2022

The Effects of Weather and Photoperiod on Mood in Seasonal Affective Disorder Treatment with Light Therapy or CBT

Beth M. McCormick
The University of Vermont

The Effects of Weather and Photoperiod on Mood in Seasonal Affective Disorder Treatment with Light Therapy or CBT

Undergraduate Honors Thesis

Beth McCormick

Advisor: Kelly Rohan

Department of Psychological Science

University of Vermont

Abstract

The current study examined the relationship between weather variables and mood in the context of a randomized clinical trial comparing two first-line treatments for seasonal affective disorder (SAD; *N* = 177 adults): SAD-tailored cognitive-behavioral therapy (CBT-SAD) and light therapy. Weather variables included daylength, temperature, precipitation, sky cover, solar radiation, and wind speed at the study site corresponding to date of mood assessment. Regression analyses tested the predictive effect of each weather variable, treatment condition, and their interaction on depression severity at post-treatment and at follow-ups one and two winters after treatment. Weather variables were hypothesized to affect mood, with more pronounced effects for light therapy participants, particularly at Winter 2 follow-up where the parent study found superiority of CBT-SAD over light therapy. For Structured Interview Guide for the Hamilton Depression Rating Scale-SAD Version (SIGH-SAD) scores, daylength and a wind speed X treatment interaction were predictive at post-treatment, and sky cover was predictive at Winter 1 follow-up. For Beck Depression Inventory-Second Edition (BDI-II) scores, daylength and temperature were predictive at post-treatment, and daylength and solar radiation were predictive at Winter 2 follow-up. In the light therapy group, each unit increase of wind speed at and above 8.03 knots was associated with a decrease of 2.43 points on the SIGH-SAD at post-treatment. All models controlled for pre-treatment depression scores, which accounted for much of the variance in later depression scores at each timepoint. CBT-SAD was associated with significantly lower depression severity at Winter 2 than light therapy, even after adjusting for pre-treatment depression severity and each weather variable, bolstering the primary efficacy results of the parent study.

Keywords: CBT, cognitive-behavioral therapy, light therapy, seasonal affective disorder, mood, depression, weather

The Effects of Weather and Photoperiod on Mood in Seasonal Affective Disorder Treatment with Light Therapy or CBT

First described by Rosenthal et al. (1984), seasonal affective disorder (SAD) is a mood disorder consisting of major depressive episodes that follow a seasonal pattern – usually recurring in the winter months and remitting in the summer months. A small body of research has sought to identify the environmental trigger(s) underlying the predictable pattern of SAD episode recurrence and remission. Candidate environmental triggers include photoperiod (i.e., daylength from dawn to dusk), which is completely fixed by location and date, and various weather-related variables (e.g., precipitation, cloud cover, average daily temperature), which fluctuate within a fixed location and vary by and within calendar date at any location. One study supports a predictive relationship between photoperiod and risk for winter depression recurrence, and several studies support an association between shorter photoperiod and increased depression symptom severity in SAD. Only a few studies have supported a relationship between daily weather fluctuations and mood in SAD. This literature is reviewed below to provide background for the current project, which examined the effects of daily weather variables on mood in the context of a clinical trial comparing two first-line SAD treatments.

In a sample of 29 depressed patients (all of whom exhibited seasonality) from the greater Washington D.C. metro area, Rosenthal et al. (1984) found a significant negative correlation (r = -0.98) between the percentage of participants who were in a current depressive episode in a given month (by history) and the average local daily temperature for that same month. The correlation between the percentage who were depressed in a given month and the mean local photoperiod for that same month was strong (r = -0.87) but increased in magnitude when correlated with mean local photoperiod for the month prior (*r* = -0.98), suggesting a time-lagged effect of short photoperiod on depression (Rosenthal et al., 1984).

In a sample of 22 participants in a Swiss-German population, Wirz-Justice et al. (1986) replicated Rosenthal and colleagues' methodology to correlate the percentage of depressed participants in any given month with local photoperiod and weather variables in the context of a light treatment study for SAD. Wirz-Justice et al. (1986) examined local weather data for both locations (for the Swiss-German sample and for the Washington D.C. sample in Rosenthal et al., 1984): local photoperiod, mean monthly temperatures, number of hours of cumulative sunshine per month, and monthly cumulative rain. Only local photoperiod length (*r* = -0.94) and mean monthly temperature with a one-to-two-month time lag (*r* = -0.91) were highly correlated with the percentage of patients who were depressed in any given month. Mean monthly temperature was only moderately correlated with the percentage of depressed patients when evaluated from the same month as depression scores were collected (*r* = -0.67). Wirz-Justice et al. (1986) used retrospective self-report to determine the percentage of participants who were depressed in any given month in the past 20 years. On average, depression in the Swiss German sample lasted 1.5 months longer than in Rosenthal's sample, and this could not be accounted for by differences in temperature or photoperiod alone. Another possible explanation assessed was the difference in amount of sunshine, but there were no clear differences in amount of rain that could explain the discrepancy in depression longevity between the two populations.

Oren et al. (1994) examined the relationship between ambient light exposure (measured using ambulatory light sensor) over one week and mood at the end of the week in a sample of 13 adults diagnosed with SAD and 13 age- and sex-matched healthy controls at the National Institute of Mental Health in Bethesda, Maryland. SAD patients and controls did not differ significantly on median time at detectable light onset in the morning, median time at light offset in the evening, or daily light exposure profiles (i.e., total, median, or peak lux). In the sample, there was a significant inverse correlation between photoperiod (defined as median number of hours/day when at least 2 lux was detected) and depression severity on the Hamilton Depression Rating Scale. In addition, a positive correlation between median time at light onset in the morning and depression trended towards significance.

A study of 126 participants with SAD in Copenhagen, Denmark examined local meteorological variables in relation to scores on the Beck Depression Inventory, administered every other week from September to May (Molin et al., 1996). Mood was significantly associated with minutes of sunshine, global radiation, and photoperiod, but not with cloud cover, rainfall, or atmospheric pressure. Additionally, there was some support for a temperature-mood relationship with a 14-day delay. These results suggest that measures of luminosity (i.e., the brightness of available light) and temperature, as well as photoperiod, may be prospectively associated with the severity of depressed mood during the winter months in people with SAD.

In contrast, in a series of two studies, Young et al. (1997) found a relationship between photoperiod and winter depression onset risk, but not between weather and onset risk. The first study included data from 387 people with SAD across five Northern locations: Chicago, New York, and Washington, D.C. in the United States and Basel, Switzerland and Oslo, Norway in Europe. They used survival analysis to examine the relationship between daily photoperiod, averaged across the month at each location, and typical month of depressive episode onset, as determined by self-report. Risk of depression onset was significantly associated with photoperiod, but the study did not examine any weather-related variables in relation to risk. In an effort to disentangle effects of photoperiod from weather-related variables, the second study enrolled 190 Chicago residents with SAD between November and March over seven study years and asked them to recall the week their first SAD symptom began that year. The second study found no significant effects of daily hours of sunshine, daily solar radiation, and daily temperature, which were averaged across the years of the study, when considered either together or individually, on risk of SAD episode onset. Photoperiod, but none of the three weather variables nor their interaction with photoperiod, accounted for significant variance (26%) in weekly SAD episode risk.

A nationwide study analyzing the percentage of depressed outpatients at 53 psychiatry clinics spanning various latitudes across Japan who qualified for a diagnosis of SAD, as defined by Rosenthal et al. (1984), found that total hours of sunshine from September to March (averaged over the past 30 years at the clinic's location) was significantly associated with SAD prevalence (r = -0.66) but latitude and mean temperature in December (averaged across 30 years at the clinic's location) were not (Sakamoto et al., 1993). These results support a relationship between an index of luminosity of available light and SAD prevalence in Japan. Unfortunately, Sakamoto et al. (1993) did not examine the correlation between photoperiod and SAD prevalence.

Another study collected daily diary measures for two years in a sample of 10 SAD patients from the greater Washington, D.C. area (Albert et al., 1991). The majority of patients (8/10) showed statistically significant seasonal changes in energy with highest levels in summer and lowest levels in winter. The summer vs. winter differences in energy persisted in seven of these eight patients after controlling for several daily local weather variables (i.e., minimum temperature, precipitation, barometric pressure, relative humidity, and daily sunshine computed as the product of photoperiod × the proportion of the day without cloud cover). In within-subject analyses designed to explore temporal effects of the weather variables on energy after adjusting for seasonal trends in energy, only four participants showed significant weather effects, with higher energy linked to increased temperature in two participants and to increased sunshine in two participants. Albert et al. (1991) concluded that, overall, seasonal change had more influence on energy levels in SAD patients than daily variations in weather. However, this analysis only examined the effect of daily weather variables on energy, which is only one facet of SAD symptomatology.

Yet, other studies have also found moderate to strong effects of daily weather on SAD symptoms. Lingjærde & Reichborn-Kjennerud (1993) examined characteristics of SAD in Oslo, Norway in a sample of 128 adults, 121 with a SAD diagnosis and seven with subsyndromal SAD. Participants were asked to retrospectively self-report symptoms from their worst winter depression period. Lingjærde & Reichborn-Kjennerud (1993) calculated mean responses to items on the Seasonal Pattern Assessment Questionnaire (SPAQ) that assess the perceived effect of different weather variables on mood on a -3 (markedly lowers) to +3 (markedly improves) scale. Participants, on average, endorsed at least a moderate positive effect of sunny and long days on their moods, and at least a moderate negative effect of short days on their moods (Lingjærde & Reichborn-Kjennerud, 1993). They concluded that these SAD patients are likely influenced by weather fluctuations, especially those which influence light duration and intensity and noted that some participants were more influenced by daily weather variables than by season, while other participants showed the opposite effect (Lingjærde & Reichborn-Kjennerud, 1993).

