The Effects of Sleep Loss on Medical Residents' Emotional Reactions to Work Events: a Cognitive-Energy Model

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Study objectives: This study investigated the relationship between sleep loss and emotional reactivity in medical residents. We hypothesized that this relationship is shaped by the effect of sleep loss on cognitive-energy resources required for coping with goal-disruptive events or for capitalizing on new opportunities offered by goal-enhancing events.
Settings: 15 medical wards in 4 large hospitals in Israel.
Participants: 78 medical residents, 67% men, aged 26 to 39 years.
Design: Actigraphic sleep-wake cycles were measured for 5- to 7-day periods, surrounding nightshifts, every 6 months, covering the first 2 years of residency. During each study period, emotional reactivity was investigated using the experience-sampling methodology by which residents received 3 phone calls at random times during their working day for 3 consecutive days. These calls reminded them to fill out brief questionnaires concerning change of circumstances over the previous 15 minutes and to rate their emotional response to these circumstances using the Positive Affect and Negative Affect Scales. Fatigue at those times was measured by a subscale of the Profile of Mood States.
Measurements and Results: Multilevel regression analysis was used to determine the influence of sleep duration and sleep fragmentation on the emotional reactions to goal-disruptive and goal-enhancing daytime events. We found that sleep loss intensified negative emotions and fatigue following daytime disruptive events, while positive emotion was mitigated following goal-enhancing events. Sleep loss also resulted in an overall elevated baseline for positive emotion.
Conclusions: Sleep loss amplifies the negative emotive effects of disruptive events while reducing the positive effect of goal-enhancing events. Methodologically, the study highlights the utility and advantages of event-level analysis as opposed to the current practice of random sampling of emotion states during waking hours, disregarding contextual factors associated with purposeful, goal-oriented behavior episodes.
Key Words: sleep, emotions, experience sampling, medical residents, actigraph.
Citation: Zohar D; Tzischinsky O; Epstein R et al. The Effects of sleep loss on medical residents' emotional reactions to work events: a cognitive-energy model. *SLEEP* 2005;28(1):47-54.

INTRODUCTION

EMOTIONAL CONSEQUENCES OF SLEEP LOSS HAVE BEEN LITTLE STUDIED, DESPITE COMMON COMPLAINTS OF IRRITABILITY AND AFFECTIVE VOLATILITY FOLLOWING SLEEPLESS NIGHTS. In many sleep-deprivation studies investigating the effects of sleep loss on performance, mood was also investigated using either the profile of mood states (POMS) or visual analog scales (VAS), administered at regular intervals during the sleep-deprivation period or at the beginning and end of the study periods.[1-7] Generally, results have shown a significant negative effect of sleep loss on most mood states. Dinges et al,[1] for instance, reported an increasing mood disturbance over 7 days of sleep restriction in a controlled laboratory setting, using 3 daily mood recordings with the POMS and VAS questionnaires. Moreover, subjects' responses on an open-ended daily log revealed increasing complaints concerning cognitive and emotional difficulties.

At the same time, available studies offer no formal explanation for this relationship. One objective of the present study is to offer a theoretical explanation of the sleep-mood relationship. A second objective concerns the fact that recent advances in emotion research indicate that emotion is fundamentally a response to changing life circumstances, ie, it must be interpreted in the context of psychologically relevant events at work or home, eg, Affective Events Theory.[8] Frijda[9] noted thus that "emotions have an object, they are about something… One is happy about something, angry at someone, afraid of something."[9p381] Measuring emotional states at random times during the day to the exclusion of precipitating events (ie, the current practice in available studies on sleep and emotion), suffers thus from a methodologic weakness. A superior methodology should incorporate affective events in the study design, measuring the effect of sleep loss on emotional reaction to psychologically relevant events. The second objective of this study is, therefore, to test the effect of sleep loss on intensity of emotional reaction following relevant events during the day.

The theoretical link between sleep and emotion is provided by Zohar et al,[10] whose cognitive-energy model posits that, because disruptive or challenging circumstances require effortful self-regulation, the levels of energy available for behavior self-regulation will influence intensity of emotional reaction. This model relates to extensive literature concerning feedback-control models of behavior[11,12] and cognitive models of emotion.[13] Jointly, these models and accompanying research indicate that feedback information signifying progress toward a valued goal[11,13] or a satisfactory rate of progress in reference to some temporal criterion[14,15] promotes positive emotion, whereas information signify-

Disclosure Statement
This is not an industry supported study. Dr. Lavie is a consultant and board member of Itamar Medical Ltd. and SLP Ltd.; is a board member of Sleep Medicine Center, Israel, and Sleep Health Centers, U.S.; and has received research support from Itamar Medical and SLP. Drs. Zohar, Epstein, and Tzischinsky have indicated no financial conflicts of interest.

