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Preliminary communication

Relationship among latitude, climate, season and self-reported mood in bipolar disorder

Michael Bauer [a,*], Tasha Glenn [b,1], Paul Grof [c], Natalie L. Rasgon [d], Wendy Marsh [e], Kemal Sagduyu [f], Martin Alda [g], Greg Murray [h], Danilo Quiroz [i], Yanni Malliaris [j], Johanna Sasse [a], Maximilian Pilhatsch [a], Peter C. Whybrow [k]

[a] *Department of Psychiatry and Psychotherapy, Universitätsklinikum Carl Gustav Carus, Technische Universität Dresden, Germany Fetscherstr. 74, 01307 Dresden, Germany*
[b] *ChronoRecord Association, Inc., PO Box 3501, Fullerton, CA, 92834, USA*
[c] *Mood Disorders Center of Ottawa, Ottawa, Canada, 1929 Russell Road, Ottawa, Canada K1G 4G3 and Department of Psychiatry, University of Toronto, ON, Canada*
[d] *Department of Psychiatry and Behavioral Sciences, Stanford School of Medicine, 401 Quarry Road, Room 2368, Palo Alto, CA 94305-5723, USA*
[e] *Department of Psychiatry, University of Massachusetts, 55 Lake Avenue North, Worcester, MA 01655, USA*
[f] *Department of Psychiatry, University of Missouri Kansas City School of Medicine, Kansas City, MO, USA and PO Box 23430, Stanley, KS 66283, USA*
[g] *Department of Psychiatry, Dalhousie University, 5909 Veteran's Memorial Lane, QEII Health Sciences Centre, Halifax, NS, Canada B3H 2E2*
[h] *Faculty of Life and Social Sciences, Swinburne University of Technology, PO Box 218 John St., Hawthorn 3122 Melbourne, Victoria, Australia*
[i] *Mood and Anxiety Center Efeso, Santiago, Chile*
[j] *P025, Health Service and Population Research, Institute of Psychiatry, King's College London, De Crespigny Park Road, SE5 8AF, London, UK*
[k] *Department of Psychiatry and Biobehavioral Sciences, Semel Institute for Neuroscience and Human Behavior University of California Los Angeles (UCLA), 300 UCLA Medical Plaza, Los Angeles, CA, 90095, USA*

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ABSTRACT

Objective: Many researchers have analyzed seasonal variation in hospital admissions for bipolar disorder with inconsistent results. We investigated if a seasonal pattern was present in daily self-reported daily mood ratings from patients living in five climate zones in the northern and southern hemispheres. We also investigated the influence of latitude and seasonal climate variables on mood.
Method: 360 patients who were receiving treatment as usual recorded mood daily (59,422 total days of data). Both the percentage of days depressed and hypomanic/manic, and the episodes of depression and mania were determined. The observations were provided by patients from different geographic locations in North and South America, Europe and Australia. These data were analyzed for seasonality by climate zone using both a sinusoidal regression and the Gini index. Additionally, the influence of latitude and climate variables on mood was estimated using generalized linear models for each season and month.
Results: No seasonality was found in any climate zone by either method. In spite of vastly different weather, neither latitude nor climate variables were associated with mood by season or month.
Conclusion: Daily self-reported mood ratings of most patients with bipolar disorder did not show a seasonal pattern. Neither climate nor latitude has a primary influence on the daily mood changes of most patients receiving medication for bipolar disorder.

1. Introduction

Most studies of seasonal variation in bipolar disorder have analyzed the pattern of hospital admissions for manic or depressed episodes. Results have been inconsistent. Investigators

* Corresponding author. Tel.: +49 351 458 0; fax: +49 30 450 51 79 62.
E-mail address: Michael.Bauer@uniklinikum-dresden.de (M. Bauer).
[1] www.chronorecord.org.