In summary, relatively few studies to date have explored the effects of photoperiod and weather-related variables on SAD. Existing studies are often limited to one or only a few locations, consideration of few (if any) weather variables, small sample sizes, and the reliance on retrospective recall of when depressive episodes began. Additionally, many studies have only examined depression episode occurrence, rather than depression severity as an outcome measure. More research is needed to understand photoperiod-mood and weather-mood relationships in individuals with SAD in more places, with larger samples, and with more varied and comprehensive weather measurements. Furthermore, studies use different measurements of mood, depression severity, and SAD episode onset/recurrence. Different methods of data collection (clinical interviews versus self-report) might also produce very different results due to capturing different perspectives (clinical rater vs. the individual). This between-study variability makes it difficult to compare results across studies, and no meta-analysis has been conducted to date. To our knowledge, no study has yet examined the effect of weather and photoperiod on mood in the context of treatment for SAD.

The parent trial of this project, Dr. Kelly Rohan's previous National Institute of Mental Health-funded R01 study, has already been completed. The study compared the efficacy of light therapy (i.e., timed, daily exposure to bright artificial light) versus cognitive-behavioral therapy (i.e., a type of talk therapy that focuses on changing thoughts and behaviors to improve mood) as treatments for SAD. In total, 177 community adults with SAD were randomized to 6-weeks of treatment with light therapy or cognitive-behavioral therapy. After treatment, the study involved longitudinal follow-up the next summer and one and two winters later. The parent clinical trial found that both treatments were associated with large and comparable improvements in depression over the 6-week treatment phase, with no differences between light therapy and cognitive-behavioral therapy on any outcome at treatment endpoint (Rohan et al., 2015). A similar proportion of participants were in remission at post-treatment: 47.6% in cognitive-behavioral therapy and 47.2% in light therapy. Although the treatments did not differ at the first winter follow-up, cognitive-behavioral therapy was associated with significantly less severe depression symptoms and lower depression recurrence (27.3% vs. 45.6%) at the second winter follow-up (Rohan, Meyerhoff, et al., 2016).

This project will explore one potential explanation for the greater durability of cognitive-behavioral therapy over light therapy following acute treatment. It is expected that weather and photoperiod will have significant effects on mood for participants in both treatment conditions at all time points, but that this effect will be larger for those who received light therapy, particularly at second winter follow-up where the treatments significantly differed in outcome. This hypothesis is plausible, given that SAD follows a seasonal pattern, and light therapy reinforces the idea that, to feel well, participants need greater light intake (which is affected by the photoperiod and weather variables that influence the intensity of available light, such as solar radiation, cloud cover, and precipitation). In contrast, cognitive-behavioral therapy is intended to create a greater sense of personal agency over one's own mood by encouraging participants to engage in actions and thinking styles that contribute to positive mood and, therefore, should weaken the effects of environmental factors, such as weather and photoperiod, on mood.

Methods

This is a secondary analysis of a larger randomized clinical trial comparing the efficacy of light therapy and SAD-tailored cognitive-behavioral therapy (CBT-SAD) in the treatment of SAD over the course of 6 weeks (Rohan et al., 2015). Depression symptoms and severity were assessed at pre-treatment, each week during the course of treatment, post-treatment, and follow-ups one- and two-winters later.

Participants

One hundred seventy-seven adults, 18 years of age and older, were randomized to either CBT-SAD (n=88) or light therapy (n=89) for a 6-week clinical trial. Participants were recruited from the Burlington, VT area and met criteria for Major Depression, Recurrent, with Seasonal Pattern, as assessed by the Structured Clinical Interview for DSM-IV Axis I Disorders – Clinical Version. They were also required to score at least 20 on the total scale and 5 of the atypical scale on the Structural Interview Guide for the Hamilton Rating Scale for Depression – Seasonal Affective Disorder Version (SIGH-SAD) before starting treatment.

Participants were excluded for history of light treatment or CBT treatment for seasonal affective disorder, current psychotherapy for depression, plans to begin new treatment for depression or SAD during the winter of participation, plans to travel outside of the Burlington area for more than a week between December and March, or evidence of hypothyroidism as assessed by a thyroid panel during medical workup.

Participants with comorbid diagnoses were included if those diagnoses did not meet the criteria for psychotic disorders, bipolar disorders, current substance-use disorders, or any other Axis I disorder that required immediate attention. Additionally, participants were excluded if they endorsed serious suicidal intent. Antidepressant use was allowed given stable dosage at least four weeks prior to the study with no plans for a dose change during the study. Further details of the randomization process and study procedures are published (Rohan et al., 2013).

Treatments

CBT-SAD. A version of CBT tailored specifically to the treatment of SAD was created by the Principal Investigator of the parent study (Rohan, 2008). CBT-SAD uses classic cognitive-behavioral strategies such as behavioral activation and cognitive restructuring to target the cognitions and behavior which contribute to the onset and maintenance of SAD, encouraging participants to identify and engage in pleasurable activities during the winter and to challenge negative thoughts related to the winter, weather, and daylength. In the study, CBT-SAD was administered in the format of twice-weekly 90-minute group sessions for 6 weeks, with each group co-facilitated by a licensed psychologist and a clinical graduate student co-therapist (Rohan et al., 2013).

Light Therapy. Participants randomized to light therapy were provided an instructional session, standardized by a script, in which they were taught the light treatment rationale, given a light box demonstration, and prescribed a starting dose of 30 minutes upon waking in the morning. Participants were given a standard 10,000-lux cool-white florescent light box unit with an ultraviolet shield, the SunRay (SunBox Company Gaithersburg, MD). Dosage was individually-adjusted each week according to a treatment algorithm to maximize treatment effectiveness and minimize side effects (Rohan, Meyerhoff, et al., 2016). Further information on individual finishing dosages are reported in the parent study (Rohan et al., 2015).

Outcome Measures

Structured Interview Guide for the Hamilton Rating Scale for Depression-Seasonal Affective Disorder Version (SIGH-SAD). The SIGH-SAD is a semi-structured clinical interview adapted from the Hamilton Rating Scale for Depression (HAM-D) (Hamilton, 1960), specifically for Seasonal Affective Disorder (Williams, 1988). The interview contains the 21-item HAM-D and 8 additional items which assess atypical symptoms of depression (Williams, 1988). The SIGH-SAD was administered every-other-week before the start of treatment to monitor for depressive symptoms. Once participants met a threshold of a total score of 20 and atypical score of 5, they were moved into the treatment phase of the study. SIGH-SADs were then administered at pretreatment, every week during treatment, posttreatment, summer follow-up, Winter-1 follow-up, and at Winter-2 follow-up. Each interview was conducted and scored by a trained, blind clinical rater; assessments were recorded and scored by a second blind rater. If the total SIGH-SAD scores of the original and second rater differed by more than 5 points or if the original and second rater disagreed on recurrence status (at follow-up), then the assessment was re-rated by two additional trained, blind raters. Inter-rater ranged from .923 to .967 and was generally very good (Rohan, Meyerhoff, et al., 2016). The exact protocol and item-by-item scoring rules for administration of the SIGH-SAD used in the parent study is published (Rohan, Rough, et al., 2016).

Beck Depression Inventory-Second Edition (BDI-II). The BDI-II is a 21-item depression severity rating scale (Beck et al., 1996). The validity and reliability of the BDI-II has been supported by various studies, and it correlates with other depression measures such as the Revised HAM-D (Beck et al., 1996). It was administered at pre-treatment, mid-treatment (Week 3), and post-treatment (Rohan et al., 2015).

Weather Variable Measures

Weather data were collected and matched up by date of outcome measure assessment, such that there were data for all six weather variables for every date on which a SIGH-SAD was conducted in the study. Weather data also correspond to the dates on which BDI-II assessments and SBQ surveys were collected, so that the data could also be matched to these outcome measures.

Daylength. Daylength (i.e., photoperiod from dawn to dusk) data were obtained from timeanddate.com (Time and Date AS) a private company based in Norway. Daylength is a variable which is astronomical in nature and is determined for specific dates and locations. The data obtained from Time and Date AS were formatted in hours, minutes, and seconds (hh:mm:ss); these datapoints were converted into hours prior to data analysis, such that a daylength of 8:30:00 would be converted to 8.5 hours.

Average Daily Temperature. Temperature data were obtained from the National Weather Service station in Burlington, Vermont at the Burlington International airport (BTV). Raw data were obtained at 1.5 meters above ground level as minimum and maximum daily temperature values in degrees Fahrenheit, which were the lowest and highest instantaneous temperatures, respectively, during the full 24-hour period of that day. Following one convention of the weather and climate community, average daily temperature was calculated as the average of the minimum and maximum daily temperatures.

Precipitation. Precipitation data were also obtained from the National Weather Service station at the BTV airport and was provided in cumulative daily inches within a 24-hour period. Precipitation data are collected from multiple sensors – radar and rain gauge – with precipitation estimates provided by NWS River Forecast Centers and National Centers for Environmental Prediction. Precipitation measures include any form of water that reaches the ground from the sky, including rain, snow, or hail, among others. The amount of water is expressed as inches of liquid water depth, regardless of the form of precipitation (NOAA).

