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Meteorological analysis of symptom data for people with seasonal affective disorder

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ABSTRACT

It is thought that variation in natural light levels affect people with Seasonal Affective Disorder (SAD). Several meteorological factors related to luminance can be forecast but little is known about which factors are most indicative of worsening SAD symptoms. The aim of this meteorological analysis is to determine which factors are linked to SAD symptoms. The symptoms of 291 individuals with SAD in and near Groningen have been evaluated over the period 2003–2009. Meteorological factors linked to periods of low natural light (sunshine, global radiation, horizontal visibility, cloud cover and mist) and others (temperature, humidity and pressure) were obtained from weather observation stations. A Bayesian zero adjusted auto-correlated multilevel Poisson model was carried out to assess which variables influence the SAD symptom score BDI-II. The outcome of the study suggests that the variable sunshine duration, for both the current and previous week, and global radiation for the previous week, are significantly linked to SAD symptoms.

1. Introduction

The influence of weather conditions on general wellbeing has been reported in several studies, but there is no consistent evidence for these relationships (Barnston, 1988; Watson, 2000; Geoffroy et al., 2014). It is also difficult to distinguish between the impacts of different weather conditions on wellbeing because some of them are often highly correlated (Young et al., 1997).

Seasonal differences in hospital admissions for people with mood disorders and admissions of people with a bipolar disorder because of mania compared to depressive states as a reason for admission are described in a number of studies There is some evidence that meteorological factors trigger bipolar symptoms and that admissions of mania are related to the seasons, mostly spring or summer (Shapira et al., 2004; Volpe et al., 2010; Medici et al., 2016). In unipolar depressive disorders, no differences were found (Shapira et al., 2004).

In a study using daily self-reported mood ratings in bipolar disorder no seasonal variation in mood was reported (Bauer et al., 2009). In a review article, Geoffroy et al. (2014) concluded that there is some evidence of seasonality and that meteorological conditions may trigger bipolar depression symptoms (Geoffroy et al., 2014).

Besides photoperiodism (sunshine/daylight hours), the other environmental aspects of weather conditions are not firmly related to wellbeing and mood (Geoffroy et al., 2014). There are studies that show that there is a relationship between humidity and affective disorders (Morrisey et al., 1996; Salib and Sharp, 2002). Temperature has been shown to have a relationship with mood in some studies (Morrisey et al., 1996) but this relationship was not present in another study (Garvey et al., 1988). In a large scale screening programme in the general population (n = 14,748), the data of people with depression were compared to a number of meteorological factors such as temperature, sunshine and rainfall. Weather conditions were not found to be associated with mood (Huibers et al., 2010). Another study reported only a very small effect of weather on mood (Denissen et al., 2008). Although most studies found a relationship with photoperiodism, a study by Radua et al. (2010) supports a meteorological influence instead of the established seasonal influences in specific subtypes of depression. Bauer et al. (2014) found that a larger springtime increase in sunlight can have an influence on the onset of bipolar disorder in addition to influences of, for example, a family history of mood disorders.

Seasonal Affective Disorder (SAD) is a mood disorder characterized by recurrent episodes of major depression occurring with a seasonal pattern. (American Psychiatric Association, 1994). The symptoms occur in a nearly yearly pattern in autumn/winter and disappear completely in spring/summer (Rosenthal et al., 1984). Over recent decades, exposure to artificial bright light has become the first choice treatment for

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people with SAD (Meesters et al., 1995; Terman and Terman, 2005; Westrin and Lam, 2007; Meesters and Gordijn, 2016). In addition, exposure to "natural" light was also found to be effective in the treatment of SAD (Wirz-Justice et al., 1996).

In a very small ($n = 10$) retrospective study it was found that the effect of the seasons on SAD is far more robust than the effects of the weather on energy and sleep patterns. The effects of the weather, if discernible, were most pronounced in the summer (Albert et al., 1991) or spring (Keller et al., 2005). In a larger study, no relationship between cloud cover, rainfall or atmospheric pressure and depression scores was found, but a significant relationship was found between depression scores of SAD patients and duration of sunshine, global radiation, temperature and length of daylight (Molin et al., 1996).

