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ILLUMINATING THE IMPACT OF HABITUAL BEHAVIORS IN DEPRESSION

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Researchers have hypothesized that habitual behaviors are *zeitgebers* for the circadian clock. However, few studies have examined the relationship between habitual behaviors and light, the strongest *zeitgeber*. Depression is an ideal model in which to explore this relationship because depression is a disorder associated with disruptions in circadian biological activity, sleep, and social rhythms (or patterns of habitual behaviors). We hypothesized that individuals with fewer habitual behaviors have less average exposure to light from morning rise time to evening bedtime and that a reduction in light exposure increases the likelihood of depression. Thirty-nine depressed and 39 never-depressed participants wore an ambulatory light monitor and completed the Social Rhythm Metric over the course of 2 weeks. Linear and logistic regression techniques were used to calculate regression coefficients, and confidence limits based on the distribution of the product of two normal random variables were computed to test the significance of the mediation effect. Infrequent habitual behaviors were associated with a decrease in average levels of light exposure, and low levels of light increased the likelihood of depression. This mediation effect was partial; the overall number of habitual behaviors had a direct relationship with depression above and beyond the association with light exposure. Longitudinal studies are needed to empirically demonstrate the direction of relationships between each of the variables tested.

Keywords Light, Depression, Social rhythms, Habit, Non-photic *zeitgebers*, *Zeitgeber*, Mediation

INTRODUCTION

Social interactions, physical activity, and sleep-wake times are habitual behaviors that occur in rhythmic cycles, or as social rhythms (Ehlers et al.,

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1988). In humans, social rhythms are thought to correspond to the 24 h light/dark cycle with the highest frequency of habitual behaviors occurring during times of light exposure. However, few empirical studies have actually tested the relationship between habitual behaviors and light. A primary goal of this study was to improve our understanding of this relationship, in hopes that clarification of the correlation between these variables may eventually ascertain whether habitual behaviors operate as social *zeitgebers* (Ehlers et al., 1988; Mrosovsky, 1988; Klerman et al., 1998; Aschoff et al., 1971; Honma et al., 1995) or as mechanisms by which individuals increase their exposure to light, the strongest *zeitgeber* (Lewy et al., 2003). Speculatively, habitual behaviors may alter retinal exposure to light (*e.g.*, via photoperiod length, light exposure intensity) or the circadian system response to light (*e.g.*, via attenuating levels of *Per1*, moderating sensitivity to light), which then impacts entrainment.

A second goal of this study was to test the relationship between habitual behaviors and light in a clinical population. Unipolar depression is a good model in which to explore this relationship for two reasons. First, research in Seasonal Affective Disorder (SAD) has suggested that decreased exposure to daytime light (due to decreased photoperiod length in the winter) plays an important role in the development of mood symptoms (Rosenthal et al., 1984). To our knowledge, no research has tested the actual, average level of ambient light exposure in currently depressed outpatients with unipolar depression. One study did find that low levels of bright light were associated with depressive symptoms in the general population (Espiritu et al., 1994). Another study found that depressed individuals have diminished perception of ambient light (Friberg and Borrero, 2000). The current study assesses actual levels of light exposure in normal controls and clinically depressed individuals.

In addition to the possibility of less exposure to light, depressed individuals likely have disruptions in habitual behaviors. As compared to non-clinical populations, depressed individuals have more irregular social rhythms (Brown et al., 1996; Szuba et al., 1992), and individuals with remitted depression have more variability in week-to-week social rhythms (Monk et al., 1991). On the other hand, overall activity levels generally do not differ between depressed, remitted-depressed, and non-depressed individuals (Szuba et al., 1992; Monk et al., 1991), although one study did find that elderly individuals with bereavement-related depression had lower activity levels than elderly individuals without depression (Brown et al., 1996). To our knowledge, only one study to date has tested habitual behavior type (Monk et al., 1991). This study found that, compared to normal controls, individuals with remitted depression had more habitual behaviors in which other people were actively involved (*e.g.*, having lunch together) versus passively involved (*e.g.*, watching TV together) (Monk et al., 1991).

Together these studies offer support for the hypothesis that depressed individuals have disrupted social rhythms and decreased daytime light exposure. However, the relationship between social rhythms and light exposure has not been tested in depressed persons or in other populations. Moreover, findings relating to the consistency of daily habitual behaviors (Szuba et al., 1992), the overall number of habitual behaviors (Monk et al., 1991), and the type of habitual behaviors (Monk et al., 1991) have not been replicated or tested within a group of currently depressed outpatients.

This study sought to address these important issues. We hypothesized that average light exposure levels (from morning rise time to evening bedtime) would mediate the relationship between habitual behaviors and depression. Thus, individuals with (1) irregular social rhythms and (2) fewer habitual behaviors would have lower average levels of ambient daytime light, and exposure to lower average light levels would be directly associated with an increased likelihood of depression. Based on previous findings (Monk et al., 1991), we also hypothesized that a subset of the overall number of habitual behaviors (behaviors with others actively involved) tested in hypothesis 2 would be especially important in increasing exposure to light and indirectly in improving mood. See Figure 1 for the general, hypothesized mediational model.