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have identified a peak in hospital admissions for mania in spring/summer (Carney et al., 1988; Lee et al., 2007; Cassidy and Carroll, 2002; Kerr-Corrêa et al., 1998) and in winter/spring (Volpe and Del Porto, 2006), a peak in admissions for depression in autumn (Sato et al., 2006; Silverstone et al., 1995), winter (Lee et al., 2007) and spring/summer (Shapira et al., 2004), and a peak in admissions for mixed episodes in early spring (Lee et al., 2007) and late summer (Cassidy and Carroll, 2002). Other investigators have found no seasonal peak in admissions for mania (Silverstone et al., 1995; Jain et al., 1992; Eastwood and Stiasny, 1978), no peak in admissions for mania and depression (Partonen and Lönnqvist, 1996; Suhail and Cochrane, 1998; Whitney et al., 1999; Goikolea et al., 2007; Daniels et al., 2000; Upshur, 2005; Mortazi et al., 2002), and no peak in admissions for depression (Kerr-Corrêa et al., 1998). Since dysregulation of circadian rhythms (Wehr et al., 1983) including abnormalities in the biological response to sunlight (Lewy et al., 1985; Nurnberger et al., 2000) may underlie the pathophysiology of bipolar disorder, climate and latitude would be expected to influence seasonality. Although hospital admissions studies have included patients residing at many locations and latitudes, there are few studies of the relation between climate and seasonality and these have also had ambiguous results. A 3-year study of 56 bipolar patients in Denmark found no relationship between daily temperature, precipitation, humidity, wind-velocity, barometric pressure, sunshine and cloudiness and the onset of episodes of either depression or mania (Christensen et al., 2008). In contrast, others have reported a positive (Carney et al., 1988; Peck, 1990; Lee et al., 2002; Volpe and Del Porto, 2006; Sayer et al., 1991) or inverse (Lee et al., 2007) relation between hospitalizations for mania and hours of sunshine, and a relation between hospitalizations for mania and temperature (Sayer et al., 1991; Volpe and Del Porto, 2006; Myers and Davies, 1978). Additional observations involving climate variables include a relation between hospital admissions for depression and temperature (Shapira et al., 2004), a relation between the prevalence of depression and latitude (Friedman et al., 2006), and no relation between latitude and seasonality (Schaffer et al., 2003).

The purpose of this study was to analyze if seasonality was present in the daily self-reported mood ratings of patients residing in five climate zones in the northern and southern hemisphere. We also investigated if there was a relationship between mood, latitude and seasonal climate variables.

2. Methods

2.1. Participants and data collection

Daily self-reported mood and sleep data were obtained from adult outpatients with a diagnosis of bipolar disorder by DSM-IV criteria. All patients volunteered, provided informed written consent, and received treatment as usual throughout the study. The naturalistic approach with minimal exclusion criteria was selected to better reflect routine clinical practice and patient heterogeneity. The study was approved by each local institutional review board. Patients installed the previously validated ChronoRecord software in their native language on a home computer for data collection (Bauer et al., 2004, 2008a). A detailed account of the data collection is described elsewhere (Bauer et al., 2008b). A 100-unit visual analogue scale was used to rate mood between the most extreme mania and depression the patient ever experienced. Based upon the validation studies comparing the self-ratings with clinician ratings on the Hamilton Depression Rating Scale (HAMD) and the Young Mania Rating Scale (YMRS), (Bauer et al., 2004, 2008a), a mood entry less than 40 was considered depression, 40 to 60 euthymia, and greater than 60 hypomania/mania. The self-ratings of mania reflect activation levels for either euphoric or dysphoric mood (Bauer et al., 2004).

