that elevated cortisol level forecasted increases in physical symptoms over time only among participants who experienced both, high levels of negative affect and inefficient sleep. By contrast, the adverse effect of high negative affect on the association between cortisol and physical symptoms was ameliorated by efficient patterns of sleep, just as low levels of negative affect buffered the effect of poor sleep on the association between high cortisol level and increases in physical symptoms. These effects were statistically independent from participants' sociodemographic characteristics.

The supplemental analyses documented that changes in cortisol level were unrelated to baseline levels of physical symptoms, affect, or sleep. These results lend additional support to our interpretation of the direction of effects by indicating that physical health effects were driven by biological, affective, and behavioral processes, and not vice versa (for effects on changes in affect and sleep, see Footnote 4). Based on these findings, we conclude that cortisol disturbances can influence physical health problems when they co-occur in the context of other emotional and behavioral problems. In particular, the simultaneous experience of emotional problems and poor sleep can exert an additive effect on the health-related consequences of cortisol disturbance. By contrast, adaptive sleep patterns may compensate for the adverse effect of high levels of negative affect, and vice versa.

We did not find the same effects for the experience of positive affect. A lack of positive emotions was not associated with increases in physical health problems, neither as a main effect nor in interaction with cortisol level and sleep problems. This is surprising, given that research has demonstrated beneficial effects of positive affect on clinical disease outcomes (Cohen, Doyle, Turner, Alper, & Skoner, 2003). A potential explanation for the observed pattern of findings would be that positive affect also exerted some maladaptive functions, and therefore resulted in a null effect on changes in health problems. In fact, there is some indication that extreme levels of positive affect may predict autonomic nervous system activation and thereby could trigger disease events (for a review, see Pressman & Cohen, 2005). In addition, Pressman and Cohen (2005) addressed the possibility that high positive affect may be associated with underreporting of symptoms, which could lead to inappropriate treatment of illness. Although these possibilities may explain differential health effects of positive and negative affect, our study was not designed to provide further empirical evidence for this explanation.

Overall, the study's findings have important implications for psychological models of physical health, as they point to a pathway in which negative affect and sleep can influence the association between biological problems and subsequent physical problems. This implies that there are reliable interactions between biology, personality, and behaviors in the development of physical health problems, and that disturbed cortisol secretion can translate into physical health problems, but not for everyone. In particular, cortisol disturbances may influence physical health problems if