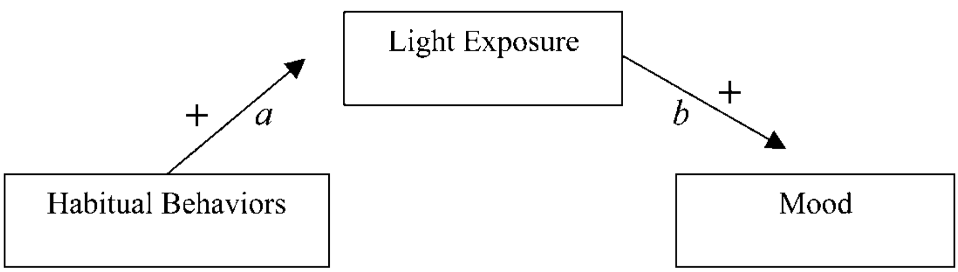

FIGURE 1 Hypothesized mediational model.

RESEARCH DESIGN AND METHODS

Study Design

The current project used a cross-sectional design to predict the likelihood of major depression (versus no depression) from the pattern of habitual behaviors assessed over a period of 2 weeks and light exposure assessed over a period of 3 days.

Participants

Thirty-nine depressed patients and 39 aged ($\pm$5 yrs) and gender-matched normal controls met inclusion criteria and completed the study.

Participants ranged in age from 19 to 64 yrs (mean age = 43.73 yrs; SD = 12.88 yrs). The majority of participants were employed ($n = 51$), Caucasian ($n = 53$), male ($n = 54$), and had 12 to 16 yrs of education ($n = 47$). Approximately one-half of participants were married ($n = 34$).

Depressed participants were recruited from the Veterans Administration San Diego Healthcare System (VASDHS) Mood Disorders Clinic and the San Diego State University (SDSU) Psychology Clinic. All depressed individuals met Diagnostic and Statistical Manual, Fourth Edition (DSM-IV; American Psychiatric Association, 1994) criteria for current major depressive disorder (MDD), without psychotic features. They were excluded from participation if they were diagnosed with a current comorbid substance abuse/dependence diagnosis, bipolar depression, seasonal affective disorder, or a psychotic disorder. Normal control participants were recruited from the VASDHS Primary Care Clinics and Administration Services, SDSU Psychology 101 class subject pool, and from the general population via posted flyers, classified advertising, and e-mail solicitations. Normal controls were excluded from study participation if they were diagnosed with a current psychiatric illness or past mood disorder by DSM-IV criteria (American Psychiatric Association, 1994).

All participants were excluded from the study if they (1) had indications of a major medical disorder that would interfere with participation in the study; (2) participated in shift work; (3) had indications of primary sleep disorders (*e.g.*, severe circadian phase disturbance, sleep apnea, periodic limb movements, psycho-physiological insomnia); (4) were on their current medication regimen for less than 6 weeks; or (5) had alterations in their medications over the course of the study.

The majority of depressed individuals were diagnosed with Recurrent Major Depressive Disorder ($n = 22$; 56%) with current depressive symptom scores in the moderate range (mean HRSD-17 scores = 20.28; SD = 4.70). The most frequent past comorbid psychiatric disorder among individuals with depression and normal controls was alcohol use disorder (36% prevalence for both populations). Some 44% of the depressed participants reported being currently engaged in psychiatric treatment ($n = 17$); as expected, this was significantly different from normal controls ($\chi^2(78) = 32.94$; $p < 0.001$).

Measures

Mood Disorder

For clinical interviews, all raters completed a structured training program and established test-retest and interrater reliabilities >0.90.

Structured Clinical Interview for the DSM-IV (SCID). The SCID (Spitzer et al., 1992) is a standardized, semi-structured interview for diagnosing

DSM-IV lifetime and current prevalence of Axis I mental disorders. The overview portion gathers information about relevant demographic and treatment variables, including current and lifetime work history, social and relationship history, and treatment history. The SCID is considered the gold standard for diagnostic assessment (Zanarini et al., 2000; Shear et al., 2000).

Hamilton Rating Scale for Depression (HRSD). The HRSD (Hamilton, 1960) is an interview assessment of depression symptom severity. The 24-item version, which includes several cognitive symptoms (Kivela, 1992), was administered, and scores for the standard 17-item version were calculated as a measure of baseline depression severity. Previous studies have demonstrated internal consistency reliability coefficients ranging from 0.83 to 0.94, and inter-rater reliability above 0.85 in 7 of 8 studies (Rabkin and Klein, 1987).

Light Measure

Actillume. The Actillume (Ambulatory Monitoring, Inc., Ardsley, NY) is a wrist-mounted actigraph and light transducer that records illumination exposure in 60 s epochs. Each participant was instructed to wear the Actillume on his/her wrist, over sleeves, for at least 3 consecutive days and nights and to record the times when the Actillume was removed. The participants were instructed to take-off the Actillume when exposed to water.