Submitted for publication September 2003
Accepted for publication August 2004
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ing interrupted or excessively slow progress promotes negative emotion. One factor likely to influence rate of progress is availability of cognitive energy, which is required for sustaining the various aspects of self-regulated action.[16-19] Cognitive energy associated with self-regulation is a critical resource because it is finite, rapidly consumed, and slow to recover, requiring timely replenishment before delay further undermines regulation efficiency.[20,21] Since any motive-relevant change of circumstances (identified also as affective event) requires change of plans, posing higher behavior-regulation demands, it endangers cognitive-energy costs. Unless the available energy resources match the demands associated with the pursuit of an important goal, this misfit will be assessed as a threat, resulting in negative emotion, whereas assessment of the situation as a challenge based on adequate resources will result in positive emotion. All of the above suggests that, if sleep-loss reduces available energy supplies (inasmuch as adequate sleep replenishes spent energy resources), this provides a link between sleep and emotion.

The proposition that sleep loss exerts a significant effect on cognitive-energy supplies is based on evidence suggesting that sleep loss, totally or partially, results in impaired performance on cognitive tests requiring self-regulation, such as psychomotor tasks, and in a significant decrease in subjective assessment of energy levels.[1,22] Surgeons operating after a disturbed night's sleep have been shown to display lower levels of performance,[23] as have hospital residents performing psychomotor tasks after being on call the previous night.[24] The extensive literature indicating that sleep loss results in elevated subjective sleepiness, fatigue, and confusion the following day[25] provides strong support for the proposition that sleep loss affects the cognitive-energy supplies.

In the present study, we consider 2 facets of sleep loss, which should have similar effects on energy supplies, ie, reduced duration of sleep and its fragmentation by frequent wake ups. (In fact, we use a derivative of sleep fragmentation, identified as wake-up density, or the number of wake ups per unit of time in bed). Both facets will affect the replenishment of energy resources during sleep, influencing cognitive-energy availability the following day.[26,27]

Further analysis suggests that the relationship between sleep loss and emotion will vary depending on event type. Broadly speaking, motive-relevant change of circumstances may disrupt or enhance progress toward desired goals. Goal-disruptive events in which pursuit of the focal goal is disrupted require extra behavioral effort associated with coping strategies such as confronting, distancing, and support seeking.[28] If the initial level of energy is low due to lack of sleep or fragmented sleep, negative emotion following a goal-disruptive event is expected to increase because the event consumes depleted resources while presenting a smaller likelihood of successful coping. This is conducive to incremental resource loss, which is, in itself, a threatening situation.[29,30] Congruently, feedback concerning progress[13,14] will also be unsatisfactory. All this should result in stronger negative emotion when disruptive events are encountered under conditions of sleep loss or fragmented sleep, leading to the following hypotheses:

Hypothesis 1a: The relationship between goal-disruptive events and negative emotion will be moderated by sleep duration (ie, more negative emotion with decreasing sleep).

Hypothesis 1b: The relationship between goal-disruptive events and negative emotion will be moderated by wake-up density (ie, more negative emotion with increasing wake-up density).

The situation is different for positive emotion indicative of challenge after goal-enhancing events. Goal-enhancing events derive from unexpected opportunities, which often lead to raising performance standards[31] or adopting new, more-challenging, hence, more-difficult goals derived from higher-level personal goals.[13,32] In this case, emotional intensity should decrease under conditions of sleep loss or fragmented sleep because this situation offers limited prospects for capitalizing on new opportunities for self-enhancement precisely because there is too little energy available, ie, lesser challenge. In this case, resource limitation should attenuate appraisal of coping potential[30] and curtail tendencies to raise performance standards or adopt more-challenging goals. These arguments suggest the following hypotheses:

Hypothesis 2a: The relationship between goal-enhancing events and positive emotion will be moderated by sleep duration (ie, lesser positive emotion with decreasing sleep).

Hypothesis 2b: The relationship between goal-enhancing events and positive emotion will be moderated by wake-up density (ie, lesser positive emotion with increasing wake-up density).

Finally, since major models of emotion consider negative and positive affect as the valence dimension of emotional reaction, with activation providing the second dimension (eg, Russell and Carroll's circumplex model[33]), we used the fatigue-inertia subscale in the POMS[34] as the complementary variable in our analysis, representing the activation dimension. Arguably, any motive-relevant change of circumstances (disruptive or enhancing) requires changes of plan—posing higher behavior-regulation demands—ie, it endangers cognitive-energy costs. In addition to the direct cost of self-regulation (ie, cognitive effort), such events also induce greater behavioral efforts associated with increased behavioral output. When required energy resources are diminished due to sleep loss or frequent wake ups, the individual would have to allocate scarce resources to maintain progress toward desired goals.[15] However, drawing on scarce resources results in further dwindling of these resources, resulting in a loss cycle,[35] ie, greater fatigue. This leads to the following hypotheses:

Hypothesis 3a: The relationship between motive-relevant events and fatigue will be moderated by sleep duration (ie, greater fatigue with decreasing sleep).