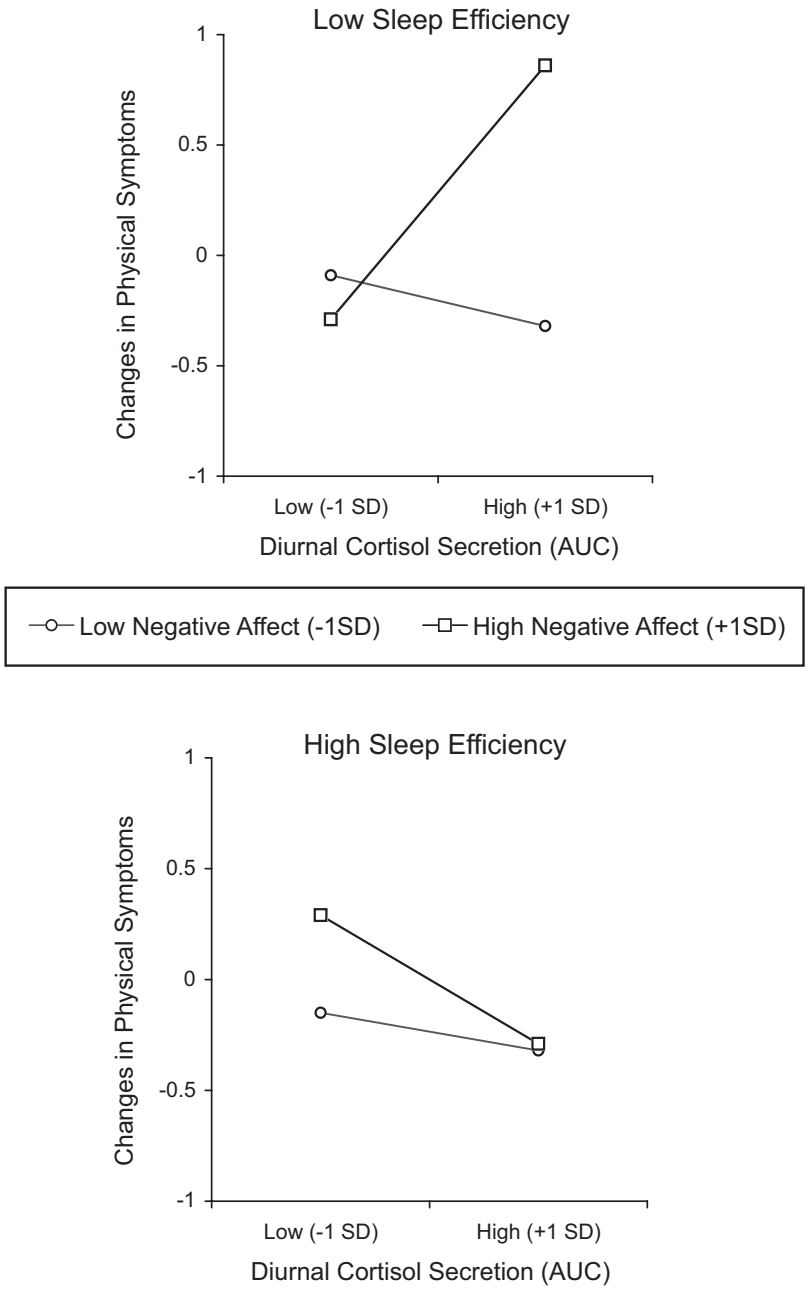


*Figure 2.* Three-way interaction illustrating for participants with inefficient sleep (upper panel) and efficient sleep (lower panel) the moderation effect of negative affect on the association between level of diurnal cortisol secretion (AUC) and 2-year changes in physical symptoms.

people experience emotional problems and engage in maladaptive sleep behaviors. By contrast, people who are emotionally well or engage in effective sleep patterns may not experience adverse physical health effect of increased levels of cortisol secretion.

The identification of this pathway may also inform more general models of stress and disease, which conceptualize cortisol secretion as a mediator between stressful experiences and physical problems (Cohen et al., 1995). However, research has struggled with documenting a direct link between stressful experiences, cortisol, and clinical outcomes (Cohen et al., 1998; Wrosch, Bauer et al., 2007). In fact, results from this line of research suggest that the direct impact of cortisol on the association between stress and physical health is, at best, only small. This implies that the pathways linking stress and health are still not very well understood, and theoretical models may be improved if the complex interactions between personality, behaviors, and biology are considered more comprehensively. In this regard, we note that our primary aim was to demonstrate a general mechanism, and there are likely

other personality, social, and behavioral variables (e.g., coping, social support, or other health-compromising behaviors) that could exert similar effects and contribute to improving psychological theories about physical health.

Finally, our study may have some clinical implications. For obvious reasons, it may be difficult to change a person's general tendency to experience negative emotions. However, our findings suggest that trait negative affect is not necessarily closely linked with sleep problems, and negative affect may not increase a person's vulnerability for developing physical problems if the person exhibits effective sleep patterns. Thus, clinical interventions may be more successful if they target changes in sleep patterns (e.g., Morin, Culbert, & Schwartz, 1994) than in emotional tendencies. In this regard, it may be possible to screen people for high cortisol levels, negative affect, and poor sleep, and to support them in maintaining their physical health.

## Limitations and Future Research

There are limitations to this research that need to be addressed in future studies. First, our measures of physical symptoms were based on self-reports, and negative affect could have biased participants' physical health reports (Watson & Pennebaker, 1989). However, we do not think that this limitation seriously compromises the interpretation of findings, given that we predicted a change measure as the outcome variable, which is likely to partial out some of the potential biases in health reports. In addition, it seems unlikely that negative affect had biased 2-yr changes in health reports only among participants who secreted high levels of diurnal cortisol and poor sleep at baseline. Nonetheless, future research should assess objective health outcomes (e.g., physician reports, morbidity, and mortality) to substantiate our findings.