Participant records were divided into two time periods: (1) the period of time during which the subjects indicated they were out of bed in the morning to the time they got into bed at night (*i.e.*, morning rise time to evening bedtime; out-of-bed period) and (2) the period of time during which participants indicated they were in bed in the evening to the time they got out of bed in the morning (*i.e.*, evening bedtime to morning rise time; in-bed period). Records were included in analyses if they had at least 1 full out-of-bed period or 1 full in-bed period. Each of these periods was not considered acceptable if participants removed the Actillume for 3 h or more.

Of the 78 participants, no Actillume data were gathered from one participant due to mechanical problems. Four individuals did not wear the Actillume for the expected period of time (*i.e.*, $\geq$3 h missing) when out-of-bed. Anecdotally, the participants stated that they either forgot until mid-day or evening to put the Actillume back on after a morning shower, had social or work obligations that made wearing the Actillume obtrusive, or engaged in water sports for an extended period of time. For the remaining 72 participants, the mean number of days (out-of-bed periods) worn was 3.51 (SD = 1.73); 7 participants wore the Actillume for 1 day only. All participants wore the Actillume for at least 2 full in-bed periods. The mean number of full nights (in-bed periods) worn for the 77 participants was 4.91 (SD = 1.59). No statistically significant differences between groups were observed for Actillume adherence across the two time periods (in-bed or out-of-bed).

The main light variable was the average light exposure per minute calculated for the period of time during which participants indicated they arose in the morning to the time they retired to bed at night (*i.e.*, out-of-bed period). This summary variable was computed and expressed on a logarithmic scale. To facilitate interpretation, we refer to this summary statistic as "average light exposure," instead of mean log lux. We chose this variable as our main light summary variable because it captures exposure to light at all intensities, which allows an average over the entire out-of-bed period instead of only brief periods across the day in which a specific intensity lux is detected.

However, we conducted a number of follow-up analyses testing the impact of light at different intensities and different times. The following summary statistics were computed for follow-up analyses: (a) average light exposure for the period of time from evening bedtime to morning rise time; (b) mean number of minutes exposed to bright light ($\geq$1000 lux) from morning rise time to evening bedtime; (c) mean number of minutes exposed to bright light ($\geq$1000 lux) from evening bedtime to morning rise time; (d) mean number of minutes exposed to moderate intensity light (100 to $<$1000 lux) from morning rise time to evening bedtime; and (e) mean number of minutes exposed to moderate intensity light (100 to $<$1000 lux) from evening bedtime to morning rise time.

A series of one-way analyses of variance (ANOVAs) revealed no statistically significant differences in any of the light indices between individuals who wore the Actillume for few days ($\leq$2 days) and those who wore the monitor for more days ($\geq$3 days). In addition, zero-order correlations indicated no statistically significant relationships between the number of days the monitor was worn and any of the light variables.

Social Rhythms

Social Rhythm Metric (SRM). The SRM (Monk et al., 1994) is a self-report, daily diary designed to measure the variability of times when 18 typical habitual behaviors occur. Participants were instructed to complete one SRM sheet in the evening before going to bed. Seven sheets from a given week were scored as a unit based on an algorithm developed by Monk and colleagues (1991), which calculates the average time of social interactions after discounting daily outliers. At the end of the two weeks, both units were averaged to achieve a single score.

The main index derived from this instrument represents the regularity of an individual's life (*i.e.*, SRM index). However, the volume of activities performed per week (*i.e.*, Activity Level Index, ALI) and the level of involvement of other people in activities (Others Actively Involved, OTH-A) were also computed and examined separately (Monk et al., 1991). The SRM exhibits adequate test-retest reliability between week 1 and week 2 (rho = 0.44, $N = 49$, $p < 0.001$) and also over 12 to 30 months ($r = 0.48$) (Monk et al., 1994).

Adherence rates for the SRM were relatively high (mean days completed = 13.28, SD = 2.44). One participant failed to complete any days of the SRM, 7 participants completed only 7 days of the SRM, and 10 participants completed between 10 to 13 days of the SRM. Incomplete weeks were included in the data analyses if at least 4 days were complete. The SRM scoring algorithm was adjusted to calculate hits per number of days completed accordingly, and both ALI and OTH-A were expressed as a ratio of the total behaviors performed per total behaviors in the completed diary. Separate one-way ANOVAs yielded no statistically significant differences between participants who did and who did not complete at least 14 days of the SRM on the main study variables, including group, light, and SRM indices.