Hypothesis 3b: The relationship between motive-relevant events and fatigue will be moderated by wake-up density (ie, greater fatigue with increasing wake-up density).

METHOD

Subjects

A total of 78 hospital residents were recruited for this study. The residents were 26 to 39 years old, 67% were men (mean age: 30.7 ± 2.1 years) and 33% women (mean age: 30.3 ± 3.3 years) working in 15 different medical departments in 4 large hospitals in Israel (Rambam, Bnei-Zion, and Carmel in Haifa and Ichilov in Tel Aviv). At the start of the study, 67% were married and 14% had children (mean number of children was 2.1). Participants' identities were encoded to ensure absolute confidentiality, and the senior hospital staff were thus unable to recognize participants and eliminated potential pressure in this regard.

It should be noted that residents in Israel work 6 days a week (45 hours a week), with 2 days off each month. In addition, they work 9 to 10 shifts per month during the first year of residency and 6 to 8 shifts per month in the second year. Shifts begin at 4:00

PM, after a regular working day, and last until 8:00 AM the next morning. During the night, residents are permitted to sleep after completing the required night duties, although they may be awoken whenever required. Following the night shift, some residents finish working (at 8:00 AM) whereas others continue to work until the end of the following day (4:00 PM in the afternoon). Thus, one shift might involve a stretch of 32 hours of continuous work.

Procedure

The study combined a longitudinal design with experience sampling methodology (ESM). This methodology involves in situ, signal-contingent recording of events and related cognitions and emotions.[36,37] Participants received 3 phone calls at random times during their workday for 3 consecutive days, reminding them to fill out the 1-page questionnaire (ie, questionnaires have been filled only during daytime hospital work). If engaged in urgent duties at the time, they had to complete the questionnaire within the next 15 minutes. The questionnaire requires factual data concerning change of circumstances (ie, event occurrence) during the preceding 15 minutes and includes brief emotion and fatigue scales. We used a semirandom signaling schedule, excluding time bands for scheduled activities such as meals or doctors' rounds.

The longitudinal design involved repeated, semiannual ESM applications, so that each participant provided 4 sets of ESM data, 6 months apart. This resulted in hierarchical within-subject data sets, with each data point nested within 1 day, 3-day sampling period, and subject. As noted by Alliger and Williams,[36] ESM provides reliable data concerning daily activity and environmental circumstances under a wide variety of experimental conditions. Thus, although sleep-induced energy loss might have affected the reporting and appraisal of events, such bias is expectedly limited. Furthermore, data analysis by hierarchical linear modeling (HLM) eliminates self-report bias because repeated observations are adjusted by each person's mean response on the dependent variable, in addition to controlling confounding of between- and within-subject variance.[38,39] When subjects were on the night shift, they were asked to wear an actigraph recorder, providing temporally based data concerning the distribution of inactivity episodes, which are functionally equivalent with sleep. Data concerning wake ups during the night shift was obtained from a log kept by participants, who turned it in during the next day. This information provided a distinction between spontaneous and externally induced wake ups.

Measures

Affective events were measured with yes/no questions concerning change of circumstances over the previous 15 minutes. Goal-disruptive events were measured with the following questions, prefixed with the phrase "During the last 15 minutes: Has someone or something disrupted your scheduled activity? Have you had to divert time or effort from medical duties to administrative issues? Have you encountered an unforeseen or new difficulty in continuing a scheduled activity?" Examples of such events include cases where the doctor is paged by phone in the middle of scheduled activity, requiring him or her to leave a patient's bed and pick up the phone at the nursing station. A similar event is an intrusive query by a patient or nurse in the midst of some other activity, which might require cognitive effort to provide a satisfactory answer. Alternatively, a doctor might confront machine malfunction or medication unavailability, requiring departure from planned behavior. Goal-enhancing events were measured with the following questions: "During the last 15 minutes: Have you had an opportunity to perform a medically challenging task? Have you had an opportunity to diversify your professional work? Have you encountered a medically interesting issue or subject?" These questions were based on preliminary interviews and debriefings, during which it became apparent that hospital residents perform the basic medical duties in each department. Completing such duties on schedule constitutes the focal, task-level goal (eg, completing doctors' rounds at a specific time), and "goal-disruptive items" refer to this goal. Although scheduled activity offers substantial clinical experience, hospital residents always look for new experiences in order to broaden their clinical skills, and goal-enhancing items refer to this metatask (professional) goal. For example, goal-enhancing events include performing a little-practiced or novel professional task or having the opportunity to watch a senior physician perform such a task. Another example relates to managing a complex case with multiple symptoms and interacting medications. Jointly, scale items are based on the notion of goal hierarchy whereby, although attention is normally directed at task-level goals, it oscillates between levels depending on situational constraints and opportunities.[12,13] The questions employ phrases that are widely used in this population, eg, "scheduled activity," "administrative duties (as hassle)," "medical challenges," or "interesting cases." Pretest versions of the questionnaire also requested brief event descriptions next to each "yes" answer, to ascertain that items trigger responses referring to actual events from the corresponding category. Each event category is coded as a dummy variable, receiving a value of 1 if 1 or more items were checked "yes," otherwise receiving 0. This procedure was adopted because a single event might prompt respondents to check more than 1 item. Furthermore, event frequency was highly skewed, with very few 15-minute intervals associated with more than 1 disruptive and/or enhancing event.