Second, we acknowledge that the pattern of the reported effects may suggest that cortisol secretion was associated with some small health improvements among participants who experienced low negative affect or efficient sleep. Of importance, none of these associations were significant in our analyses. However, we note that a recent study found that treating participants with cortisol predicted improved mood after a stressful experience (Het & Wolf, 2007). Such an effect could also contribute to adaptive behaviors and thereby may provide an explanation for the small but nonsignificant trends.

Third, it could be that previous reciprocal effects between affect, cortisol, and sleep had resulted in a combination of elevated cortisol, negative affect, and sleep problems that we found among participant who experienced increases in physical symptoms. In addition, we note that our data showed that negative affect was associated with sleep problems at baseline. This makes it possible that stable emotional tendencies could have influenced baseline levels of sleep problems (for associations between personality and behaviors, see Allport, 1961), and thereby produced an adverse effect on the association between cortisol and physical health problems. Given that our study design cannot address these possibilities, future research should conduct fine-grained longitudinal studies to explore whether cortisol, affect, and behaviors may influence each other and mediate effects on physical health.

Fourth, our analyses did not identify factors that contributed to the observed increase of cortisol secretion over time. We therefore suggest that future studies should cover a wider range of variables that could prevent increases in cortisol secretion by facilitating effective coping with stressful events.

Finally, the analyses did not address other biological processes (e.g., immune responses or metabolic processes, Irwin et al., 2006; Miller et al., 2004; Spiegel et al., 1999) or the development of more severe health problems (e.g., cancer, heart problems, or functional limitations). Our study did not include other biological variables, and we predicted physical symptoms because our sample of older adults was on average relatively healthy. However, this sample is currently approaching a life phase during which severe health problems become more prevalent (Smith & Baltes, 1997). Therefore, we suggest to examine other biological processes and the development of severe health problems in our future studies. We are confident that research along these lines has the potential to further illuminate the importance of psychological factors in the associations between biological processes and physical health.

## References


Adler, N. E., Epel, E., Castellazzo, G., & Ickovics, J. (2000). Relationship of subjective and objective social status with psychological and physiological functioning: Preliminary data in healthy white women. *Health Psychology, 19,* 586–592.

Aiken, L. S., & West, S. G. (1991). *Multiple regression: Testing and interpreting interactions.* Newbury Park: Sage.

Allport, G. W. (1961). *Pattern and growth in personality.* New York: Holt, Rinehart, & Winston.

Bruce, M. L. (2000). Depression and disability. In G. M. Williamson & D. R. Shaffer (Eds.), *Physical illness and depression in older adults: A handbook of theory, research, and practice* (pp. 11–29). New York, Kluwer Academic/Plenum Press Publishers.

Buckley, T. M., & Schatzberg, A. (2005). Review: On the interactions of the hypothalamic-pituitary-adrenal (HPA) axis and sleep: Normal HPA axis activity and circadian rhythm, exemplary sleep disorders. *The Journal of Clinical Endocrinology and Metabolism, 90,* 3106–3114.

Buysse, D. J., Reynolds, 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 Research, 28,* 193–213.

Cacioppo, J. T., Hawkley, L. C., Crawford, L. E., Ernst, J. M., Burleson, M. H., Kowalewski, R. B., et al. (2002). Loneliness and health: Potential mechanisms. *Psychosomatic Medicine, 64,* 407–417.

Clements, A. D., & Parker, C. R. (1998). The relationship between salivary cortisol concentrations in frozen versus mailed samples. *Psychoneuroendocrinology, 23,* 613–616.

Cohen, S., Doyle, W. J., Turner, R. B., Alper, C. M., & Skoner, D. P. (2003). Emotional style and susceptibility to the common cold. *Psychosomatic Medicine, 65,* 652–657.

Cohen, S., Frank, E., Doyle, W. J., Skoner, D. P., Rabin, B. S., & Gwaltney, J. M. (1998). Types of stressors that increase susceptibility to the common cold in health adults. *Health Psychology, 17,* 214–223.