Procedure

The study was reviewed and approved by the local research institutions and met the ethical and good practice standards of the Journal for the conduct of human biological rhythm research (Touitou et al., 2004). Participants indicating an interest in participating in the research study were contacted and invited to an initial screening appointment. At the screening appointment, written consent was obtained, and participants received the SCID, HRSD, and a clinical sleep interview (supervised by the second author, SAI, who is board certified in Clinical Sleep Medicine and in Behavioral Sleep Medicine) to rule out exclusion criteria. Participants were instructed to complete the SRM daily at bedtime over the next week. Participants returned approximately 1 week later (mean = 7.96 days; SD = 3.04 days). At this time, they were given an Actillume to wear on their non-dominant wrist to measure light exposure. They were instructed to wear the Actillume for at least 3 consecutive days and nights. They were also given another 7-day packet of the SRM to complete. Participants returned the SRM sheets and Actillume one week later (mean = 7.34 days; SD = 2.67), at the last interview. At every assessment, adherence to the research protocol was thoroughly assessed.

Data Analysis

A preliminary logistic regression analysis was first conducted to assess for the potential impact of any demographic or behavioral differences between groups. Employment status, monthly income, marital status, ethnicity, and caffeine and nicotine intake were simultaneously entered as independent variables predicting the likelihood of depression. Any statistically significant variable(s) was then included as a covariate in each step of the main analyses.

For hypothesis 1 (average light exposure mediates the relationship between the SRM index and depression), the following analyses were conducted to test for mediation in accordance with the Baron and Kenny (1986) approach. Step 1 used logistic regression to estimate whether lower scores on the SRM index (Independent Variable, IV) increased the likelihood of depression (Dependent Variable, DV). Step 2 used linear regression to test whether lower scores on the SRM index (IV) predicted lower average light exposure from morning arise time to bedtime at night (Mediator, M). Step 3 used logistic regression to estimate whether lower levels of light (M) increased the likelihood of depression (DV), when controlling for the SRM index (IV). If *full* mediation is present, the effect of the SRM index (IV) on depression (DV) should be significantly reduced. If both the SRM index (IV) and light exposure (M) significantly predict depression, the finding supports *partial* mediation.

For hypothesis 2 (average light exposure mediates the relationship between the number of habitual behaviors and depression), all analyses remained the same, except ALI (Hypothesis 2a) and OTH-A (Hypothesis 2b) were separately substituted as the IV.

To test for the significance of the mediation effect, confidence limits were computed based on the distribution of the product of two normal random variables (MacKinnon et al., 2004), $|a \times b| \pm$(Empirical M Distribution critical value) $\times \sqrt{(b^2 \times s_\mathrm{a}^2 + a^2 \times s_\mathrm{b}^2)}$. A recent statistical simulation performed by (MacKinnon and colleagues, 2004) revealed that these confidence limits are more accurate than confidence limits based on the normal distribution assumption. The normal distribution has low power and imbalanced confidence limits for the indirect effect (Mackinnon et al., 2002, 2004).

A number of follow-up analyses tested alternative versions of the mediator in order to examine potential effects related to the intensity and timing of light exposure. The following new mediator variables were entered separately in place of the major light variable, average light exposure during the out-of-bed period, in the mediational regression equations delineated above. The variables are: (a) average light exposure during the in-bed period; (b) mean number of minutes exposed to bright light ($\geq$1000 lux) during the out-of-bed period; (c) mean number of minutes exposed to bright light ($\geq$1000 lux) during the in-bed period; (d) mean number of minutes exposed to moderate intensity light (100 lux $\leq$ exposure $<$1000 lux) during the out-of-bed period; and (e) mean number of minutes exposed to moderate intensity light (100 lux $\leq$ exposure $<$ 1000 lux) during the in-bed period.

Through these mediational analyses, we were able to test the direct effects of the SRM indices on depression. We separately tested the direct effects of all the light variables on depression (without SRM indices in the model) in order to provide preliminary ambient light exposure data in this clinical population. For each analysis conducted, Cook's Distance was calculated to assess for significant outliers. With any significant outlier detected, analyses were conducted both with and without the outlier; differences were interpreted accordingly.

RESULTS

Preliminary Analyses

Employment status emerged as the only difference between groups; individuals with depression were less likely to be employed (odds ratio = 0.13; $p < 0.05$). In order to control for the potential differential influence of this variable, employment status was included as a covariate in all analyses. Descriptive statistics for each group, independent variable, and mediator variable are reported in Table 1.

Hypothesis 1: Average Light Exposure Mediates the Relationship Between the SRM Index and Depression

Regression coefficients for each of the following SRM index analyses are reported in Table 2. Logistic regression analyses used in Step 1

TABLE 1 Mean (SD) for Each Independent Variable and Mediator*

	MDD		NC	
	Mean	SD	Mean	SD
SRM indices, $N = 77$				
SRM index	2.60	0.87	3.42	0.76
ALI	0.66	0.12	0.71	0.08
OTH-A	0.14	0.12	0.28	0.14
Light indices, out-of-bed period, $N = 72$				
Mean lux†	1.10	0.47	1.60	0.49
Mean No. min bright light (≥1000 lux)	85.56	54.80	115.84	72.85
Mean No. min moderate light (100 to <1000 lux)	180.94	187.81	301.04	226.06
Light indices, in-bed period, $N = 77$				
Mean lux†	−0.80	0.21	−0.89	0.08
Mean No. min bright light (≥1000 lux)	0.75	2.08	0.13	0.39
Mean No. min moderate light (100 to <1000 lux)	18.13	93.14	1.61	3.21

*MDD = Major Depressive Disorder. NC = Normal Controls. SRM = Social Rhythm Metric. ALI = Activity Level Index. OTH-A = Activities with Others Actively Involved.