A further study suggests that weather variables may influence the mood of people with SAD more than people with non-seasonal depression (Sigmon et al., 2010).

As discussed above, photoperiodism and the amount of sunshine are related to the seasons. Exposure to light improves the mood and energy levels for people with SAD (Meesters and Gordijn, 2016). This applies not only from exposure to artificial light, but also from exposure to "natural" light. (Wirz-Justice et al., 1996). Spending time outside can be influenced by weather conditions, so other weather conditions might also influence the course of mood.

In this study we investigate the effects on depressed mood of weather variables in a sample of people with SAD who visited an SAD outpatient clinic and were followed during six winter seasons.

2. Methods

2.1. Clinical data

In the SAD outpatient clinic at the University Center of Psychiatry at the University Medical Center Groningen, Netherlands, patients have been followed through the scores on a weekly depression self-rating questionnaire, each year between mid September and mid April (from week 37 till week 17) (Meesters et al., 1993).

Patients with seasonal complaints are referred to this clinic. Only patients who are diagnosed with SAD (Major Depressive Disorder with a seasonal pattern, winter type) are asked to participate in the programme. Patients are diagnosed following a structured interview (MINI, Sheehan et al., 1998) by an experienced clinical psychologist and are assessed according to the criteria of the DSM-IV (American Psychiatric Association, 1994). No patient in the cohort uses anti-depressant medication, and all were diagnosed with a unipolar depression.

Data for participating patients have been collected in winter seasons between 2003 and 2009. In the first seasons the Beck Depression Inventory II (BDI-II, Beck et al., 1996, 2002) was used. From the start of the winter season of 2007 the Inventory of Depressive Symptomatology, Self Rating version (IDS-SR, Rush et al., 1996) was adopted. The questionnaire provides a score measuring severity of symptoms, the greater the score the more severe the symptoms. Patients with scores of 15 or more on the BDI-II and 20 or more on the IDS-SR were invited for light treatment. Whilst the IDS-SR questionnaire is used more in the later years, BDI-II scores form most of the SAD symptomatic data. To retain data quality, the IDS-SR scores have been converted to BDI-II using the conversion tables provided by the University Center for Psychiatry, University Medical Center Groningen. This conversion table was based on calculations of scores gathered from both instruments. During a winter season the assessment of depression of 236 patients took place with the use of BDI-II and the IDS-SR at the same point every week during the whole winter season (Meininger, 2007).

2.2. Meteorological data

Groningen is situated in northern Netherlands, about 25 km from the coast on the southern side of the North Sea. Groningen has an oceanic climate (Köppen classification Cfb) with mean temperatures ranging from 5 °C in winter to 22 °C in summer.

Meteorological data were provided by the Koninklijk Nederlands Meteorologisch Instituut (KNMI). These consisted of hourly data for 36 weather observation stations throughout the Netherlands, from 1st January 2003 to 30th April 2009. The weather measurements used were sunshine duration, global radiation, horizontal visibility, cloud cover and mist. The hourly data was first converted to weekly arithmetic means such that sunshine duration can be expressed as the number of hours of sunshine each week and mist is a probability of an hour within the week when mist will occur. Additional weather measurements of air temperature, humidity (measured by the dewpoint temperature) and surface atmospheric pressure were provided by the Met Office via the MEDMI service (www.data-mashup.org.uk). The estimates of the weekly exposure at the location of residence of each patient were calculated by Inverse-Distance Weighted (IDW) interpolation of the weekly means of measurements taken at the 36 sites. The IDW method ensures that the measurements taken at the sites closest to the patients have the most weight and hence the interpolation provides a good estimate of exposure (Perry and Hollis, 2005). The weather stations close to Groningen have little difference in elevation therefore no adjustments were made for altitude.