Cohen, S., Janicki-Deverts, D., & Miller, G. E. (2007). Psychological stress and disease. *Journal of the American Medical Association, 298,* 1685–1687.

Cohen, S., Kessler, R. C., & Underwood, L. G. (1995). Strategies for measuring stress in studies of psychiatric and physical disorders. In S. Cohen, R. C. Kessler, & L. G. Underwood (Eds.), *Measuring stress: A guide for health and social scientists* (pp. 3–28). New York: Oxford University Press.

Dew, M. A., Hoch, C. C., Buysse, D. J., Monk, T. H., Begley, A. E., Houck, P. R., et al. (2003). Healthy older adults' sleep predicts all-cause mortality at 4 to 19 years of follow-up, *Psychosomatic Medicine, 65,* 63–73.

Dickerson, S. S., & Kemeny, M. E. (2004). Acute stressors and cortisol responses: A theoretical integration and synthesis of laboratory research. *Psychological Bulletin, 130,* 355–391.

Griffin, K. W., Friend, R., Eitel, P., & Lobel, M. (1993). Effects of

environmental demands, stress, and mood on health practices. *Journal of Behavioral Medicine, 16,* 643–661.

Heim, C., Ehlert, U., & Hellhammer, D. (2000). The potential role of hypocortisolism in the pathophysiology of stress-related bodily disorders. *Psychoneuroendocrinology, 25,* 1–35.

Het, S., & Wolf, O. T. (2007). Mood changes in response to psychosocial stress in healthy young women: Effects of pretreatment with cortisol. *Behavioral Neuroscience, 121,* 11–20.

Irwin, M. R., Wang, M., Campomayor, C., Collado-Hidalgo, A., & Cole, S. (2006). Sleep deprivation and activation of morning levels of cellular and genomic markers of inflammation. *Archives of Internal Medicine, 166,* 1756–1762.

Jacobs, N., Myin-Germeys, I., Derom, C., Delespaul, P., van Os, J., & Nicolson, N. A. (2007). A momentary assessment study of the relationship between affective and adrenocortical stress responses in daily life. *Biological Psychology, 74,* 60–66.

Jennings, J. R., Muldoon, M. F., Hall, M., Buysse, D. J., & Manuck, S. B. (2007). Self-reported sleep quality is associated with the metabolic syndrome. *Sleep, 30,* 219–223.

Kirschbaum, C., & Hellhammer, D. (1989). Salivary cortisol in psychobiological research: An overview. *Neuropsychobiology, 22,* 150–169.

Kirschbaum, C., Kudielka, B. M., Gaab, J., Schommer, N. C., & Hellhammer, D. H. (1999). Impact of gender, menstrual cycle phase, and oral contraceptives on the activity of the hypothalamic-pituitary-adrenal axis. *Psychosomatic Medicine, 61,* 154–162.

Lupien, S. J., de Leon, M., De Santi, S., Convit, A., Tarshish, C., Nair, N. P. V., et al. (1998). Cortisol levels during human aging predict hippocampal atrophy and memory deficits. *Nature Neuroscience, 1,* 69–73.

McEwen, B. S. (1998). Protective and damaging effects of stress mediators. *New England Journal of Medicine, 338,* 171–179.

Miller, G. E., Chen, E., & Zhou, E. S. (2007). If it goes up, must it come down? Chronic stress and the hypothalamic-pituitary-adrenocortical axis in humans. *Psychological Bulletin, 133,* 25–45.

Miller, G. E., Cohen, S., Pressman, S., Barkin, A., Rabin, B. S., & Treanor, J. J. (2004). Psychological stress and antibody response to influenza vaccination: When is the critical period for stress, and how does it get inside the body? *Psychosomatic Medicine, 66,* 215–223.

Morin, C. M., Culbert, J. P., & Schwartz, S., M. (1994). Nonpharmacological interventions for insomnia: A meta-analysis of treatment efficacy. *American Journal of Psychiatry, 151,* 1172–1180.