†Computed and expressed on a logarithmic scale.

TABLE 2 Regression Coefficients for Hypothesis 1: Mediational Analyses with the Social Rhythm Metric (SRM) Index as the Independent Variable (IV)

Step	DV*	IVs	β	*SE*	*p*
1	Group				
		Employment	3.20	0.83	<0.001
		SRM	−1.56	0.45	<0.001
2	Light				
		Employment	0.34	0.12	0.007
		SRM	0.17	0.06	0.009
3	Group				
		Employment	2.72	0.83	0.001
		SRM	−1.37	0.46	0.003
		Light	−1.27	0.73	0.080

*DV = Dependent Variable. $N = 72$.

indicated that lower levels of the SRM index significantly increased the likelihood of depression [$-2\text{LL} = 60.25$; $\Delta\chi^2$ $(72) = 17.93$; $p < 0.001$; odds ratio = 0.21]. For Step 2, linear regression analyses indicated a significant positive relationship between SRM index scores and light exposure from morning arising time to evening bedtime ($\Delta R^2 = 0.08$; ΔF $(1, 69) = 7.20$; $p < 0.01$). A trend emerged from logistic regression analyses in Step 3. Lower levels of the light variable increased the likelihood of depression, after controlling for the SRM index [$-2\text{LL} = 56.91$; $\Delta\chi^2$ $(72) = 3.34$; $p = 0.07$; odds ratio = 0.28]. Because the SRM index remained statistically significant in Step 3 (see Table 2; odds ratio = 0.26), these findings provide support for a partial mediation trend. The partial mediation effect ($a \times b = -0.22$) was not statistically significant at $\alpha = 0.05$, although a trend was observed at $\alpha = 0.10$ (90% CI = 0.01, 0.49). Thus, irregular social rhythms were directly associated with an increased likelihood of depression and lower average levels of light exposure. With the SRM index in the model, lower average levels of light were associated with an increased likelihood of depression; however, this indirect effect was not statistically significant at $\alpha = 0.05$.

Hypothesis 2: Average Light Exposure Mediates the Relationship Between Activity Level Indices and Depression

Regression coefficients for each of the following ALI analyses are reported in Table 3. Logistic regression analyses used in Step 1 indicated that lower levels of ALI significantly increased the likelihood of depression [$-2\text{LL} = 70.52$; $\Delta\chi^2$ $(72) = 7.66$; $p = 0.006$; odds ratio = 0.00]. For Step 2, linear regression analyses indicated a positive relationship between ALI scores and average light exposure from morning rise time to evening bedtime ($\Delta R^2 = 0.05$; ΔF $(1, 69) = 4.49$; $p = 0.04$). A significant effect for the light variable emerged from logistic regression analyses in

TABLE 3 Regression Coefficients for Hypothesis 2a: Mediational Analyses with the Activity Level Index (ALI) as the Independent Variable (IV)

Step	DV*	IVs	β	*SE*	*p*
1	Group				
		Employed	3.01	0.75	< 0.001
		ALI	−7.72	3.12	0.01
2	Light				
		Employed	0.39	0.13	0.003
		ALI	1.17	0.55	0.04
3	Group				
		Employed	2.58	0.76	< 0.001
		ALI	−6.81	3.48	0.05
		Light	−1.52	0.65	0.02

*DV = Dependent Variable. $N = 72$.

Step 3. Lower levels of exposure to light from morning rise time to bedtime at night were associated with an increased the likelihood of depression, after controlling for ALI [$-2\text{LL} = 64.29$; $\Delta\chi^2$ $(72) = 6.23$; $p = 0.01$; odds ratio = 0.22]. The significance level for ALI decreased slightly (see Table 3; odds ratio = 0.00), which indicated that there was a partial mediation effect. The partial mediation effect ($a \times b = -1.78$) was statistically significant at $\alpha = 0.05$ (95% CI = 0.09, 4.44). Thus, fewer numbers of habitual behaviors were directly associated with an increased likelihood of depression and indirectly associated with an increased likelihood of depression (via reduced exposure to light when out-of-bed).