2.2. Climate data

Each patient was categorized by climate zone based on their residence using the Köppen climate classification, the most widely used system to classify climate (Peel et al., 2007). The Köppen system groups land areas into climate zones using climate data such as extremes, means and ranges of temperature, participation and aridity (Trewartha and Horn, 1980). Monthly mean maximum and minimum temperature (°C), mean precipitation (mm) and days with precipitation were obtained from the World Meteorological Organization (www.worldweather.org) and the Western Regional Climate Center (www.wrcc.dri.edu). Climate data from the same month as the mood ratings were analyzed because that from the prior month was reported to be less useful (Lee et al., 2007; Shapira et al., 2004), and sunlight has immediate effects on the release of neurotransmitters including serotonin in both mammals and man (Reiter, 1991; Lambert et al., 2000; Ferraro and Steger, 1990). The maximum hours of daylight for the 21st of each month for each city were obtained from the US Naval Observatory http://aa.usno.navy.mil/data/docs/RS_OneDay.php. The change in the maximum hours of daylight from the prior month was also analyzed since the rate of change in daylight is not linearly related to latitude. Seasons for the northern hemisphere were defined as winter (December through February), spring (March through May), summer (June through August) and fall (September through November) (Trenberth, 1983). For each climate zone, temperature phases were created by assigning each month as either warm, warm to cold transition, cold or cold to warm transition. All data for patients residing in the southern hemisphere were shifted by 6 months to be comparable with months, seasons and temperature phases in the northern hemisphere.

2.3. Data analysis

For each patient, the percent of days depressed, manic and euthymic were calculated for each month, season and temperature phase where patients reported 15 or more days of data per month. Data in twelve consecutive months were required for a patient to be included in the seasonality analysis. Episodes of hypomania/mania and depression were determined based on the DSM-IV length criteria, using a published algorithm to calculate episodes from daily self-reported mood data (Denicoff et al., 1997). Episodes were categorized into months, season and temperature phase by the starting date. For patients with episodes, the distribution of episodes across months, seasons or temperature phase was used in the analysis.

Table 1
Patient residence by Köppen climate zones ($n = 360$).

Climate zone	n	Locations	Climate description[a]
Cfb	66	Berlin, Germany Dresden, Germany London, UK	Temperate, without dry season, with cool summer
Csa	95	Los Angeles (inland), US San Diego, US Santiago, Chile	Temperate, with dry, hot summer
Csb	108	San Francisco, US Coastal cities in northern and southern California, US Melbourne, Australia	Temperate, with dry, warm summer
Dfa	47	Kansas City, US	Cold, without dry season, with hot summer
Dfb	44	Halifax, Canada Ottawa, Canada	Cold, without dry season, with warm summer

[a] Peel et al., 2007.

2.4. Tests for seasonality

Seasonal variation in the percent of time depressed, manic, and euthymic and the distribution of episodes was analyzed in two ways. The first test used a sinusoidal regression to estimate the phase and amplitude of seasonal affects for all patients in a climate zone (Ockene et al., 2004). A sine function was used to estimate periodic seasonal fluctuations with a 12-month cycle and a peak and trough month separated by 6 months. The variation of estimated coefficients of the peak and amplitude were calculated using both a Taylor series expansion and a bootstrapped empirical analysis (Carpenter and Bithell, 2000) to determine confidence intervals for the estimated coefficients. The second test for seasonality was the Gini index (Lee, 1996), which compared the distribution of a variable to a uniform distribution. Confidence intervals for the Gini index were used to assess for inequality in mood patterns over the 12 month period for each climate zone.

2.5. Climate variable analysis

Generalized linear models (GLM) were estimated to determine whether climate variables were significantly associated with the percent of days depressed, euthymic or manic, and/or the number of episodes for each season, month and temperature phase. The monthly climate variables included maximum and minimum precipitation, maximum and minimum temperature, number of days with precipitation, sunrise, sunset, hours of daylight, change in hours of daylight from the prior month, aridity, as well as latitude. Age and gender were also included to accommodate significant differences in the sample characteristics among climate zones.

2.6. Statistical analysis

The demographic characteristics were compared using the Pearson 2-sided X^2 test for distributions, and the independent sample 2-sided t-test for mean values. A p value of less than 0.05 was considered statistically significant for all tests. SPSS version 14.0 was used for all GLM calculations. R version 2.7.0 was used for all sinusoidal, bootstrap and Gini analysis.

3. Results

Data were available from 371 patients living in 6 Köppen climate zones. Since one climate zone (California desert) contained data from only 11 patients, this data were excluded leaving 360 patients in 5 climate zones as shown in Table 1. Meteorological parameters varied greatly for these climate zones as shown in Table 2. Latitude varied from 32.44° (San Diego, CA) to 52.27° from the equator (Berlin, Germany).