Sky Cover. Sky Cover data, also known as cloud coverage, were obtained from the Northeast Regional Climate Center. Sky Cover describes the percentage of observable sky that is covered by clouds. Data were provided hourly; values indicate the percent sky cover based on the percent of opaque clouds covering the sky (NOAA). The data were distilled for the purposes of this study into a daily average, by taking the 24, hourly values from each day and calculating a mean for the entire 24-hour period.

Solar Radiation. Solar radiation data were obtained from the Northeast Regional Climate Center (NRCC) at Cornell via a web call to the NRCC server for the data spanning 2010 through 2014. Older solar radiation data were obtained from a database directly from NRCC. All solar radiation data, a measure of electromagnetic radiation that reaches the Earth's surface in a particular location, also called sunshine, were provided in Langleys as a daily cumulative measure. Solar radiation varies based on geographic location, time of day, season, local landscape, and other weather variables. Higher values indicate that more solar energy (Office of Energy Efficiency & Renewable Energy).

Average Wind Speed. Average wind speed data were obtained from the National Weather Service (NWS) and was provided as a daily average in knots. One knot is equivalent to 1.15 miles per hour or 1.85 kilometers per hour. Wind speed measures horizontal air flow in relation to the Earth's surface (NOAA).

Data Analytic Plan and Missing Data

Continuous depression scores were examined on two measures; the SIGH-SAD was considered the primary outcome measure, and the BDI-II was considered as a secondary measure. A series of hierarchical regressions were run for each of the six weather variables at four time points: pre-treatment, post-treatment, Winter 1 follow-up, and Winter 2 follow-up. All analyses were conducted using SPSS version 27 for Windows.

Examination for outliers was conducted, both as aggregates of each weather variable, and by time point for each weather variable. Although there were some weather variables that were identified as potential outliers, this is likely due to the nature of weather patterns during the December to March period in Burlington, VT, so these values were kept. Only one extreme outlier was excluded. A precipitation value of 4.93 inches was recorded for a 14-degrees

Fahrenheit day, which would amount to approximately 50 inches of snow, based on average estimates. Therefore, we dropped this datapoint, as it appears it might be due to error in the precipitation dataset derived from NWS. Neither SIGH-SAD nor BDI-II data evidenced any outliers that would not have been controlled for and corrected by the parent study (Rohan et al., 2015)

Second, correlations were computed between each depression outcome (SIGH-SAD and BDI-II scores) and each weather variable and between the weather variables themselves. Daylength and solar radiation were significantly correlated across, but only strongly correlated at 4 of 10, timepoints. As these variables measured different constructs (i.e., actual solar energy received and length of the day), both of these variables were kept.

In order to examine the influence of weather variables on depression scores and whether their influence differed by treatment group, a series of hierarchical regression analyses were run to test the main effects of individual weather variables, treatment type, and a weather variable X treatment interaction in order to examine treatment modality as a moderator effect of weather's influence on depression scores. Separate models were run for each depression outcome (SIGH-SAD and BDI-II scores) and for each weather variable predictor (daylength, temperature, solar radiation, sky cover, precipitation, and wind speed) at each time point: pre-treatment, post-treatment, Winter 1 follow-up, and Winter 2 follow-up. Pre-treatment depression scores were entered in Step 1 of all models, except for those where pre-treatment depression score was the outcome. Specifically, in the regressions predicting pre-treatment depression, the weather variable of interest was added in the first step, and treatment group was added in the second step. In the regressions predicting post-treatment or follow-up depression, pre-treatment depression (SIGH-SAD or BDI-II) score was controlled for in the first step, the weather variable of interest was added in the second step, and treatment group was added in the third step. In all models, an interaction for the corresponding weather variable and treatment group was added in the final step of the model. Significant treatment X weather interactions were further examined using the PROCESS macro for SPSS (Hayes, 2022), where the slopes were plotted and probed through the analyses of simple slopes (Aiken et al., 1991).

In examination of potential covariates, age, and race/ethnicity (non-Hispanic white versus all others) were analyzed to determine if they were predictive of SIGH-SAD scores at any of the timepoints. These variables were determined to not be significantly predictive of depression scores at any timepoint, and as such were excluded in the final models.

Missing data were handled with listwise deletion. There were very few datapoints lost through this method, with the highest number lost (n = 14) for the SIGH-SAD regression at Winter 2 follow-up and for the BDI-II regression (n = 13) at Winter 2 follow-up. Little's MCAR test was utilized to assess whether data was missing at random or in a biased manner. For variables at pre-treatment (p = .73), post-treatment (p = .88), and Winter 2 follow-up (p = .89), missing data was missing at random. However, for variables at the Winter 1 follow-up, variables were not missing at random (p = .001).

Results

Descriptive Findings. The mean age of participants was 45.6 years (*SD*=12.8), and the sample was primarily female (83.6%) and non-Hispanic white (92.1%). Participants did not differ significantly in age, race, or sex between the two treatment modalities. These demographics are presented in Table 1.

Tables 2-4 present the correlations between weather predictor variables, possible covariates, and both outcome measures used in this analysis (SIGH-SAD and BDI-II scores).

Notably, BDI-II and SIGH-SAD scores had a moderate positive correlation at pre-treatment {$r(175) = 0.41$, $p < .001$} and post-treatment {$r(170) = 0.70$, $p < .001$}, and a strong positive correlation at Winter 1 follow-up {$r(167) = 0.76$, $p < .001$} and Winter 2 follow-up {$r(166) = 0.81$, $p < .001$}. Additionally, solar radiation and sky cover had a moderately negative correlation at Winter 1 {$r(167) = -0.55$, $p < .001$} and Winter 2 {$r(165) = -0.61$, $p < .001$} timepoints and had a strong negative correlation at pretreatment {$r(175) = -0.81$, $p < .001$} and posttreatment {$r(147) = -0.73$, $p < .001$}. Solar radiation and daylength had a moderate positive correlation at pretreatment {$r(175) = 0.70$, $p < .001$}, posttreatment {$r(147) = 0.68$, $p < .001$}, Winter 1 {$r(167) = 0.67$, $p < .001$}, and Winter 2 {$r(165) = 0.53$, $p < .001$}.

Weather Variables as Predictors of SIGH-SAD Scores. Results of the multiple linear regressions in predicting SIGH-SAD scores at each timepoint based on individual weather variables, and their interactions with treatment group, are presented in Table 5.

When pre-treatment SIGH-SAD scores were entered in the first step of the regression models, pre-treatment SIGH-SAD scores were predictive of post-treatment SIGH-SAD scores ($F(1, 171) = 13.01$, $p <.001$) with an R^2 change of .07, Winter 1 follow-up scores ($F(1, 167) = 12.05$, $p <.001$) with an R^2 change of .067, and Winter 2 follow-up ($F(1, 165) = 5.20$, $p = .02$) with an R^2 change of .03. Treatment group was also significantly predictive of SIGH-SAD scores at Winter 2, after adjusting for pre-treatment SIGH-SAD and each weather variable, with less severe depression in CBT-SAD than light therapy, all *p'*s<.01.

In predicting post-treatment SIGH-SAD scores, daylength was significantly predictive, $\beta = 1.08$, $t(170) = 1.98$, $p = 0.05$ and explained 2 percent of the variance (with an R^2 change of .02) in the overall model. The interaction term between wind speed and treatment group was predictive of post-treatment SIGH-SAD scores, $\beta = -0.70$, $t(168) = -1.99$, $p = 0.05$, and explained 2 percent of the variance (with an R^2 change of .02) in the overall model. For models predicting SIGH-SAD scores at Winter 1 follow-up, sky cover was predictive, β = -0.06, $t(166) = -2.35$, $p = 0.02$, where sky cover explained 3 percent of the variance (with an R^2 change of .03) in the overall model..

Other than the above, no other individual weather variable or weather X treatment interactions terms significantly predicted SIGH-SAD scores at any timepoint. The overall models for temperature ($F(4, 168) = 4.41$, $p = .002$) with a total R^2 of .10; solar radiation ($F(4, 168) = 4.38$, $p = .002$) with a total R^2 of .09; sky cover ($F(4, 168) = 3.77$, $p = .006$) with a total R^2 of .08; precipitation ($F(4, 168) = 3.84$, $p = .005$) with a total R^2 of .08 were predictive of post-treatment SIGH-SAD scores. However, for each of these regressions, pre-treatment SIGH-SAD scores explained the majority of the variance in the overall models, and significant unique variance in post-treatment SIGH-SAD scores was not explained by these individual weather variables or their interactions with treatment group.

In addition, the overall regression models for daylength ($F(4, 164) = 3.12$, $p = .02$) with a total R^2 of .07; temperature ($F(4, 164) = 3.19$, $p = .02$) with a total R^2 of .07; solar radiation ($F(4, 164) = 3.74$, $p = .01$) with a total R^2 of .08; precipitation ($F(4, 164) = 3.39$, $p = .01$) with a total R^2 of .08; and wind speed ($F(4, 164) = 3.00$, $p = .02$) with a total R^2 of .07 were predictive of Winter 1 SIGH-SAD scores. Again, most of the variance accounted for in these models was largely explained by pre-treatment SIGH-SAD scores, and unique variance in Winter 1 SIGH-SAD scores was not accounted for by these individual weather variables or their interactions with treatment group.