Similar results emerged for habitual behaviors with others actively involved. Regression coefficients for each of the following OTH-A analyses are reported in Table 4. Logistic regression analyses used in Step 1 indicated that lower levels of OTH-A significantly increased the likelihood of depression [$-2\text{LL} = 66.31$; $\Delta\chi^2$ $(72) = 11.87$; $p < 0.001$; odds ratio = 0.00]. For Step 2, linear regression analyses indicated a positive

TABLE 4 Regression Coefficients for Hypothesis 2b: Mediational Analyses with Activities with Others Actively Involved (OTH-A) as the Independent Variable (IV)

Step	DV*	IVs	β	*SE*	*p*
1	Group				
		Employed	2.71	0.77	<0.001
		OTH-A	−7.25	2.31	0.002
2	Light				
		Employed	0.33	0.13	0.02
		OTH-A	0.76	0.42	0.08
3	Group				
		Employed	2.42	0.80	0.002
		OTH-A	−6.59	2.35	0.005
		Light	−1.63	0.69	0.02

*DV = Dependent Variable. $N = 72$.

trend between OTH-A scores and average light levels from morning arising time to bedtime at night ($\Delta R^2 = 0.04$; ΔF $(1, 69) = 3.21$, $p = 0.08$). A significant effect for the light variable emerged from logistic regression analyses in Step 3. Lower amounts of exposure to light from morning arise time to evening bedtime increased the likelihood of depression, after controlling for OTH-A [$-2\text{LL} = 59.89$; $\Delta\chi^2$ $(72) = 6.42$; $p = 0.01$; odds ratio = 0.20]. The effect of OTH-A did not decrease significantly with light in the model (see Table 4; odds ratio = 0.00), which indicates that mediation is partial rather than full. The partial indirect effect ($a \times b = -1.24$) was not statistically significant at $\alpha = 0.05$, although a trend was observed at $\alpha = 0.10$ (90% CI = 0.09, 2.85). These findings indicate that fewer numbers of habitual behaviors with others actively involved were directly associated with lower average levels of light exposure and an increased likelihood of depression, although the former finding was not as strong as the latter. As such, this indirect effect was not statistically significant at $\alpha = 0.05$.

Follow-Up Analyses

The mediational analyses were repeated with the following light summary variables replaced as mediator variables: (a) Average light exposure during the in-bed period; (b) mean number of minutes exposed to bright light ($\geq$1000 lux) during the out-of-bed period; (c) mean number of minutes exposed to bright light ($\geq$1000 lux) during the in-bed period; (d) mean number of minutes exposed to moderate intensity light (100 lux $\leq$ exposure $<$1000 lux) during the out-of-bed period; and (e) mean number of minutes exposed to moderate intensity light (100 lux $\leq$ exposure $<$1000 lux) during the in-bed period.

With the causal method of mediation, none of the variables were significant mediators for both Step 2 and Step 3. Similarly, none of the indirect effects was statistically significant at $\alpha = 0.05$. In all of these analyses, only one outlier emerged; one depressed participant had significantly more exposure to moderate intensity lux when out-of-bed as compared to other depressed individuals. The findings did not differ when this data point was excluded from analyses.

Statistically significant direct effects indicated that irregular social rhythms were associated with higher average levels of light in bed [$\beta = -0.06$; SE $\beta = 0.02$; $\Delta R^2 = 0.10$, ΔF $(1, 73) = 8.44$; $p < 0.01$]. Fewer habitual activities (ALI) were also associated with higher average levels of light in bed [$\beta = -0.56$; SE $\beta = 0.17$; $\Delta R^2 = 0.13$, ΔF $(1, 73) = 11.20$; $p < 0.01$] and more bright light while in bed [$\beta = -5.76$; SE $\beta = 1.53$; $\Delta R^2 = 0.16$, ΔF $(1, 73) = 14.15$; $p < 0.001$].

Individuals were more likely to be categorized as depressed with: (a) low average levels of light when out of bed [$\beta = -2.20$; SE $\beta = 0.61$;

$-2LL = 82.26$; χ^2 $(72) = 17.50$; $p < 0.001$; odds ratio $= 0.11$]; (b) fewer minutes exposed to moderate intensity light when out of bed [$\beta = -0.005$; SE $\beta = 0.002$; $-2LL = 92.26$; χ^2 $(72) = 7.50$; $p < 0.01$; odds ratio $= 1.00$]; and (c) high average levels of light in bed [$\beta = 4.62$; SE $\beta = 2.13$; $-2LL = 100.00$; χ^2 $(77) = 6.73$, $p < 0.05$; odds ratio $=$ 101.63]. A trend emerged showing that the likelihood of depression increased when individuals received fewer minutes of bright light when out of bed [$\beta = -0.01$; SE $\beta = 0.004$; $-2LL = 95.78$; χ^2 $(72) = 3.98$; $p = 0.06$; odds ratio $= 0.99$].

DISCUSSION

The goal of this study was to test whether average levels of ambient light exposure mediated the relationship between habitual behaviors and depression. Specifically, we tested whether individuals with (1) irregular social rhythms, (2a) fewer habitual behaviors, and (2b) fewer habitual behaviors with others actively involved had lower average levels of exposure to light for the period of time when they were active, *i.e.*, between the times when the subjects indicated they arose in the morning and retired in evening. We also tested whether lower average levels of light exposure were associated with an increased likelihood of depression.

The results were consistent with our hypotheses. Light exposure partially mediated the relationship between habitual behaviors and mood. Individuals with fewer habitual behaviors were exposed to lower average levels of light while out of bed during the day, and this light variable was associated with an increase in the likelihood of depression. Lower numbers of habitual behaviors continued to increase the likelihood of depression when light exposure was controlled. Therefore, these results suggest that the frequency of habitual behaviors influence mood indirectly and mood and light exposure directly.