The 360 patients consisted of 100 males (27.8%) and 260 females (72.2%), with a mean age of 38.2 years, and a mean of 16.7 years of illness. Of the 360 patients, 225 had a diagnosis of BP I (62.5%), 120 BP II (33.3%) and 15 BP NOS (4.2%), and the patients took a mean of 3.09 medications daily to treat bipolar disorder. The 360 patients returned 59,422 days of data. Considering all days, the 360 patients spent about 21% of days depressed, 70% of days euthymic, and 9% of days hypomanic/manic.

For the seasonality analyses, data were available from 212 patients. Of the 212 patients, 38 resided in Köppen climate zone Cfb, 43 in Csa, 66 in Csb, 35 in Dfa and 30 in Dfb. 25 sinusoidal regressions and 25 Gini index analyses were completed to analyze seasonality based on the percent of days depressed, euthymic or manic, and the distribution of manic or depressed episodes in the 5 climate zones. Three of the 25 sinusoidal estimates of peaks and troughs were significant using the basic confidence interval (percent of days depressed in Cfb, percent of days depressed in Csb, and percent of days depressed in Csa). However, in all three cases visual inspection of the data failed to demonstrate a seasonal pattern and the Gini index was not significantly different from a uniform distribution. One of the 25 analysis of monthly distributions using the Gini index was significant (Dfb for percent of days manic), but this result also was not confirmed by visual inspection or sinusoidal analysis. Neither the results

Table 2
Seasonal climate variables in Köppen climate zones by patient residence.

		Climate zone				
Season[a]	Mean monthly value	Cfb	Csa	Csb	Dfa	Dfb
Winter	Precipitation (mm)	46.2	10.5	3.2	52.9	90.6
	Rain days	12.6	6.3	9.3	6.6	15.4
	Min temp (C)	0.5	7.4	5.3	−6.6	−12.2
	Max temp (C)	6.1	18.3	15.1	2.5	−3.1
	Daylight hours	9.1	10.5	10.2	10.0	9.6
Spring	Precipitation (mm)	49.0	2.8	1.4	86.8	89.5
	Rain days	11.2	4.1	5.6	8.6	13.0
	Min temp (C)	5.7	11.0	8.3	5.0	0.0
	Max temp (C)	14.7	21.9	19.9	15.9	10.1
	Daylight hours	13.9	13.1	13.3	13.4	13.7
Summer	Precipitation (mm)	59.8	0.6	0.1	101.3	90.0
	Rain days	10.0	0.7	0.4	7.6	11.3
	Min temp (C)	13.1	16.3	12.6	17.5	13.4
	Max temp (C)	23.3	28.1	25.2	28.5	24.3
	Daylight hours	15.3	13.9	14.2	14.4	14.9
Fall	Precipitation (mm)	49.5	3.0	1.0	80.8	94.1
	Rain days	10.8	2.6	3.6	6.9	12.7
	Min temp (C)	7.2	12.8	9.9	7.2	3.3
	Max temp (C)	14.7	24.8	22.1	17.9	12.5
	Daylight hours	10.5	11.2	11.1	11.0	10.6

[a] Seasons defined as: Winter: Dec, Jan, Feb in northern latitudes and Jun, Jul, Aug in southern latitudes. Spring: Mar, Apr, May in northern latitudes and Sep, Oct, Nov in southern latitudes. Summer: Jun, Jul, Aug in northern latitudes and Dec, Jan, Feb in southern latitudes. Fall: Sep, Oct, Nov in northern latitudes and Mar, Apr, May in southern latitudes.

Table 3
Influence of maximum temperature, mean precipitation or latitude on percent of days depressed, euthymic and manic, adjusted for age and gender by season.