Finally, the overall regression models for daylength ($F(4, 162) = 4.21$, $p = .003$) with a total R^2 of .09; temperature ($F(4, 162) = 4.44$, $p = .002$) with a total R^2 of .10; solar radiation

(F(4, 162) = 3.70, p = .01) with a total R^2 of .08; sky cover (F(4, 162) = 3.98, p = .004) with a total R^2 of .09; precipitation (F(4, 162) = 4.15, p = .003) with a total R^2 of .09; and wind speed (F(4, 162) = 3.84, p = .01) with a total R^2 of .09 were predictive of Winter 2 SIGH-SAD scores. No individual weather variables or interactions terms explained unique variance in SIGH-SAD scores, and most of the variance accounted for in Winter 2 SIGH-SAD scores was explained by pre-treatment SIGH-SAD scores.

Weather Variables as Predictors of BDI-II Scores. Regression analyses for the BDI-II outcome are presented in Table 6. Pre-treatment BDI-II scores were predictive of BDI-II scores in the first step of the regression models predicting BDI-II scores at post-treatment (F(1, 170) = 24.05, p < .001) with an R^2 of .12, Winter 1 follow-up (F(1, 167) = 28.25, p < .001) with an R^2 of .15, and Winter 2 follow-up (F(1, 165) = 29.60, p < .001) with an R^2 of .15. Treatment group was also predictive of Winter 2 BDI-II scores in all regressions, all p's < .01.

At pre-treatment, temperature significantly predicted BDI-II scores, β = -0.15, t(175) = -2.82, , p = 0.01, and explained 4 percent of the variance (with an R^2 change of .04) in the overall model.

At post-treatment, daylength was predictive of BDI-II scores, β = 1.30, t(169) = 2.56, p = 0.01, and explained 3 percent of the variance (with an R^2 change of .03) in the overall model. Additionally, temperature was predictive of BDI-II scores at post-treatment, β = 0.09, t(169) = 2.85, p = 0.01, and explained 4 percent of the variance (with an R^2 change of .04) in the overall model.

At Winter 2 follow-up, daylength was predictive of BDI-II scores, β = 1.83, t(164) = 2.13, p = 0.04, and explained 2 percent of the variance (with an R^2 change of .02) in the overall model. Solar radiation was predictive of Winter 2 BDI-II scores, β = 0.02, t(164) = 2.10, p =

0.04, and explained 2 percent of the variance (with an R^2 change of .02) in the overall model. Lastly, the precipitation x treatment group interaction was marginally predictive of BDI-II scores at Winter 2 follow-up, β = 21.90, *t*(162) = 1.95, *p* = 0.053, and may have explained 2 percent of the variance (with an R^2 change of .02) in the overall model; however, the alpha associated with this interaction was slightly above the point of significance before rounding.

No other individual weather variables or interactions terms significantly accounted for variance in their respective models. Similar to results for the SIGH-SAD outcome, overall models for the BDI-II outcome measure were predictive at post-treatment, Winter 1 follow-up, and Winter 2 follow-up. Across all overall models, variance accounted for in BDI-II score was largely explained by pre-treatment BDI-II scores and by treatment group at Winter 2.

Moderation effects. The weather variable X treatment interaction terms that were found to be significant at the p = 0.05 level were further examined to explore how the effect of the weather variable on depression severity differed between CBT-SAD and LT. Specifically, the wind speed x treatment group interaction at post-treatment for the SIGH-SAD (β = -0.70, *t*(168) = -1.99, *p* = 0.05) and the precipitation x treatment group interaction at Winter 2 follow-up for the BDI-II (β = 21.90, *t*(162) = 1.95, *p* = 0.053) warranted further investigation.

The Process moderation analysis revealed that the slope of estimated post-treatment SIGH-SAD scores in relation to windspeed was not significantly different from zero in either the light therapy group (β = -0.38, *t*(168) = -1.78, *p* = .08) or CBT-SAD group (β = 0.32, *t*(168) = 1.14, *p* = .26). Figure 1 graphically displays this interaction, plotting estimated SIGH-SAD scores in each treatment at the mean and at 1 SD above and below the mean windspeed. When analyzed further, utilizing the Johnson-Neyman analysis in Process, it was revealed that these two slopes (light therapy treatment group and CBT-SAD treatment group) diverged significantly at and above 8.03 knots of wind speed. At this point, there is a decrease of 2.43 points on the SIGH-SAD in the light therapy group for each knot increase of wind speed (roughly 1.15 miles per hour).

The precipitation X treatment group interaction was further examined for predicting BDI-II scores at Winter 2 follow-up. In the Process moderation analysis, the slope of estimated Winter 2 BDI-II scores based on precipitation was not significantly different from zero in light therapy (β = -2.23, $t(162) = -0.41$, $p = .68$), but differed significantly from zero in CBT-SAD (β = -24.13, $t(162) = -2.45$, $p = .02$), albeit with a very large the confidence interval [95%: -43.59, -4.67]. Due to the interaction effect crossing the threshold of significance (p = .053) and the large confidence interval, we did not probe further in examining this interaction effect.

Discussion

The a priori hypotheses were two-fold. (1) It was expected that weather and photoperiod would have significant effects on mood, as measured by the SIGH-SAD and the BDI-II, for participants in both treatment conditions at all time points. (2) This effect was expected to be larger for those who received light therapy, particularly at second winter follow-up where CBT-SAD had significantly fewer depression recurrences and less severe symptoms than light therapy in the parent trial (Rohan et al., 2016). Both hypotheses were only partially supported by the current analysis.

Weather Variables Predicting SIGH-SAD Scores. The regression analyses for the SIGH-SAD outcome revealed effects of daylength on depression severity at post-treatment and of sky cover on depression severity at Winter 1 follow-up, such that for each hour increase in daylength at post-treatment, there was an increase in SIGH-SAD score by 1.08 points; and for each percentage increase of sky cover at Winter 1 follow-up, there was a decrease in SIGH-SAD score by .06 points. When considered in these terms, these effects on mood are quite subtle and not particularly clinically meaningful, as scores on the SIGH-SAD range from 0 to 90, and a .06 increase or even a 1.08 increase is unlikely to have any real clinical significance (e.g., cause a treating clinician to change course in delivering SAD treatment).

Weather Variables Predicting BDI-II Scores. The regression analyses for the secondary outcome of BDI-II scores revealed that temperature was a significant predictor of depression severity at pre-treatment and post-treatment, daylength was a significant predictor of depression severity as post-treatment and Winter 2 follow-up, and solar radiation was a significant predictor of depression severity at Winter 2 follow-up.

At pre-treatment, for each increase in temperature of 1 degree Fahrenheit, BDI-II scores decreased by 0.15 points. At post-treatment, each increase of 1 degree Fahrenheit was associated with a 0.09 increase in BDI-II score. As BDI-II scores range from 0 to 63, these effects are very small and unlikely to have any real clinical significance. It would take an increase of over 11 degrees Fahrenheit at post-treatment to affect BDI-II scores by 1 point, which would still have little clinical significance in making treatment decisions.

At post-treatment, a 1-hour increase in daylength was associated with a 1.30-point increase in BDI-II scores. And at second Winter follow-up, a 1 hour increase in daylength predicted a 1.83-point increase in BDI-II scores. In the context of the overall range of daylength, this relatively large increase in photoperiod predicted only a small change in depression severity and, again, is unlikely to hold clinical meaning.

Finally, at second Winter follow-up, a 1-Langley increase in solar radiation predicted a 0.02 increase in BDI-II score. Given that solar radiation at this time point ranged from 40.00

Langleys to 388.20 Langleys, this is still quite a small change in BDI-II score and may not hold any real clinical significance.

Moderation Effects. Of the two interaction terms that were examined – wind speed x treatment group at post-treatment for SIGH-SAD scores and precipitation x treatment group at Winter 2 follow-up for BDI-II scores –the precipitation x treatment group interaction, which fell just above the level of significance at $p = 0.053$, is unlikely to reflect any clinically meaningful effects.

The wind speed X treatment group interaction term was significant and suggests the relationship between wind speed and depression severity differs by treatment group. The slopes for each treatment group were not significantly different from zero, as can be seen in Figure 1 displaying estimated SIGH-SAD scores at post-treatment in CBT-SAD and LT at the mean and at 1 SD above and below the mean for windspeed. It is also important to note that high wind was operationalized as one standard deviation above the mean ($M = 6.36$, $SD = 2.92$), falling at 9.28 knots (10.67 mph) or above, and low wind was categorized as one standard deviation below the mean, falling at 3.44 knots (3.96 mph) or below. This, therefore, may only reflect a difference between “light air” or a “light breeze” and a “gentle breeze” (NOAA).

However, the slopes did diverge significantly between the treatment groups at and above 8.03 knots (approximately 1.15 mph) of wind speed, such that higher levels of wind speed beyond that point were associated with lower SIGH-SAD scores at post-treatment for those in light therapy. In the light therapy group, each unit increase of wind speed at and above 8.03 knots was associated with a decrease of 2.43 points on the SIGH-SAD at post-treatment. Beyond this point, each additional increase of 1.15 MPH corresponds to another 2.43-point reduction in SIGH-SAD scores. Therefore, as windspeed increases beyond the cut point of 8.03 knots towards increasingly higher levels, there are correspondingly larger magnitude decrease in SIGH-SAD scores for light therapy participants.