2.3. Analysis

There are three components in the data that disqualify the use of standard regression models for analysing the relation between the weather variables and the depression score: (1) the non-normal distribution of the scores; (2) the hierarchical structure of the data; (3) time series data is used which invalidates the standard assumption that subsequent error-terms are uncorrelated.

We overcome these problems by employing a zero-adjusted, autocorrelated multilevel Poisson model for the depression scores. In Subsections 2.3.1–2.3.3, we outline the problems of the three issues raised and how we deal with them. In Subsection 2.3.4, we present the final model.

2.3.1. Non-normality

The distribution of *BDI*-scores has a very large peak at 0. Therefore, it was decided to model the data using a zero-adjusted Poisson distribution. A regular Poisson distribution is suitable for modelling integer-scores, such as count data. The zero-adjusted distribution accounts for the fact that there are more zero-values than one normally expects in Poisson data. More background on this type of modelling can be found in Long (1997) and Hadfield (2010).

2.3.2. Hierarchical data

The data are hierarchical: there are multiple measurements per individual. Individual depression base rates will differ and this hierarchical structure is incorporated by using the so-called multilevel model (c.f. Snijders and Bosker, 1999; Goldstein, 2011).

2.3.3. Time series data

In a standard regression model, the error terms are expected to be mutually independent. A feature of time series data is that this is generally not the case: when a certain value is very high (low), then it is expected that the value at the next time point still is above (below) average. This is called inertia, and it is well known from psychiatric literature (c.f. Chen et al., 2012) that for depression data inertia is quite high. To overcome this, we include an auto-regressive term in the model (c.f. Diggle et al., 2002; Liang and Zeger, 1986). That is, the $BDI_{i,t}$ score of week t is not only regressed on meteorological values, but also on the $BDI_{i,t-1}$ score of the previous week.

2.3.4. The Bayesian zero-adjusted auto-correlated multilevel Poisson regression model

Combining the elements of 2.3.1-2.3.3, we arrive at the final model. This is a generalised mixed model using the link-function for the zero-adjusted binomial distribution. Conceptually, the model reads:

$$BDI_{i,t} \sim \mu_i + BDI_{i,t-1} + WEATHER_{i,t} + WEATHER_{i,t-1}$$

where t denotes the week-number, i the participant, and $WEATHER_{i,t}$ is a (set of) weather variable(s).

The weather variables have been centred and scaled. Principally, this has no influence on the resulting p-values but does improve the convergence and accuracy of the Markov Chains. The weather variables include: $S_{i,t}$, sunshine, $GR_{i,t}$, global radiation, $HV_{i,t}$, horizontal visibility, $CC_{i,t}$, cloud cover, $M_{i,t}$, probability of mist, $AT_{i,t}$, air temperature, $H_{i,t}$, humidity (measured as dewpoint temperature) and $AP_{i,t}$, atmospheric pressure. Both the weather variables of the current as of the previous week could be included, yielding $2 \times 8 = 16$ variables.

A large amount of overlap between these sixteen weather variables is expected, so including all sixteen would be over-fitting. To decide upon the final model, we employed a backward elimination procedure (c.f. Cohen et al., 2003). Starting from the full model, with all sixteen weather variables and previous week's BDI-score, the least significant weather variable was excluded in each step of the procedure (always keeping the previous week's BDI-score), until none of the predictors was non-significant (at the $\alpha = 0.01$ level).

3. Results

Data for 291 patients have been collected in winter seasons between 2003 and 2009. It can be seen from the distribution of variables experienced each week by each patient (illustrated in Appendix 1) that most patients experience similar conditions while some patients experience quite different weather. This is due to the fact that most patients reside in or very near Groningen while some reside as far as Drachten or Hoogeveen (~ 50 km away).

It is clear from these data that sunshine duration, global radiation, air temperature and dewpoint temperature are low in winter. Horizontal visibility is also somewhat lower in winter and cloud cover somewhat higher. Mist tends to occur in winter. The high correlation between weather variables is confirmed by the correlation coefficients listed in Table A1. As expected sunshine and radiation are well correlated (correlation coefficient 0.91).