Sleep duration was monitored by a wrist-worn actigraph (Ambulatory Monitoring, Inc., Mini-Act-32, Ardsley, NY). The actigraph was attached to the nondominant hand for 5 to 7 days and collected data in 1-minute intervals. Actigraphic data were analyzed with the actigraphic scoring analysis software program for personal computers.[40] Sleep duration is a continuous variable referring to the number of sleep hours during night sleep that preceded the collection of daily events and emotion data (note, however, that median splits are performed to construct the figures describing relevant interactions).

Sleep fragmentation was measured with self-reported log data of wake-up calls during night shifts. As noted above, residents' sleep during night shifts is often interrupted.[25] The fragmentation parameter is a continuous variable representing the ratio between total sleep duration and number of wake ups on that night (ie, number of wake ups divided by sleep hours, or wake-up density). Fragmentation improves when the same number of sleep hours is accompanied by fewer wake ups.

Negative and positive affect was measured with a brief version of the NA and PA subscales in PANAS[41] (Positive Affect and Negative Affect Scales), using 4 items on each subscale. NA items were Irritable, Nervous, Upset, and Distressed. PA items were Inspired, Attentive, Interested, and Proud. No item overlaps with the fatigue adjectives used this study. This scale has been validated for measuring state and trait affectivity, depending on instructions.[42] Subjects were instructed to rate each item to describe their immediate emotions, using a 5-point scale varying from “Not at all” to “Extremely.” Alpha reliability of the NA subscale was 0.94 and of the PA subscale, -0.89.

Fatigue was measured with 4 adjectives from the Fatigue (FA) subscale in POMS.[34] The descriptors here were Fatigued, Tired, Exhausted, and Spent, and they were randomly inserted between the PANAS items, using the same 5-point scale. Alpha reliability of this scale was 0.87.

Statistical Analysis

Comparison of sleep duration between the 24 hours before the shift, during the shift, and after the shift was done by means of mixed-effects analysis of variance followed by planned post-hoc comparisons. Moderated multilevel regression models were used for testing the various hypotheses. The independent variables in these models were event types (ie, occurrence of goal-disruptive and goal-enhancing events, entered simultaneously in the statistical model), the dependent variables were emotional reactions (ie, level of immediate NA, PA, or FA), and the moderator variables were indicators of sleep loss during night shifts that preceded the collection of daytime events and emotion data (ie, sleep duration and sleep fragmentation). As noted above, sleep duration was based on actigraphic data, whereas sleep fragmentation was based on self-reported log data, both represented as continuous variables (subsequently dummy coded for constructing the figures describing relevant interactions). Assuming that the pattern of sleep over the last few nights might exert cumulative effects, we performed stepwise regression analysis, entering last night’s sleep data (Night-n) in step 1, Night (n-1) data in step 2, and Night (n-2) data in step 3. Results indicated that only the Night-n data influenced the outcome variables; thus, the final statistical models only include these data.

Because ESM data result in nested within-subject data sets, we analyzed the data by means of multilevel, or HLM.[44] We adopted the procedure recommended by Bliese in 2002[38] and Singer in 1998[45] using SAS Proc Mixed (SAS Institute Inc, Cary, NC).[46] As noted above, HLM statistical models minimize the effect of response bias, which is especially relevant in emotion research. To estimate effect sizes for HLM models, we used the procedure recommended by Snijders and Bosker[47] for computing level-1 R^2 values for such models (ie, explained event-level variance). This procedure estimates the proportional reduction of error in predicting individual values of the dependent variable (ie, Y_{ij}, where Y_i is emotional reaction nested in Subject_j). The explained event-level variance is thus defined as the proportional reduction in mean squared prediction error. These R^2_1 values also provide estimates of the incremental effect of relevant interaction terms. The sampling period (ie, 4 measurement waves) provided no main or interaction effects and was therefore removed from statistical models. Because work schedules become increasingly more regular with the progression of residency, the null effect of sampling period suggests that global sleep regularity provides no incremental effects over last night’s (night-n) data. This is consistent with the absence of incremental effects for previous nights’ sleep data (ie, nights n-1, n-2) concerning daytime emotional reactivity.