Season [a]	% Days	Adjusted model *df*	*F*	*p*
Winter	Depressed	7,204	1.686	0.114
	Euthymic	7,204	1.825	0.084
	Manic	7,204	1.424	0.197
Spring	Depressed	7,230	0.614	0.744
	Euthymic	7,230	0.593	0.861
	Manic	7,230	0.432	0.882
Summer	Depressed	7,206	1.240	0.202
	Euthymic	7,206	0.920	0.492
	Manic	7,206	0.714	0.660
Fall	Depressed	7,194	0.925	0.489
	Euthymic	7,194	0.982	0.486
	Manic	7,194	0.456	0.865

[a] Seasons defined as: Winter: Dec, Jan, Feb in northern latitudes and Jun, Jul, Aug in southern latitudes. Spring: Mar, Apr, May in northern latitudes and Sep, Oct, Nov in southern latitudes. Summer: Jun, Jul, Aug in northern latitudes and Dec, Jan, Feb in southern latitudes. Fall: Sep, Oct, Nov in northern latitudes and Mar, Apr, May in southern latitudes.

of the sinusoidal regression nor the Gini index indicated any meaningful seasonal variation.

For the climate variable analyses, data were available from varying numbers of patients (about 300 for the percent of days depressed or manic by season). The estimated GLM results using climate variables were not significant or each season, temperature phase, or month. See Table 3.

4. Discussion

No seasonal variation was observed in the self-reported mood data in any climate zone. There was also no association among latitude or seasonal climate variables and mood in spite of the dissimilarity between climate zones in the sample. The consistency in results obtained from very different statistical approaches strengthens the findings of this study. Most evidence for seasonal variation in bipolar disorder is derived from studies of hospital admissions, using a methodological approach that is very different from this study. Hospital admission studies only collect data from episodes whereas the self-reported data in this study were collected daily. In hospital admission studies, the intensity of all episodes is so extreme that confinement to a psychiatric unit is required. Aggressive behavior including suicidal ideation often contributes to the need for hospitalization, and aggression may have a seasonal pattern in affective disorders (D'Mello et al., 1995; Doganay et al., 2003; Valtonen et al., 2006). In contrast, the daily mood ratings are primarily euthymic, and subsyndromal depression is the most common symptom (Judd et al., 2002, 2003; Paykel et al., 2006; Bauer et al., 2007). Mania may be underreported in daily mood ratings due to impaired insight (Dell'Osso et al., 2002). The contradictory results between hospital admission studies and this naturalistic study of outpatients are not surprising and supplement prior findings. Additionally, hospital admission studies are generally based upon retrospective or claims data, and classify data by hospitalization date rather than episode onset (Suhail and Cochrane, 1998; Lee et al., 2007). Moreover, many hospital admissions studies also did not detect a seasonal pattern (Partonen and Lönnqvist, 1996; Suhail and Cochrane, 1998; Whitney et al., 1999; Goikolea et al., 2007; Daniels et al., 2000; Upshur, 2005; Mortazi et al., 2002).

Seasonality is reported to occur in about 10% of all patients with mood disorders (Faedda et al., 1993) and about 20% of patients with bipolar disorder (Goikolea et al., 2007; Shin et al., 2005; Schaffer et al., 2003). Multiple pathophysiologic mechanisms contribute to the etiology of seasonality (Lam and Levitan, 2000), and genetic factors may establish vulnerability or protection (Hakkarainen et al., 2003). However, the intensity of the seasonality effect varies, and most patients including those with bipolar disorder experience only a mild seasonality effect (Terman, 2007; Hardin et al., 1991; Thompson et al., 1988; Shin et al., 2005). With a relatively low prevalence and predominantly mild impact the sample size in this study may have been too small to detect a seasonal pattern across a climate zone, although individual patients in this study may have experienced seasonality.

Other limitations of this study may also have contributed to the negative results. As all data were self-reported, no objective measures of clinical parameters were analyzed. The study period was relatively short in length and multiple years of data may be required to detect statistically significant seasonal effects. This analysis involved climate data consisting of mean values compiled over decades, so the impact of local weather events was not considered. Shifting data from the southern hemisphere by 6 months ignores the social dimension of seasonality. For example, the New Year holiday season occurs in winter in the northern hemisphere and in summer in the southern hemisphere. All patients were taking medications and it is unclear if these may enhance or mask seasonal effects. Some researchers suggest that patients with bipolar II disorder are more susceptible to seasonality (Friedman et al., 2006; Goikolea et al., 2007) and the number of patients with BP II disorder was relatively small. This study also required all patients to have access to a computer.