Similar results were found for the regularity and type of habitual behaviors, although the indirect effects for these two variables were smaller than that of overall frequency of habitual behaviors. Individuals with irregular social rhythms and fewer numbers of habitual behaviors with others actively involved had less exposure to light when out of bed and were more likely to be depressed. This relationship was again partially mediated, meaning that habitual behavior regularity and type had a direct association with depression, above and beyond their association with light exposure.

These results are the first to identify light exposure as a variable mediating the relationship between habitual behaviors and mood. These findings have important implications for research of the etiology, course, and treatment of depression. Through infrequent and inconsistent habitual behaviors (*e.g.*, sleeping late, napping, unemployment), individuals with depression may be reducing their exposure to light. Alternatively, depressed individuals may have a behavioral preference for darkness, potentially due to a hypersensitivity of photoreceptors (Bunney and Bunney, 2000). This preference may dampen the activation system and decrease motivation to engage in habitual behaviors. Either way, a reduction in light exposure may be responsible for a number of biological circadian abnormalities in depression, including disrupted sleep (Wehr and Wirz-Justice, 1983). Thus, some circadian abnormalities seen in depression may be physiological reactions to low levels of light (an environment stimulus), rather than the expression of the genetic diatheses of the disorder.

In addition to decreased light exposure, we also found direct effects for nighttime exposure to light. Low numbers of habitual behaviors may increase exposure to light during the bedtime period, which then increases the likelihood of depression. One previous study using the SRM found an association between decreased activity levels and poor sleep in depressed individuals (Brown et al., 1996). Potentially, depressed individuals with irregular social rhythms may be unable to sleep at night and subsequently increase exposure to artificial light. They may also arise later in the morning, thus having more light exposure during the in-bed period. Both of these explanations would indicate that depressed individuals have a phase-delay of the sleep-wake cycle or a blunting of the activity rhythm. Both of these circadian rhythm effects have been proposed as etiological mechanisms for unipolar depression (Wehr and Wirz-Justice, 1983; Schulz et al., 1979).

Follow-up exploratory analyses indicated the strongest direct relationship between light exposure and mood was for the average exposure to light while out of bed, although direct associations were found for mean minutes exposed to moderate and bright intensity light throughout the day. It was beyond the scope of this study to calculate light exposure at certain times of the day (*e.g.*, dawn and dusk). Nonetheless, these positive findings for overall levels of light exposure may indicate that continuous mechanisms (Johnson et al., 2003) play some role in circadian rhythm stability for depressed individuals. Speculatively, the endogenous period of the circadian clock may be altered in depression due to overall low exposure to light and/or abnormal sensitivity to light, which may also explain phase abnormalities in sleep patterns of depressed individuals (Wehr and Wirz-Justice, 1983).

These findings provide support for the potential efficacy of light therapy in persons with unipolar depression. Although light boxes are relatively noninvasive forms of treatment as compared to medications (Kripke, 1998), an increase in natural, outdoor light via increasing habitual behaviors is a less expensive and more naturalistic treatment option. Furthermore, behavioral activation has lasting benefits independent of light exposure (Hopko et al., 2003). Behavioral activation encourages participation in other behaviors that improve mood, including exercise and pleasurable activities.

In addition to identifying light exposure as a mediating variable, these results are the first to replicate previous findings suggesting associations between depression and light and depression and habitual behaviors. Our findings are consistent with SAD research, in which less exposure to light during winter is thought to trigger the development of mood symptoms (photoperiod hypothesis: Rosenthal et al., 1984). These findings are also consistent with several studies testing the social rhythm hypothesis of depression (Ehlers et al., 1988), which posits that depressed individuals have disrupted and irregular social *zeitgebers*. Similar to previous studies, we found direct effects between depression and the variability of habitual behaviors (Szuba et al., 1992) and the number of activities with others actively involved (Monk et al., 1991). The significant main effect for overall activity level was consistent with one study (Brown et al., 1996) but inconsistent with others (Szuba et al., 1992; Monk et al., 1991). This inconsistency may be due to differences in study populations. The Szuba and colleagues study (1992) tested depressed psychiatric inpatients, whose daily activities are likely enhanced by the structured, hospital environment. The Monk and colleagues study (1991) tested non-symptomatic outpatients with remitted depression.

Although this study provides support for the social rhythm hypothesis of depression, a number of other possibilities may also account for the direct relationships between habitual behaviors and depression. For instance, third variables associated with irregular social rhythms may be responsible for depression (*e.g.*, cognitive attributions relating to uncontrollability, sleep disturbances). Also, the variability of habitual behaviors may be an epiphenomenon of depression or of low exposure to light. Lastly, activity type may be particularly important in depression. Monk and colleagues (1991) suggested that individuals with depression rely more upon the prompting of others to participate in structured activities (OTH-A) than nondepressed individuals. Our results are consistent with this interpretation; however, research employing circadian rhythm measures is necessary to determine how this reliance translates into the biological symptoms of depression.