The various moderation hypotheses specify sleep duration or sleep fragmentation as 2 lower-level moderators of emotional reaction elicited by the higher-level categories of disruptive events or enhancing events. The statistical model for testing the various moderation hypotheses was as follows (using Hypothesis 1a as an example):

$L1$: $NA = \beta_{0j} + \beta_{1j} {*} SD + e_{ij}$

$L2$: $\beta_{0j} = \gamma_{00} + \gamma_{01} {*} DE + \upsilon_{oj}$

$L3$: $\beta_{1j} = \gamma_{10+}\ \gamma_{11} {*} DE + \upsilon_{1j}$

Note: L1 = Level 1; L2 = Level 2; NA = Negative Affect; DE = Disruptive Event; SD = Sleep Duration; β_{0j}; = Intercept; β_{1j};= Slope of SD; γ_{00}; = Intercept of level-2 regression predicting β_{0j}; γ_{01} = Slope of level-2 regression (DE) predicting β_{0j}; γ_{10} = Intercept of level-2 regression predicting β_{1j}; γ_{11} = Slope of level-2 regression (DE) predicting β_{1j}; υ_{oj} = Error term for level-1 intercept (β_{0j}); υ_{1j} = Error term for level-1 slope (β_{1j}); e_{ij} = overall error term.

RESULTS

Hospital residency entails multiple demands with implications on sleep loss that need to be described before proceeding with hypothesis testing. Analysis of actigraphic data revealed no significant differences between men and women in any of the sleep parameters, neither at home nor during the night shift, thus their data were pooled for analysis. The mean number of shifts per week was 2.08 ± 0.8 at the beginning of residency, resulting in 9 to 10 shifts per month during the first year of residency. Sleep duration was averaged separately for the 24 hours before, during, and after the shift. Since there were no differences in sleep duration between the different recording periods, data obtained during the 2-year residency period were pooled for statistical analysis. During the first year of residency, 11% to 14% of residents remained awake all night during the night shift. Sleep efficiency, that is the percentage of sleep time out of total bedtime, was relatively high (mean 91.8% ± 5.5%), without significant differences between sleep at home (91.6% ± 6.3%) and at the hospital (92.1% ± 6.3%). Comparing sleep during the night before and the night after the shift and on the shift itself revealed that, as expected, residents slept significantly less during a night shift compared to the nights surrounding the shift (255 ± 61 vs 434 ± 69 minutes, $P < .0001$). They slept almost an additional hour on the night after the shift compared to the night before the shift, but this difference fell short of statistical significance (472 ± 92 minutes vs 414 ± 70.7 minutes). Table 1 presents the relevant sleep parameters, measured before, during, and after a shift at the beginning of residency, ie, total sleep per 24 hours, duration of night sleep, and sleep onset and wakeup times.

Descriptive statistics and intercorrelations among variables in the statistical models used for hypothesis testing are presented in Table 2. Since our data are based on repeated within-subject records, correlations are computed based on mean scores of each subject, rather than by treating each entry as an independent record.[43] Table 2 indicates that goal-disruptive events were significantly correlated with NA and FA, whereas goal-enhancing events were correlated with PA and FA. Additionally, the 3 outcome variables (NA, PA, and FA) are significantly intercorrelated, with expected sign reversals for NA and PA. However, this pattern could have been influenced by common-source bias in

Table 1—Mean Total Sleep During 24 hours, Night Sleep, Onset Time and Wake-up Time, Before, During, and After Shift, at the Beginning of Residency

	Before shift			During shift			After shift			P value
	No.	**Mean**	**SD**	**No.**	**Mean**	**SD**	**No.**	**Mean**	**SD**	
24-h sleep duration, min	55	413.8	93.7	77	230.5	118.4	57	506.0	153.5	< .01
Night duration, min	55	382.4	77.0	77	227.2	110.4	57	416.6	104.2	< .001
Onset time, h:min	55	24:00	1:18	73	2:18	1:54	57	23:54	1:12	< .001
Wake-up time, h:min	55	6:24	0:54	73	6:18	1:12	57	6:54	1:12	< .001
Sleep efficiency, %	55	91.9	8.4	73	93.3	8.5	57	92.6	8.3	NS

Table 2—Intercorrelations and Descriptive Statistics of Variables in Hierarchical Linear Modeling Models

Variables		1	2	3	4	5	6	7
1	D event	—						
2	E event	0.13	—					
3	SD	0.02	0.05	—				
4	SF	0.17	0.11	0.10	—			
5	NA	0.47	-0.14	-0.12	-0.04	—		
6	PA	-0.17	0.29	-0.01	0.14	-0.28	—	
7	FA	0.33	0.18	-0.14	-0.01	0.55	-0.57	—
Mean		0.37	0.41	4.12	2.09	1.01	1.97	1.35
SD		0.48	0.49	1.52	1.51	0.91	1.04	1.22
No.		76	75	77	73	78	78	78

If $r \geq 0.18$, then $P < .01$. Correlations are based on within-subject averages.
D event refers to disruptive event; E event, enhancing event; SD, sleep duration; SF, sleep fragmentation; NA, negative affect; PA, positive affect; FA, fatigue; SD, standard deviation.

simultaneously reporting subjective states.