The a priori hypothesis was for stronger predictive effect of weather on mood in light therapy; however, the observed moderation effect was only found at post-treatment and was in the opposite direction of what was expected (with higher windspeed associated with lower depression scores in light therapy). One possible interpretation of this is that light therapy is an indoor treatment, potentially insulating light therapy participants from the effects of windspeed, at least during their light therapy sessions.

Other Predictors of Mood. Depression severity at pre-treatment was a robust predictor of depression severity at each following timepoint. This effect was apparent for both depression severity outcome measures at all time-points. The predictive power of pre-treatment depression severity also appears to be responsible for much of the predictive power of the overall models for all weather variables at all timepoints. This finding is consistent with the larger depression literature where it is a well-replicated finding that baseline, or pre-treatment in the case of a clinical trial, depression score robustly predicts depression score at subsequent time points, regardless of treatment group (Weitz et al., 2015).

In addition, treatment was a significant predictor of Winter 2 depression scores in all models across both the SIGH-SAD and BDI-II outcomes, where CBT-SAD participants had significantly lower scores than light therapy participants. This replicates the parent study's findings, but also extends them because this study used predictive (regression) models and controlled for pre-treatment depression severity and the (respective) weather variable in the model. Even after adjusting for daylength, temperature, solar radiation, sky cover, precipitation, or wind speed on the date of assessment, CBT-SAD participants had lower depression severity across the board than light therapy participants at Winter 2 follow-up. This suggests a very robust treatment effect favoring CBT-SAD over LT two winters after treatment.

While many of these weather-mood interactions reflect very small effects, they do reflect statistically significant effects, and these predictive relationships do differ some between the two outcome measures. This slight difference in the pattern of findings when using BDI-II vs. SIGH-SAD scores as outcome may reflect a difference in the depression constructs captured by each. The BDI-II contains items representing symptoms that fall in the cognitive domain (e.g., negative thought content) and the SIGH-SAD contains several items representing fatigue and somatic symptoms. Current weather conditions may influence depressogenic negative thinking, better captured by the BDI-II, more so than fatigue and somatic symptoms more heavily weighted in the SIGH-SAD.

Strengths and Limitations

To our knowledge, this is the first analysis to assess the effects of weather on mood in the context of a treatment study for SAD, or for any other mental health disorder. In addition, there are few studies to date that has examined prospective mood ratings rendered by trained clinical raters, as opposed to retrospective self-report data. Moreover, it is a strength of the current analysis that individual daily weather variables were considered separately, as it allows for the parsing out of different individual weather variables' effect on mood, as opposed to relying on combined variables' effects, which may obscure which weather variables are and are not predictive of mood. This study design also avoids subjective categorization of "good" and "bad" weather and instead opts to consider each individual weather variable continuously. Finally, the utilization of two separate measures for depression severity, which are generally correlated but which measure slightly different constructs, is a strength of this analysis.

There are plausible theoretical reasons to support that people with SAD should be most sensitive to the effects of photoperiod and weather on mood; however, these results are not generalizable to other clinical populations and to SAD populations at other locations and with more diverse characteristics than this predominantly White, non-Hispanic sample in Burlington, VT. Additionally, there are several notable limitations to the current analysis. By virtue of the study design, weather data were collected to match the day that each clinical interview was taken. Furthermore, the SIGH-SAD and BDI-II measures retrospectively assess mood over the last two weeks. As such, the analysis can only account for day-of effects of weather on mood at the time the assessment was taken, even though the assessment accounts for mood over a longer period. Therefore, our interpretation of the data is limited to the effect of weather variables on mood, as operationalized by weather's effect on how participants answer clinical interview items day-of.

Furthermore, this presents yet another limitation, in that this analysis does not account for delayed or cumulative effects of weather on mood. For example, it remains possible that there are significant effects of these weather variables on mood when a two-week delay is accounted for. Similarly, there might be a significant effect of these weather variables on mood if weekly or bi-weekly averages are regressed with SIGH-SAD scores. This analysis cannot account for such an effect. Furthermore, this analysis does not account for weather variability throughout the day, and relies on daily averages for temperature, sky cover, and wind speed, and daily cumulative measures for solar radiation and precipitation. It is also possible that other facets of the weather are more predictive of mood – not only minimum and maximum values of the temperature, sky cover, and wind speed, but also other weather variables that this analysis did not consider.

Other limitations in the interpretation of this analysis include the single-site study design, with the clinical trial conducted in Burlington, Vermont. The nature of the weather in Burlington, Vermont may have a unique effect, or unique non-effect, on mood in people with SAD undergoing these treatments that may or may not generalize elsewhere. Winter weather conditions and severity in Burlington may also have an effect on the development and maintenance of seasonal beliefs in people with SAD. Furthermore, the analysis was limited to weather between December and March to match the timing of study assessments, and it remains possible that a study spanning more months and seasons of the year might identify more or different effects for weather variables on mood in SAD patients.

Furthermore, an a priori power analysis was not conducted for this analysis, which is a limitation of this study, as we were not able to determine the sample size needed to detect weather effects on mood, alone and in interaction with treatment. Lastly, at the Winter 1 timepoint, missing values were not missing at random ($p = .001$), so this may have skewed the results of the analyses at this timepoint.

Future Directions

Future studies should utilize multiple imputation to account for missing data, in order to lessen resulting bias in the analyses. Analyses may also use a priori power analyses to determine the sample size needed to detect weather effects on mood.

Moreover, future studies should examine different facets of these weather variables (e.g., minimum and maximum daily temperature, hourly weather data as opposed to average daily data, etc). Additionally, further analyses may examine different weather variables that were not utilized in this study or assess how cross-correlations of multiple weather variables might predict mood – particularly those weather variables which might affect each other greatly. For example, wind speed might make it feel colder than it actually is, so researchers might want to examine wind speed in combination with temperature in future studies to test for a larger effect. Likewise, there might be a difference in how precipitation affects mood depending on the temperature (such that snow might affect mood differently than rain). It might also be useful to include data from other seasons in order to introduce a wider range of weather conditions to the analyses. This would both allow the researcher to examine how people with SAD shift in depressive presentation between winter and summer, and whether it is by consequence of certain weather variables. Additionally, further analyses might examine a possible moderation effect of treatment on a wind speed-mood relationship in a location that offers more variation in wind speed.

Conclusions

The current analysis reveals that certain individual daily weather variables – namely, daylength, sky cover, temperature, and solar radiation – may predict very small changes in depression severity outcome in the context of a treatment study for SAD comparing CBT-SAD and light therapy in Burlington, VT. However, these effects are unlikely to hold much clinical significance. Furthermore, these effects are generally not moderated by treatment group, with the exception of the found effect of wind speed on SIGH-SAD scores at post-treatment for those who received light therapy. Though, further investigation is needed to assess this moderation effect at other time points, to understand how pervasive this effect is across and following the course of treatment. Since this was the only significant moderation effect found in this analysis, and it was limited to a singular time point, individual weather variables and their interaction with treatment type generally did not explain the greater durability of CBT-SAD over light therapy in the treatment of SAD in this sample.

However, the current analysis does supports and add to the depression literature that pre-treatment depression severity is a strong and robust predictor of depression severity at all subsequent timepoints, regardless of treatment type. Moreover, the current analysis replicates and bolsters the results of the parent study in that treatment type predicts depression severity outcomes at second Winter follow-up, even when controlling for daylength, temperature, solar radiation, sky cover, precipitation, or wind speed, such that the effects of CBT-SAD are more durable than light therapy following treatment.

Table 1

Demographic Information of Study Sample (N=177)

Variable	Total Sample	CBT-SAD n=88	LT n=89
	n(%)	n (%)	n (%)
Sex			
Male	29 (16.4)	14 (7.9)	15 (8.5)
Female	148 (83.6)	74 (41.8)	74 (41.8)
Age (SD)	45.6 (12.8)	46.9 (12.6)	44.4 (12.9)
Race			
American Indian	5 (2.8)	0 (0)	5 (2.8)
Asian	2 (1.1)	1 (0.6)	1 (0.6)
African American	2 (1.1)	1 (0.6)	1 (0.6)
Hispanic	3 (1.7)	2 (1.1)	1 (0.6)
White	163 (92.1)	83 (46.9)	80 (45.2)
Other	2 (1.1)	1 (0.6)	1 (0.6)

Note. CBT-SAD = SAD-tailored group cognitive-behavioral therapy, LT = Light Therapy.