The association between climate variables and mood was investigated in two recent prospective studies that were based upon clinician evaluations. In agreement with our findings, no association was found between daily meteorological variables and mood over 3 years in a European climate (Christensen et al., 2008). In an analysis of the STEP-BD study participants from multiple locations in the US, no significant difference was reported in the monthly depression rates by location, although a higher prevalence of depression was observed at northern sites compared to southern sites (Friedman et al., 2006). Although the diagnosis most associated with seasonality is seasonal affective disorder (SAD), two review articles concluded that the correlation between the prevalence of SAD and latitude is very weak (Mersch et al., 1999; Haggarty et al., 2001).

Additional lines of evidence support the lack of a robust association among climate, latitude and mood. During the twentieth century, the impact of climate on human well-being was greatly lessened by a wide range of adaptive innovations such as air-conditioning, lighting, central heating, anti-freeze, frozen foods, and satellites for weather forecasts (Ausubel, 1991). Furthermore, people who live in industrialized countries predominantly work indoors and live a sedentary lifestyle (Matthews et al., 2008; Godar, 2005). Even recreational choices have shifted from outdoor to indoor activities, primarily due to the popularity of electronic media (Pergams and Zaradic, 2006). Indeed, latitude of residence may no longer be an adequate proxy for sunlight exposure (Millen and Bodnar, 2008). To investigate exposure to environmental pollutants in the US, activity patterns of 9386 respondents were surveyed, with a minimum of 340 people in each of 10 geographical regions. Regardless of location, Americans spent 87% of their time indoors plus 6% of time in an enclosed vehicle (Klepeis et al., 2001). Furthermore, when activity patterns of 2381 Canadians (Leech et al., 1996) were compared to the US data, results were sufficiently similar that merging the datasets was recommended (Leech et al., 2002). The greatest difference for adults was that Americans spent 25 more minutes per day outside in winter (58 versus 33 min) while Canadians spent 13 more minutes outside in summer (148 versus 135 min) (Leech et al., 2002). In other words, lifestyle choices including outdoor work and pastimes may better determine sunlight exposure than latitude (Thiedien et al., 2004; Millen and Bodnar, 2008; Godar, 2005).

While light is the primary synchronizer of circadian rhythmicity, social interactions, sleep wake cycles and physical exercise also entrain the circadian pacemaker (Mistlberger and Skene, 2004), and disruptions to social rhythms can trigger episodes of bipolar disorder (Frank et al., 2000). Recent telecommunications innovations have had dramatic effects on social rhythms as email, internet, and mobile phones have allowed people living in extreme climates or isolated rural areas to remain socially connected throughout the year. For example, profound social changes were reported after the introduction of information technologies into remote tribal areas of northern Canada, with strengthened links between communities and the outside world (Ramirez et al., 2004). Yip and colleagues postulated that electronic social connectedness may have contributed to the loss of seasonal variation in adult suicide noted over recent decades in Europe and Hong Kong (Yip et al., 2000; Ajdacic-Gross et al., 2005; Yip and Yang, 2004). These new technologies have been widely disseminated as households with Internet access are equivalent in both rural and urban areas of the US (NTIA, 2004).

In conclusion, the majority of patients receiving medication for bipolar disorder do not have a seasonal variation in daily self-reported mood ratings. For most patients with bipolar disorder, neither climate nor latitude is a primary determinant of daily mood changes.

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This project was funding entirely by local university funds. The local funding sources had no involvement in the study design, collection, analysis and interpretation of data, in writing the report, and in the decision to submit for publication.

Conflict of interest

The ChronoRecord Association is a 501(c)(3) nonprofit organization that aims to increase understanding of mood disorders (www.chronorecord.org). None of the authors receive financial compensation from the Association. Tasha Glenn and Peter C Whybrow share a patent for ChronoRecord software. Michael Bauer, Paul Grof, Natalie Rasgon, and Peter C Whybrow are on the Medical Advisory Board. There are no other conflicts of interest.

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