Hypotheses 1(a,b) and 2(a,b) refer to the moderating, or interactive effect of energy resources on event-emotion relationships, ie, energy depletion due to sleep loss is expected to strengthen the event-emotion relationship for disruptive events (Hypotheses 1a, 1b) and weaken it for enhancing events (Hypotheses 2a, 2b). Table 3, part I, presents the results for Hypotheses 1(a,b), and part II presents the results for Hypotheses 2 (a,b). In both cases, emotional reaction interacted with sleep duration and with sleep fragmentation (ie, wake-up density). The shape of interactions for sleep duration is provided in Figure 1a-b, using a median split for sleep duration in constructing the figures (the interaction for sleep fragmentation was highly similar). As can be seen in Figure 1a, shorter sleep reinforces the relationship between disruptive events and NA, ie, sleep loss promotes greater NA following disruptive events ($t = 3.01$; $P < .01$) and a null effect in the absence of such events ($t = 0.54$; NS).

Figure 1b presents a different (and somewhat unexpected) pattern, ie, shorter sleep promotes an elevated PA level that remains little affected by goal-enhancing events ($t = 0.79$; NS) and greater PA in the absence of such events ($t = 3.24$; $P < .01$). Although the latter is congruent with Hypothesis 2(a), this finding could also be attributed to the elevated PA baseline following sleep loss. Longer sleep duration results in the expected pattern whereby PA is elevated selectively by goal-enhancing events ($t = 3.51$; $P < .01$), otherwise remaining at a lower level.

Hypotheses 3(a,b) suggest a similar moderation model in which the effect of both disruptive and enhancing events on fatigue should be stronger following sleep loss. Table 4 presents the pertinent results. The data indicate significant main effects for both event categories, with sleep duration (but not fragmentation) also providing a main effect after controlling for motive-relevant events. This, in itself, supports the presumed effect of sleep on cognitive-energy levels. Interaction results support Hypothesis 3(a) in that event categories interacted with sleep duration (but not fragmentation). The pertinent results are presented in Figure 2a and 2b. As can be seen, both disruptive and enhancing events are associated with greater fatigue following sleep loss, as expected.

DISCUSSION

The study was designed to test a theoretical model that

Table 3—Test of Interactions Between Event Occurrence and Sleep Duration and Fragmentation as Alternate Predictors of Negative Affect and Positive Affect

Variables	Affect Level			
Part I: NA	$F_{III\ (SF)}$	R_1^2	$F_{III\ (SD)}$	R_1^2
D event	28.8***		16.1***	
E event	-3.94*		-1.29	
SF or SD	2.17	0.27	0.39	0.26
D event × SF/SD	4.78*	0.29	3.20*	0.28
E event × SF/SD	0.19	0.29	0.11	0.28
Part II: PA	$F_{III\ (SF)}$	R_1^2	$F_{III\ (SD)}$	R_1^2
D event	-2.14		-1.35	
E event	3.17*		3.08*	
SF or SD	6.92***	0.14	0.30	0.12
D event × SF/SD	0.04	0.14	1.48	0.12
E event × SF/SD	4.48*	0.15	5.02*	0.16

Sleep deprivation (SD) and sleep fragmentation (SF) were entered separately in statistical models.
Numbers represent Type III F values in hierarchical linear modeling models.
R_1^2 values refer to cumulative level-1 (event) data.
***$P < .001$, **$P < .01$, *$P < .05$
NA refers to negative affect; D event, disruptive event; E event, enhancing event; PA, positive affect.

explains reported links between sleep loss and emotional disturbance on the following day, using a cognitive-energetic framework.[10] The basic premises of this model suggest that emotions arise in the context of motive-relevant events that require self-regulated or adaptive action, and that sleep-induced changes in energetic supplies required for self-regulation influence intensity of emotional reaction, including fatigue.

The results of this study suggest an inverted symmetry concerning the emotional effects of sleep loss. Whereas sleep loss promotes greater NA following disruptive events and a null effect in the absence of such events, the effect of sleep loss on PA is reversed, resulting in a null effect following goal-enhancing events and greater PA in the absence of such events. Considered jointly, sleep loss amplifies the negative emotive effect of disruptive events while attenuating incremental positive effects of goal-enhancing events by comparison to respective baseline levels. The latter finding could have resulted therefore from the elevated PA baseline following sleep loss, or from the hypothesized effect of sleep loss on motive-relevant events, highlighting the need for further research. The elevated PA baseline may reflect compensatory effort in maintaining performance on days following disrupted sleep, and it may also relate to the reported mood-elevation effects of partial sleep deprivation in depressive patients.[48] More adequate sleep (ie, above the sample's median) resulted in a different pattern, which is congruent with affective-event theory,[8] exhibiting elevated NA following disruptive events and elevated PA following goal-enhancing events. Jointly, these findings correspond with the cognitive-energy model, except for the elevated baseline level of PA following sleep loss, suggesting an interesting research agenda.