Table 2 *Zero order correlations of the weather variables and the Structured Interview Guide for the Hamilton Rating Scale for Depression-Seasonal Affective Disorder Version (SIGH-SAD)*

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
1. Treatment Group[a]	--																												
2. SIGH-SAD Pre-Tx	-.07	--																											
3. SIGH-SAD Post-Tx	-.11	*.27*	--																										
4. SIGH-SAD Winter 1	.01	*.26*	*.27*	--																									
5. SIGH-SAD Winter 2	*.20*	*.18*	*.22*	*.54*	--																								
6. Daily Temp Pre-Tx	-.04	-.03	-.05	-.04	.03	--																							
7. Daily Temp Post-Tx	*-.24*	.08	.11	.10	-.04	*-.22*	--																						
8. Daily Temp Winter 1	-.09	.00	-.05	-.07	-.03	-.09	.06	--																					
9. Daily Temp Winter 2	.01	-.06	.02	-.05	-.06	-.09	-.06	-.11	--																				
10. Precipitation Pre-Tx	-.11	-.10	.00	-.05	-.03	*.18*	-.07	-.05	-.07	--																			
11. Precipitation Post-Tx	.06	.08	-.02	.05	.00	-.06	.07	-.01	-.03	*.17*	--																		
12. Precipitation Winter 1	.09	.04	-.04	.07	.09	.03	-.07	-.04	.03	-.05	-.05	--																	
13. Precipitation Winter 2	.14	-.15	-.04	-.07	-.10	.11	*-.16*	-.03	*.25*	-.09	.04	-.02	--																
14. Cloud Cover Pre-Tx	-.05	.05	.02	-.04	-.08	-.14	.08	.05	-.10	*.33*	.08	.06	-.02	--															
15. Cloud Cover Post-Tx	.12	-.10	-.09	-.08	-.08	*.17*	.02	-.12	.04	.13	*.33*	-.10	.15	.00	--														
16. Cloud Cover Winter 1	-.12	-.11	-.03	*-.20*	*-.18*	-.02	-.03	*.27*	-.14	.03	.08	-.07	.08	*.16*	-.02	--													
17. Cloud Cover Winter 2	*.21*	-.02	.00	-.03	.05	*-.16*	*-.17*	-.06	*.46*	-.04	-.03	.08	*.33*	.10	-.01	.06	--												
18. Solar Radiation Pre-Tx	.07	-.02	-.01	*.16*	*.20*	*.21*	-.07	-.03	.10	*-.32*	-.06	.04	.12	*-.81*	.03	*-.16*	-.05	--											
19. Solar Radiation Post-Tx	-.12	.02	.12	-.01	.04	*-.35*	*.19*	.09	-.01	*-.20*	*-.39*	.05	*-.17*	.00	*-.75*	.02	.05	-.04	--										
2. Solar Radiation Winter 1	.08	.07	.05	.15	.06	-.11	-.02	-.04	*.18*	.02	-.12	*.17*	-.06	.00	-.08	*-.55*	.10	.05	.03	--									
21. Solar Radiation Winter 2	-.06	.01	-.07	.14	.05	.00	*.21*	.00	*-.35*	.07	.01	-.09	*-.38*	-.02	-.06	-.10	*-.61*	-.07	.06	-.05	--								
22. Wind Speed Pre-Tx	.02	.11	-.02	-.11	.06	.05	.06	.11	-.12	.10	.10	-.07	-.03	*.23*	.03	.11	.03	*-.23*	-.02	-.09	.00	--							
23. Wind Speed Post-Tx	.07	-.01	-.06	-.15	-.03	-.08	.00	.09	-.06	.04	-.09	-.02	.00	.03	*.23*	-.13	-.06	-.07	-.06	.07	.00	.03	--						
24. Wind Speed Winter 1	-.14	-.07	.01	-.02	*-.20*	-.04	*.18*	.06	.08	.05	-.05	-.10	.06	.10	-.01	.06	-.04	-.08	*.16*	.02	.07	-.01	.02	--					
25. Wind Speed Winter 2	-.01	-.03	-.05	-.04	.07	.01	.09	.02	*.33*	-.09	.09	.07	.14	-.04	.08	-.06	.13	.02	-.03	.07	-.14	-.06	.02	-.07	--				
26. Daylength Pre-Tx	.00	-.07	-.04	.09	.13	*.54*	*-.17*	-.08	.06	.03	-.03	.11	*.18*	*-.43*	.14	-.09	-.02	*.70*	*-.29*	.00	-.08	*-.24*	-.08	-.08	.01	--			
27. Daylength Post-Tx	*-.23*	.10	*.17*	-.03	-.03	*-.50*	*.57*	*.20*	-.01	.00	.05	-.06	-.11	*.28*	*-.29*	.09	.02	*-.26*	*.56*	.03	.08	.12	.02	*.19*	.05	*-.46*	--		
28. Daylength Winter 1	.02	.11	.06	.05	.04	-.15	-.08	*.32*	.09	-.01	-.10	*.21*	-.04	.05	-.13	-.01	.13	.02	.05	*.67*	-.09	-.02	.00	-.11	.07	-.03	.11	--	
29. Daylength Winter 2	.04	-.08	-.02	.14	.06	-.13	.05	.00	.13	-.02	-.08	-.10	-.02	-.06	-.08	*-.17*	-.05	.05	.13	*.17*	*.53*	-.05	.03	.10	*-.17*	-.03	.15	.11	--

[a]1 = CBT-SAD, 2 = Light Therapy

Note: Italics = $p < .05$, “daily temp” variables pertain to averaged daily temperatures

Table 3 *Zero order correlations of the weather variables and the Beck Depression Inventory-Second Edition (BDI-II)*

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
1. Treatment Group[a]	--																												
2. BDI-II Pre-Tx	.05	--																											
3. BDI-II Post-Tx	-.08	*.35*	--																										
4. BDI-II Winter 1	-.01	*.40*	*.38*	--																									
5. BDI-II Winter 2	*.22*	*.39*	*.15*	*.64*	--																								
6. Daily Temp Pre-Tx	-.04	*-.21*	*-.15*	-.08	-.12	--																							
7. Daily Temp Post-Tx	*-.24*	.06	*.22*	.15	.04	*-.22*	--																						
8. Daily Temp Winter 1	-.09	.04	.00	.01	.02	-.09	.06	--																					
9. Daily Temp Winter 2	.01	*.16*	.01	.01	-.05	-.09	-.06	-.11	--																				
10. Precipitation Pre-Tx	-.11	-.03	-.01	-.05	-.03	*.18*	-.07	-.05	-.07	--																			
11. Precipitation Post-Tx	.06	*.18*	.09	.04	-.01	-.06	.07	-.01	-.03	*.17*	--																		
12. Precipitation Winter 1	.09	-.07	-.01	.10	.03	.03	-.07	-.04	.03	-.05	-.05	--																	
13. Precipitation Winter 2	.14	.10	.04	.04	-.04	.11	*-.16*	-.03	*.25*	-.09	.04	-.02	--																
14. Cloud Cover Pre-Tx	-.05	.00	.10	-.02	.03	-.14	.08	.05	-.10	*.33*	.08	.06	-.02	--															
15. Cloud Cover Post-Tx	.12	.01	-.07	-.11	-.09	*.17*	.02	-.12	.04	.13	*.33*	-.10	.15	.00	--														
16. Cloud Cover Winter 1	-.12	-.06	.04	-.10	-.08	-.02	-.03	*.27*	-.14	.03	.08	-.07	.08	*.16*	-.02	--													
17. Cloud Cover Winter 2	*.21*	*.22*	-.01	.06	.04	*-.16*	*-.17*	-.06	*.46*	-.04	-.03	.08	*.33*	.10	-.01	.06	--												
18. Solar Radiation Pre-Tx	.07	.06	-.08	.14	.09	*.21*	-.07	-.03	.10	*-.32*	-.06	.04	.12	*-.81*	.03	*-.16*	-.05	--											
19. Solar Radiation Post-Tx	-.12	.00	.09	.09	.06	*-.35*	*.19*	.09	-.01	*-.20*	*-.39*	.05	*-.17*	.00	*-.75*	.02	.05	-.04	--										
20. Solar Radiation Winter 1	.08	.02	-.02	.04	.09	-.11	-.02	-.04	*.18*	.02	-.12	*.17*	-.06	.00	-.08	*-.55*	.10	.05	.03	--									
21. Solar Radiation Winter 2	-.06	-.11	.00	.03	.10	.00	*.21*	.00	*-.35*	.07	.01	-.09	*-.38*	-.02	-.06	-.10	*-.61*	-.07	.06	-.05	--								
22. Wind Speed Pre-Tx	.02	.06	.07	-.04	.04	.05	.06	.11	-.12	.10	.10	-.07	-.03	*.23*	.03	.11	.03	*-.23*	-.02	-.09	.00	--							
23. Wind Speed Post-Tx	.07	-.02	-.11	-.09	-.04	-.08	.00	.09	-.06	.04	-.09	-.02	.00	.03	*.23*	-.13	-.06	-.07	-.06	.07	.00	.03	--						
24. Wind Speed Winter 1	-.14	-.06	.01	-.02	-.13	-.04	*.18*	.06	.08	.05	-.05	-.10	.06	.10	-.01	.06	-.04	-.08	*.16*	.02	.07	-.01	.02	--					
25. Wind Speed Winter 2	-.01	.03	-.03	.01	.07	.01	.09	.02	*.33*	-.09	.09	.07	.14	-.04	.08	-.06	.13	.02	-.03	.07	-.14	-.06	.02	-.07	--				
26. Daylength Pre-Tx	.00	-.04	-.04	.08	.00	*.54*	*-.17*	-.08	.06	.03	-.03	.11	*.18*	*-.43*	.14	-.09	-.02	*.70*	*-.29*	.00	-.08	*-.24*	-.08	-.08	.01	--			
27. Daylength Post-Tx	*-.23*	.12	*.22*	.15	.06	*-.50*	*.57*	*.20*	-.01	.00	.05	-.06	-.11	*.28*	*-.29*	.09	.02	*-.26*	*.56*	.03	.08	.12	.02	*.19*	.05	*-.46*	--		
28. Daylength Winter 1	.02	.07	.06	.05	.07	-.15	-.08	*.32*	.09	-.01	-.10	*.21*	-.04	.05	-.13	-.01	.13	.02	.05	*.67*	-.09	-.02	.00	-.11	.07	-.03	.11	--	
29. Daylength Winter 2	.04	.11	-.02	.14	*.19*	-.13	.05	.00	.13	-.02	-.08	-.10	-.02	-.06	-.08	*-.17*	-.05	.05	.13	*.17*	*.53*	-.05	.03	.10	*-.17*	-.03	.15	.11	--

[a]1 = CBT-SAD, 2 = Light Therapy

Note: Italics = $p < .05$.