As stated above, this study is the first to test relationships between light exposure and habitual behaviors. It is also the first study to examine how these relationships differ between normal controls and clinically depressed outpatients. Thus, the data in this study represent a naturalistic (*i.e.*, non-hospitalized) sample of individuals with and without major depression. Multiple methods were used to gather information, including a diagnostic structured interview, objective light monitor, and prospective logs of habitual behaviors. Multi-site data gathering (outpatient community and hospital clinics, veteran and non-veteran populations) also potentially enhanced the external validity of the findings. Moreover, this study used a biopsychosocial model of depression that integrated theory from psychology and chronobiology.

Although this study provides an important contribution to the chronobiological and psychological literature, a number of features limit the generalizability of the findings. The majority of participants in this study were adult males from a veteran population, most of whom were Caucasian. Important gender differences have been found with social interactions (Berkman and Syme, 1979) and susceptibility to mood disturbances (Weissman et al., 1996). Future studies would benefit from exploration of potential gender differences from a biological and sociological framework.

In addition, future studies could benefit from expanding the theoretical model to include other social variables that correlate with depression (*e.g.*, employment), as these variables are likely to overlap conceptually with habitual behaviors and light exposure. Due to limitations in statistical power, we chose to statistically control for employment and test a purely confirmatory model based on theoretical predictions. However, future studies utilitizing larger samples would be able to employ structural equation modeling techniques to test multiple indirect effects and determine the unique variability explained by each factor in the model.

Another limitation of this study is its cross-sectional design, which prohibits the ability to determine the directionality of relationships. The next step in this line of research is to clarify causal and directional relationships between variables by the use of longitudinal designs. Longitudinal designs would allow researchers to establish the temporal order of habitual behaviors, light exposure, and depressed mood. Longitudinal research could also assist in identifying other variables, such as sleep and cognitive attributions, which may mediate the relationship between social and behavioral factors and depression. Much could also be gathered from further delineation of light exposure levels at various times of the day and the timing of light associated with each habitual behavior component, including ambient light levels at work. Researchers could benefit from using experimental paradigms testing the impact of prolonged light therapy and alterations in photoperiod length on mood.

Also, much could be learned from studies investigating the day-to-day variability in exposure to light. To our knowledge, no standard currently exists for the number of days of light exposure monitoring necessary to determine a stable mean for ambient light exposure. In this study, light exposure was assessed across relatively few days (range, 1 to 7 days; mean days $= 3.51$); this small sampling length is likely not of sufficient duration to determine habitual levels of light exposure. Although this is a limitation of the current study, we anticipate that it had minimal impact on the current results as preliminary analyses indicated no statistically significant differences in light exposure levels between individuals who wore the monitor for few days ($\leq$2 days) and those who wore it longer ($\geq$3 days).

In terms of other measurement issues, research is needed that incorporates assessment of circadian rhythms directly, such as in melatonin, body temperature, and cortisol. Preliminary research has examined physical activity, one type of habitual behavior, as a *moderator* of light and circadian rhythms in rodents (Mistlberger and Antle, 1998; Edelstein et al., 2003); the impact of light on the circadian system was reduced or synergized (dependent upon the timing) by physical activity. To date, this finding has not yet been replicated in humans (Youngstedt et al., 2001). To our knowledge, no studies to date have tested whether light *mediates* the relationship between daily habitual behaviors and the circadian system in humans across the entire photoperiod. Research testing this relationship is important as habitual behaviors may alter photoperiod duration, light intensity, and photoperiodic history. Each of these variables can change the waveform of the phase response curve, as well as the period and amplitude of circadian rhythms (Johnson et al., 2003). Also, few studies have explored daily light exposure or circadian rhythm variability. Much could be gathered from understanding the psychological and behavioral correlates of individuals with highly variable circadian rhythms or highly variable levels of light exposure.

Important information could also be gathered from the inclusion of prospective cognitive and emotional measures associated with the disruption of habitual behaviors. Recent research conducted on a college student population indicates that habitual behaviors are associated with a lesser experience of helplessness and stress than nonhabitual behaviors (Wood et al., 2002). Clinical researchers could benefit from testing whether these findings are consistent within a depressed population. If so, interventions that increase habitual behaviors after a disruption, *e.g.*, Interpersonal Social Rhythm Therapy (Frank et al., 1994), may be indicated for the treatment of depressive symptoms.

In summary, these results suggest that low average levels of light exposure (during the period of time between arising in the morning to bedtime at night) partially mediate the relationship between habitual behaviors and depression. The consistency, frequency, and type of habitual behaviors also have a direct relationship with depression. These findings have important implications in that they may encourage future researchers to focus on ways that behavior impacts light exposure, the circadian system, and mood. Also, these findings provide preliminary support for the therapeutic efficacy of increased exposure to light, especially through behavioral activation protocols.

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