Methodologically, our results suggest that the sleep-emotion relationship can benefit from event-level analysis, whereby emotional states are investigated in the context of precipitating events affecting the pursuit of personal goals, rather than using random sampling of emotional states that do not take into account the motivational and behavioral context at the time of measurement. Affective events, as noted in the introduction, arise due to goal congruent or incongruent change in circumstances, requiring effort investment to cope with disruptions or capitalizing on opportunities. Given the affective consequences of depletion of critical resources, and the instability of energy resources, the present study offers an explanatory mechanism for reported emotional consequences of sleep loss.[1-7] It is likely, however, that other factors, such as personal traits, influence this relationship as well. For example, neuroticism, which is known to influence emotional reactivity to motive-relevant events,[49] is likely to play a role, inasmuch extraversion, which relates to dispositional excitement and energization, is likely to play a complementary role in terms of its effect on cognitive-energy resources.[50] Likewise, having an internal or external locus of control has been shown to influence mood disturbance after sleep deprivation.[51] These possibilities outline an interesting research agenda.

The importance of context-dependent analysis is highlighted by the fact that our ESM records reveal high frequencies of disruption and enhancement episodes, amounting respectively to 38% and 41%. These data indicate that daily routine is dotted with affective events, the mapping of which provides a meaningful context for collecting emotion data. Although reported frequency of events may be attributable to sample characteristics, with hospital work being characterized by multiple work events, other studies suggest that this may be typical of other occupations. For example, a series of studies concluded that managerial activity is characterized by multiple task switches and consequent self-regulation efforts.[52-54] All this suggests that

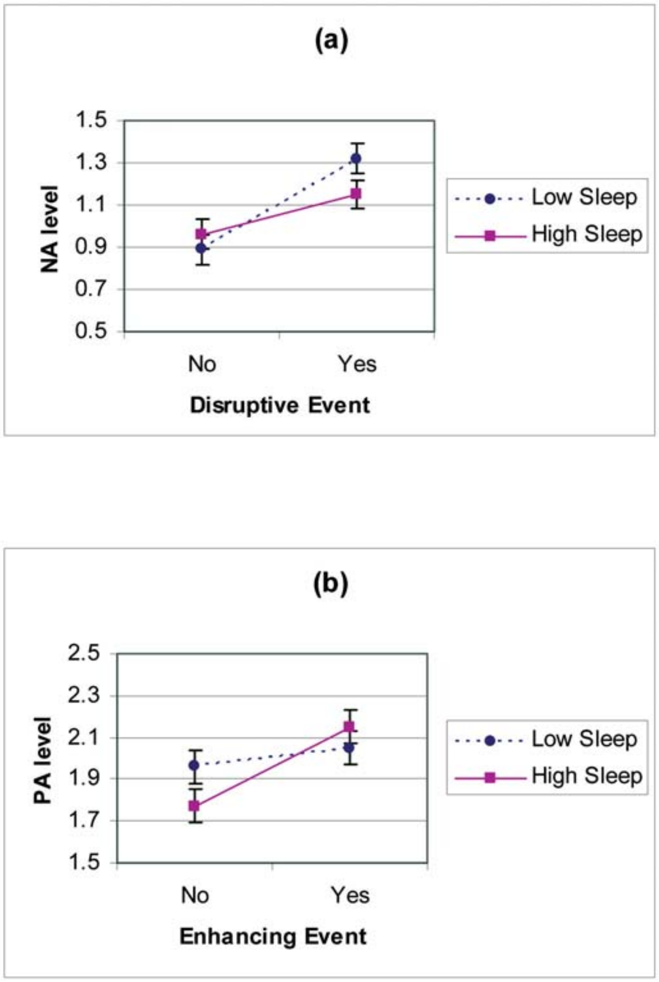

Figure 1—Interaction between disruptive/enhancing event occurrence and sleep duration (represented by a median split) as predictors of negative affect (NA) and positive affect (PA).