Table 4

Zero order correlations of the Structured Interview Guide for the Hamilton Rating Scale for Depression-Seasonal Affective Disorder Version (SIGH-SAD) and the Beck Depression Inventory-Second Edition (BDI-II)

Node	1	2	3	4	5	6	7	8
1. SIGH-SAD Pre-Tx	--							
2. SIGH-SAD Post-Tx	*.27*	--						
3. SIGH-SAD Winter 1	*.26*	*.27*	--					
4. SIGH-SAD Winter 2	*.18*	*.22*	*.54*	--				
5. BDI Pre-Tx	*.41*	*.30*	*.22*	*.30*	--			
6. BDI Post-Tx	*.28*	*.70*	*.25*	.14	*.35*	--		
7. BDI Winter 1	*.25*	*.35*	*.76*	*.56*	*.40*	*.38*	--	
8. BDI Winter 2	.13	*.16*	*.54*	*.81*	*.39*	*.15*	*.64*	--

Note: Italics = $p < .05$.

Table 5

Individual weather variables and their interactions with treatment as predictors of SIGH-SAD scores

Outcome: SIGH-SAD		**Pre-tx SIGH-SAD**					**Post-tx SIGH-SAD**					**Winter 1 SIGH-SAD**					**Winter 2 SIGH-SAD**				
	Predictor	*B*	S.E.	Beta	t	*p*	*B*	*S.E.*	Beta	t	*p*	*B*	*S.E.*	Beta	t	*p*	*B*	*S.E.*	Beta	t	*p*
1	Pre-Tx SIGH- SAD						0.33	0.09	0.27	3.61	<.001	0.41	0.12	0.26	3.47	<.001	0.29	0.13	0.18	2.28	0.02
2	Daylength	-0.71	0.73	-0.07	-0.98	0.33	1.08	0.55	0.15	1.98	0.05	0.29	0.89	0.02	0.32	0.75	1.04	1.02	0.08	1.02	0.31
	Temperature	-0.01	0.03	-0.03	-0.33	0.74	0.05	0.04	0.09	1.25	0.21	-0.06	0.07	-0.07	-0.87	0.39	-0.04	0.06	-0.05	-0.65	0.52
	Solar radiation	0.00	0.01	-0.02	-0.29	0.78	0.01	0.01	0.12	1.60	0.11	0.02	0.01	0.13	1.70	0.09	0.01	0.01	0.04	0.57	0.57
	Sky cover	0.01	0.01	0.05	0.61	0.55	-0.01	0.02	-0.06	-0.81	0.42	-0.06	0.03	-0.18	-2.35	0.02	0.02	0.03	0.05	0.65	0.51
	Precipitation	-2.88	2.11	-0.10	-1.37	0.17	-1.81	3.55	-0.04	-0.51	0.61	1.31	1.58	0.06	0.83	0.41	-5.92	5.81	-0.08	-1.02	0.31
	Wind speed	0.17	0.12	0.11	1.41	0.16	-0.14	0.17	-0.06	-0.81	0.42	-0.02	0.24	-0.01	-0.06	0.95	0.21	0.21	0.08	0.98	0.33
3	Tx group (Daylength)	-0.73	0.83	-0.07	-0.88	0.38	-0.88	1.02	-0.07	-0.86	0.39	0.42	1.28	0.03	0.33	0.75	4.05	1.38	0.22	2.94	0.00
	Tx group (Temperature)	-0.74	0.83	-0.07	-0.90	0.37	-1.03	1.03	-0.08	-1.01	0.32	0.33	1.29	0.02	0.26	0.80	4.09	1.38	0.22	2.97	0.00
	Tx group (Solar radiation)	-0.72	0.83	-0.07	-0.87	0.39	-1.10	1.00	-0.08	-1.10	0.27	0.25	1.28	0.02	0.20	0.84	4.16	1.38	0.23	3.01	0.00
	Tx group (Sky cover)	-0.71	0.83	-0.07	-0.86	0.39	-1.20	1.01	-0.09	-1.19	0.24	0.03	1.27	0.00	0.03	0.98	4.07	1.41	0.22	2.89	0.00
	Tx group (Precipitation)	-0.87	0.83	-0.08	-1.05	0.30	-1.24	1.00	-0.09	-1.24	0.22	0.33	1.29	0.02	0.26	0.80	4.33	1.38	0.24	3.14	0.00
	Tx group (Wind speed)	-0.73	0.83	-0.07	-0.89	0.38	-1.22	1.00	-0.09	-1.21	0.23	0.43	1.30	0.03	0.33	0.74	4.11	1.38	0.23	2.99	0.00
4	Daylength X tx group	0.25	1.47	0.22	0.17	0.86	-0.25	1.13	-0.20	-0.22	0.83	1.11	1.77	0.65	0.62	0.53	2.54	2.00	1.41	1.27	0.21
	Temperature X tx group	0.03	0.07	0.15	0.49	0.63	0.10	0.07	0.32	1.39	0.17	0.03	0.13	0.06	0.20	0.85	0.20	0.12	0.47	1.70	0.09
	Solar radiation X tx group	-0.01	0.02	-0.21	-0.73	0.47	-0.01	0.01	-0.22	-0.80	0.42	0.00	0.02	0.03	0.10	0.92	0.00	0.02	0.04	0.15	0.88
	Sky cover X tx group	0.03	0.03	0.29	1.00	0.32	0.01	0.03	0.08	0.27	0.79	0.04	0.05	0.22	0.73	0.47	0.07	0.05	0.44	1.29	0.20
	Precipitation X tx group	5.82	4.73	0.28	1.23	0.22	-6.14	7.99	-0.23	-0.77	0.44	7.12	7.66	0.67	0.93	0.35	7.12	13.31	0.18	0.54	0.59
	Wind speed X tx group	0.33	0.24	0.40	1.38	0.17	-0.70	0.35	-0.63	-1.99	0.05	-0.08	0.49	-0.05	-0.17	0.87	0.11	0.41	0.07	0.26	0.80

Note: tx group = treatment group
1 = CBT-SAD, 2 = Light Therapy

Table 6

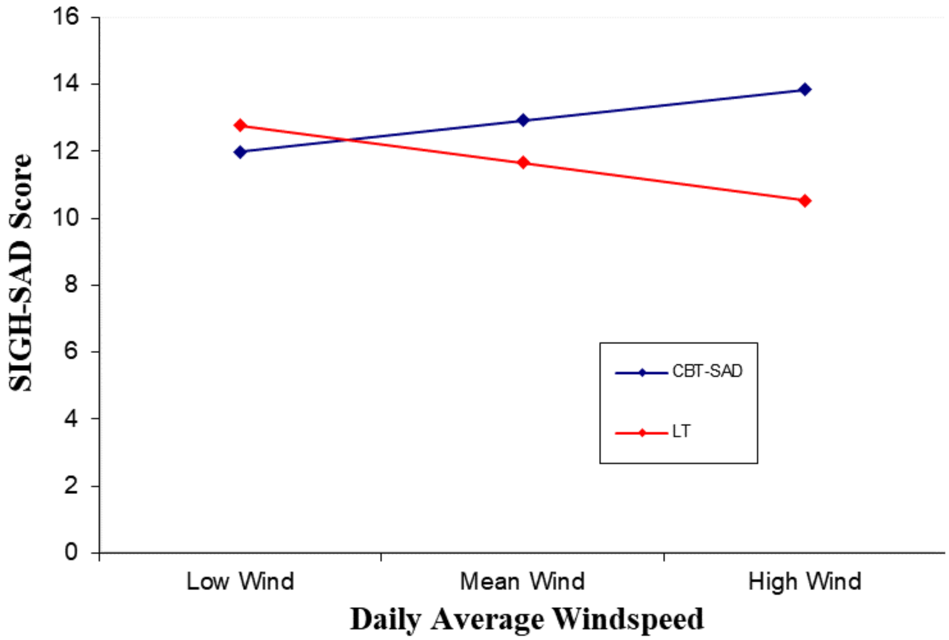
Individual weather variables and their interactions with treatment as predictors of BDI-II scores