Polk, D. E., Cohen, S., Doyle, W. J., Skoner, D. P., & Kirschbaum, C. (2005). State and trait affect as predictors of salivary cortisol in healthy adults. *Psychoneuroendocrinology, 30,* 261–272.

Pressman, S. D., & Cohen, S. (2005). Does positive affect influence health? *Psychological Bulletin, 131,* 925–971.

Pressman, S. D., & Cohen, S., Miller, G. E., Barkin, A., Rabin, B. S., & Treanor, J. J. (2005). Loneliness, social network size, and immune response to influenza vaccination in colleague freshmen. *Health Psychology, 24,* 297–306.

Schaeffer, M. A., & Baum, A. (1984). Adrenal cortical response to stress at Three Mile Island. *Psychosomatic Medicine, 46,* 227–237.

Sephton, S. E., Sapolsky, R. M., Kraemer, H. C., & Spiegel, D. (2000). Diurnal cortisol rhythm as a predictor of breast cancer survival. *Journal of the National Cancer Institute, 92,* 994–1000.

Shaver, J. L. F., Johnston, S. K., Lentz, M. J., & Landis, C. A. (2002). Stress exposure, psychological distress, and physiological stress activation in midlife women with insomnia. *Psychosomatic Medicine, 64,* 793–802.

Smith, G. D., Ben-Shlomo, Y., Beswick, A., Yarnell, J., Lightman, S., & Elwood, P. (2005). Cortisol, testosterone, and coronary heart disease. *Circulation, 112,* 332–340.

Smith, J., & Baltes, P. B. (1997). Profiles of psychological functioning in the old and oldest old. *Psychology and Aging, 12,* 458–472.

Spiegel, K., Leproult, R., & Van Cauter, E. (1999). Impact of sleep debt on metabolic and endocrine function. *Lancet, 354,* 1435–1439.

Spitzer, R. L., Williams, J. B., Kroenke, K., Linzer, M., deGruy, F. V., Hahn, S. R., et al. (1994). Utility of a new procedure for diagnosing mental disorders in primary care. The PRIME-MD 1000 study. *Journal of the American Medical Association, 272,* 1749–1756.

Steiger, A. (2002). Sleep and the hypothalamo-pituitary-adrenocortical system. *Sleep Medicine Reviews, 6,* 125–138.

Steiger, A. (2003). Sleep and endocrinology. *Journal of Internal Medicine, 254,* 13–22.

van Eck, M. M. M., Berkhof, H., Nicolson, N. A., & Sulon, J. (1996). The effects of perceived stress, traits, mood states, and stressful daily events on salivary cortisol. *Psychosomatic Medicine, 58,* 447–458.

Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: The PANAS Scales. *Journal of Personality and Social Psychology, 54,* 1063–1070.

Watson, D., & Pennebaker, J. W. (1989). Health complaints, stress, and distress: Exploring the central role of negative affectivity. *Psychological Review, 96,* 234–254.

Weiner, H. (1992). *Perturbing the organism: The biology of stressful experience.* Chicago: University of Chicago Press.

Wrosch, C., Bauer, I., Miller, G. E., & Lupien, S. (2007). Regret intensity, diurnal cortisol secretion, and physical health in older individuals: Evidence for directional effects and protective factors. *Psychology and Aging, 22,* 319–330.

Wrosch, C., & Schulz, R. (2008). Health engagement control strategies and 2-year changes in older adults' physical health. *Psychological Science, 19,* 537–541.

Wrosch, C., Schulz, R., & Heckhausen, J. (2002). Health stresses and depressive symptomatology in the elderly: The importance of health engagement control strategies. *Health Psychology, 21,* 340–348.

Wrosch, C., Schulz, R., & Heckhausen, J. (2004). Health stresses and depressive symptomatology in the elderly. A control-process approach. *Current Directions in Psychological Science, 13,* 17–20.

Wrosch, C., Schulz, R., Miller, G. E., Lupien, S., & Dunne, E. (2007). Physical health problems, depressive mood, and cortisol secretion in old age: Buffer effects of health engagement control strategies. *Health Psychology, 26,* 341–349.