Table 4—Test of Interactions Between Event Occurrence and Sleep Duration and Fragmentation as Alternate Predictors of Momentary Fatigue

Variables	**Fatigue Level**			
	$F_{III\ (SF)}$	R_1^2	$F_{III\ (SD)}$	R_1^2
D event	27.1***		28.1***	
E event	6.54**	0.18	5.59**	0.22
SF or SD	1.43	0.19	3.65*	0.24
D event × SF/SD	0.12	0.19	2.99*	0.27
E event × SF/SD	1.20	0.20	3.42*	0.27

Sleep deprivation (SD) and sleep fragmentation (SF) were entered separately in statistical models.
Numbers represent Type III F values in hierarchical linear modeling models.
R_1^2 values refer to cumulative level-1 (event) data.
***$P < .001$, **$P < .01$, *$P < .05$
D event refers to disruptive event; E event, enhancing event.

the more-customary context-free sampling of emotion states disregards much information that can be derived from transient, but frequent, emotional reactions.

The study was designed with an added goal in mind concerning the effect of hospital residency on emotional states and energy levels. Hospital residency is a very demanding professional transition period, posing cognitive, emotional, and physical demands, including 36-hour shifts of duty.[25] This is expected to result in cumulative effects of inadequate sleep as defined by Dinges et al.[1] The repeated semiannual data collected in this study have made it possible to examine cumulative effects of residency duration on emotional reaction and fatigue, ie, the extent to which reported results vary as a function of residency duration. For this reason, we included sampling period as an ordinal variable in the HLM models described above. As noted above, however, sampling period, or residency duration, exerted no main or interaction effect on emotional reaction and fatigue, ie, disruptive and enhancing events provided the same results regardless of sampling period. This suggests that cumulative effects may be masked by proximal factors such as sleep loss on the previous night, calling attention to an interesting research agenda.

Considered from an applied perspective, our results have important implications associated with reported relationships between mood disturbance and performance reliability. An extensive review by Weiss and Cropanzano[8] shows that emotional disturbance influences processes such as memory and recall (eg, impaired recall when mood differs between learning and recall situations), evaluative judgments (eg, mood impact estimated probability of positive or negative outcomes), and processing depth and strategy (eg, positive mood promotes simplified heuristic processing, whereas negative mood promotes systematic processing). In addition, positive mood enhances helping behavior and cooperation during problem solving while reducing aggression in other interdependent tasks. The multiple daily occurrences of work events in our sample, and effect of sleep loss on emotional reaction, suggest that rolling 36-hour shifts characteristic of hospital residency may compromise performance reliability in more ways than hitherto recognized (ie, mood disturbance as latent factor). This possibility should be considered against the widely publicized Institute of Medicine's report suggesting that medical errors account for more deaths than disease itself.[55] Because the importance of sleep-induced mood disturbance as a factor in patient safety has evaded attention of sleep researchers, there has been little research on the subject. We hope this study will stimulate further work in this direction.

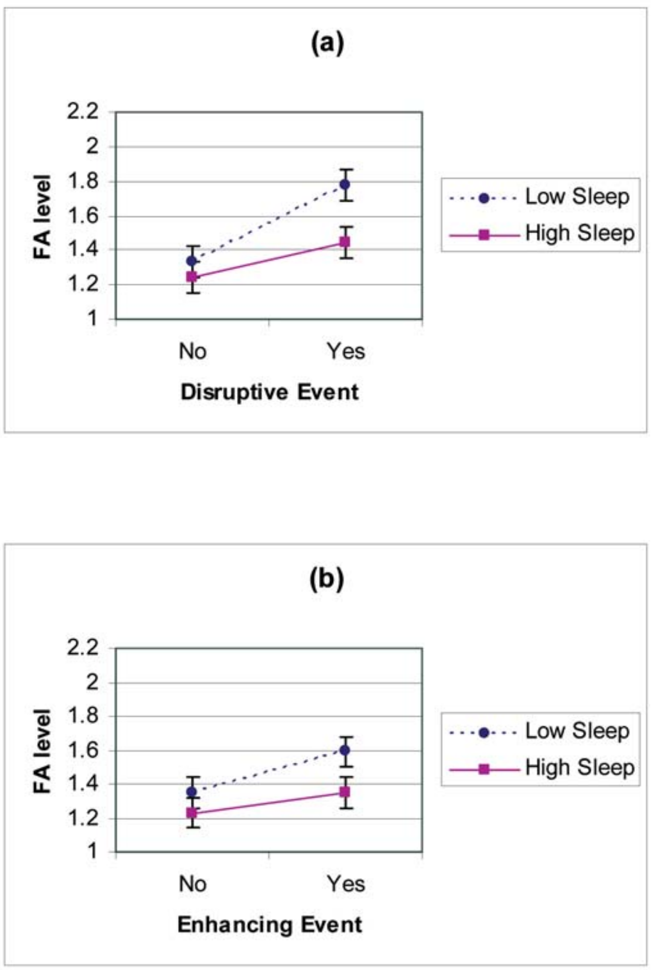

Figure 2—Interaction between disruptive/enhancing event occurrence and sleep duration (represented by a median split) as predictors of fatigue (FA).

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