Outcome: BDI-II		**Pre-tx BDI-II**					**Post-tx BDI-II**					**Winter 1 BDI-II**					**Winter 2 BDI-II**				
	Predictor	*B*	S.E.	Beta	t	*p*	*B*	*S.E.*	Beta	t	*p*	*B*	*S.E.*	Beta	t	*p*	*B*	*S.E.*	Beta	t	*p*
1	Pre-Tx BDI-II						0.25	0.05	0.35	4.90	<.001	0.32	0.06	0.38	5.32	<.001	0.36	0.07	0.39	5.44	<.001
2	Daylength	-0.66	1.21	-0.04	-0.55	0.59	1.30	0.51	0.18	2.56	0.01	0.21	0.74	0.02	0.29	0.77	1.83	0.86	0.15	2.13	0.04
	Temperature	-0.15	0.05	-0.21	-2.82	0.01	0.09	0.03	0.20	2.85	0.01	-0.01	0.05	-0.01	-0.10	0.92	-0.08	0.05	-0.11	-1.58	0.12
	Solar radiation	0.01	0.01	0.06	0.73	0.46	0.01	0.01	0.09	1.28	0.20	0.00	0.01	0.04	0.48	0.63	0.02	0.01	0.15	2.10	0.04
	Sky cover	0.00	0.02	0.00	0.03	0.97	-0.02	0.02	-0.07	-0.98	0.33	-0.02	0.02	-0.08	-1.08	0.28	-0.01	0.02	-0.04	-0.59	0.56
	Precipitation	-1.17	3.52	-0.03	-0.33	0.74	1.34	3.34	0.03	0.40	0.69	2.30	1.31	0.13	1.76	0.08	-5.24	4.90	-0.08	-1.07	0.29
	Wind speed	0.17	0.20	0.07	0.85	0.39	-0.22	0.16	-0.10	-1.40	0.16	0.01	0.20	0.00	0.04	0.97	0.14	0.18	0.06	0.80	0.43
3	Tx group (Daylength)	0.84	1.37	0.05	0.61	0.54	-0.69	0.94	-0.05	-0.73	0.47	-0.54	1.07	-0.04	-0.51	0.61	3.39	1.15	0.20	2.94	0.00
	Tx group (Temperature)	0.70	1.35	0.04	0.52	0.60	-0.59	0.94	-0.05	-0.63	0.53	-0.55	1.07	-0.04	-0.51	0.61	3.49	1.16	0.21	3.02	0.00
	Tx group (Solar radiation)	0.77	1.38	0.04	0.56	0.58	-1.06	0.93	-0.08	-1.14	0.26	-0.58	1.07	-0.04	-0.54	0.59	3.66	1.15	0.22	3.18	0.00
	Tx group (Sky cover)	0.84	1.38	0.05	0.61	0.54	-1.10	0.94	-0.09	-1.17	0.24	-0.69	1.07	-0.05	-0.64	0.52	3.80	1.19	0.23	3.20	0.00
	Tx group (Precipitation)	0.80	1.38	0.04	0.58	0.57	-1.21	0.93	-0.09	-1.30	0.20	-0.71	1.06	-0.05	-0.67	0.50	3.73	1.17	0.22	3.19	0.00
	Tx group (Wind speed)	0.86	1.38	0.05	0.62	0.54	-1.09	0.93	-0.08	-1.17	0.24	-0.54	1.08	-0.04	-0.50	0.62	3.50	1.16	0.21	3.01	0.00
4	Daylength X tx group	3.92	2.42	2.05	1.62	0.11	-0.35	1.05	-0.30	-0.34	0.74	1.55	1.47	1.05	1.06	0.29	2.87	1.68	1.75	1.71	0.09
	Temperature X tx group	0.10	0.11	0.28	0.95	0.35	0.12	0.07	0.40	1.83	0.07	0.03	0.11	0.08	0.28	0.78	0.18	0.10	0.48	1.89	0.06
	Solar radiation X tx group	0.03	0.03	0.33	1.15	0.25	-0.01	0.01	-0.38	-1.44	0.15	0.02	0.02	0.26	0.89	0.37	-0.02	0.02	-0.25	-0.95	0.34
	Sky cover X tx group	0.05	0.04	0.30	1.04	0.30	0.03	0.03	0.30	1.09	0.28	0.00	0.04	0.02	0.06	0.95	0.08	0.05	0.53	1.69	0.09
	Precipitation X tx group	0.48	7.93	0.01	0.06	0.95	3.00	7.34	0.12	0.41	0.68	6.08	6.36	0.65	0.96	0.34	21.90	11.23	0.59	1.95	0.05
	Wind speed X tx group	0.17	0.40	0.13	0.44	0.66	-0.09	0.33	-0.09	-0.28	0.78	0.10	0.42	0.07	0.25	0.81	0.20	0.35	0.15	0.58	0.57

Note: tx group = treatment group
1 = CBT-SAD, 2 = Light Therapy

Figure 1

The interactive effect of treatment group and average daily wind speed on SIGH-SAD scores at post-treatment



Note: Average daily wind speed was centered on the mean; low wind represents 1 SD below the mean, and high wind represents 1 SD above the mean; slopes are not significant

References

Aiken, L. S., West, S. G., & Reno, R. R. (1991). *Multiple regression: Testing and interpreting interactions* (Reprinted). SAGE.

Albert, P. S., Rosen, L. N., Alexander, J. R., & Rosenthal, N. E. (1991). Effect of daily variation in weather and sleep on seasonal affective disorder. *Psychiatry Research*, *36*(1), 51–63. https://doi.org/10.1016/0165-1781(91)90117-8

Beck, A. T., Steer, R. A., & Brown, G. K. (1996). *Manual for the Beck depression inventory-II*. Psychological Corporation.

Hayes, A. F. (2022). *Introduction to mediation, moderation, and conditional process analysis: A regression-based approach* (Third edition). The Guilford Press.

Lingjaerde, O., & Reichborn-Kjennerud, T. (1993). Characteristics of winter depression in the Oslo area (60°N). *Acta Psychiatrica Scandinavica*, *88*(2), 111–120. https://doi.org/10.1111/j.1600-0447.1993.tb03423.x

Molin, J., Mellerup, E., Bolwig, T., Scheike, T., & Dam, H. (1996). The influence of climate on development of winter depression. *Journal of Affective Disorders, 37*(2–3), 151–155. https://doi.org/10.1016/0165-0327(95)00090-9

Oren, D. A., Moul, D. E., Schwartz, P. J., Brown, C., Yamada, E. M., & Rosenthal, N. E. (1994). Exposure to ambient light in patients with winter seasonal affective disorder. *The American Journal of Psychiatry*, *151*(4), 591–593. https://doi.org/10.1176/ajp.151.4.591

Rohan, K. J. (2008). *Coping with the Seasons: Therapist Guide: A Cognitive-Behavioral Approach to Seasonal Affective Disorder*. Oxford University Press. https://doi.org/10.1093/med:psych/9780195341089.001.0001

Rohan, K. J., Evans, M., Mahon, J. N., Sitnikov, L., Ho, S.-Y., Nillni, Y. I., Postolache, T. T., & Vacek, P. M. (2013). Cognitive-behavioral therapy vs. light therapy for preventing winter depression recurrence: Study protocol for a randomized controlled trial. *Trials*, *14*(1), 82. https://doi.org/10.1186/1745-6215-14-82

Rohan, K. J., Mahon, J. N., Evans, M., Ho, S.-Y., Meyerhoff, J., Postolache, T. T., & Vacek, P. M. (2015). Randomized Trial of Cognitive-Behavioral Therapy Versus Light Therapy for Seasonal Affective Disorder: Acute Outcomes. *American Journal of Psychiatry*, *172*(9), 862–869. https://doi.org/10.1176/appi.ajp.2015.14101293

Rohan, K. J., Meyerhoff, J., Ho, S.-Y., Evans, M., Postolache, T. T., & Vacek, P. M. (2016). Outcomes One and Two Winters Following Cognitive-Behavioral Therapy or Light Therapy for Seasonal Affective Disorder. *American Journal of Psychiatry*, *173*(3), 244–251. https://doi.org/10.1176/appi.ajp.2015.15060773

Rohan, K. J., Rough, J. N., Evans, M., Ho, S.-Y., Meyerhoff, J., Roberts, L. M., & Vacek, P. M. (2016). A protocol for the Hamilton Rating Scale for Depression: Item scoring rules, Rater training, and outcome accuracy with data on its application in a clinical trial. *Journal of Affective Disorders*, *200*, 111–118. https://doi.org/10.1016/j.jad.2016.01.051

Rosenthal, N. E., Sack, D. A., Gillin, J. C., Lewy, A. J., Goodwin, F. K., Davenport, Y., Mueller, P. S., Newsome, D. A., & Wehr, T. A. (1984). Seasonal affective disorder. A description of the syndrome and preliminary findings with light therapy. *Archives of General Psychiatry*, *41*(1), 72–80. https://doi.org/10.1001/archpsyc.1984.01790120076010

Sakamoto, K., Kamo, T., Nakadaira, S., Tamura, A., & Takahashi, K. (1993). A nationwide survey of seasonal affective disorder at 53 outpatient university clinics in Japan. *Acta*

Psychiatrica Scandinavica, *87*(4), 258–265. https://doi.org/10.1111/j.1600-0447.1993.tb03368.x

Williams, J. B. W. (1988). A Structured Interview Guide for the Hamilton Depression Rating Scale. *Archives of General Psychiatry*, *45*(8), 742. https://doi.org/10.1001/archpsyc.1988.01800320058007

Wirz-Justice, A., Bucheli, C., Graw, P., Kielholz, P., Fisch, H. U., & Woggon, B. (1986). Light treatment of seasonal affective disorder in Switzerland. *Acta Psychiatrica Scandinavica*, *74*(2), 193–204. https://doi.org/10.1111/j.1600-0447.1986.tb10606.x

Young, M. A., Meaden, P. M., Fogg, L. F., Cherin, E. A., & Eastman, C. I. (1997). Which environmental variables are related to the onset of seasonal affective disorder? *Journal of Abnormal Psychology*, *106*(4), 554–562. https://doi.org/10.1037/0021-843X.106.4.554