As illustrated in Fig. 1, there is, as expected, a large peak (46.5% of all measurements) at 0 for the BDI-scores. The hierarchical structure is as follows: the 23,197 measurements were collected by 291 individuals, with the number of measurements per individual ranging from 33 to 198.

Computations have been performed through Bayesian Markov Chain Monte Carlo simulations using R (R Core Team, 2015) with the package MCMCglmm (Hadfield, 2010). The R-code, the settings of the MCMC-algorithm and the explanation behind various technical choices in the estimation procedure are provided in Appendix 3. As this package cannot deal with missing values in the predictor variables, 845 measurements with missing data were deleted list wise.

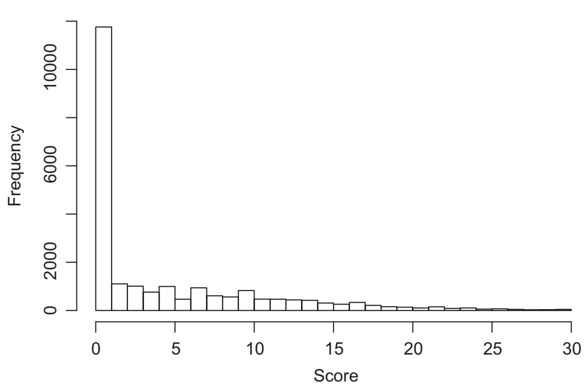

Fig. 1. Histogram of the scores on the BDI-II scale. The 216 scores (0.93%) above 30 are omitted for visualisation purposes.

Table 1
Spearman correlation coefficients between BDI-scores and observations of weather variables sunshine duration (*S*), global radiation (*GR*), horizontal visibility (*HV*), cloud cover (*CC*), the probability of mist (*M*), temperature (*AT*), humidity (*H*) and atmospheric pressure (*AP*), from the 36 KNMI weather observation stations in the Netherlands.

		BDI	BDI_{-1}
Depression score	Contemporaneous (BDI)		
	Lagged (BDI_{-1})	0.60	
		$p < 0.001$	
Duration of sunshine	Contemporaneous (S)	−0.22	−0.23
		$p < 0.001$	$p < 0.001$
	Lagged (S_{-1})	−0.17	−0.20
		$p < 0.001$	$p < 0.001$
Global radiation	Contemporaneous (GR)	−0.26	−0.27
		$p < 0.001$	$p < 0.001$
	Lagged (GR_{-1})	−0.21	−0.24
		$p < 0.001$	$p < 0.001$
Horizontal visibility	Contemporaneous (HV)	−0.14	−0.14
		$p < 0.001$	$p < 0.001$
	Lagged (HV_{-1})	−0.10	−0.13
		$p < 0.001$	$p < 0.001$
Cloud cover	Contemporaneous (CC)	0.13	0.13
		$p < 0.001$	$p < 0.001$
	Lagged (CC_{-1})	0.10	0.12
		$p < 0.001$	$p < 0.001$
Probability of mist	Contemporaneous (M)	0.04	0.04
		$p < 0.001$	$p < 0.001$
	Lagged (M_{-1})	0.03	0.04
		$p < 0.001$	$p < 0.001$
Temperature	Contemporaneous (AT)	−0.05	−0.10
		$p < 0.001$	$p < 0.001$
	Lagged (AT_{-1})	0.01	−0.04
		$p = 0.23$	$p < 0.001$
Humidity	Contemporaneous (H)	0.03	−0.02
		$p < 0.001$	$p < 0.001$
	Lagged (H_{-1})	0.08	0.04
		$p < 0.001$	$p < 0.001$
Atmospheric pressure	Contemporaneous (AP)	0.00	−0.02
		$p = 0.88$	$p = 0.026$
	Lagged (AP_{-1})	0.03	0.00
		$p < 0.001$	$p = 0.66$

Table A2 lists the order in which the backward elimination procedure discarded the variables. In the end, seven out of sixteen weather variables were discarded due to non-significance: for horizontal visibility, neither the score on the previous week nor the score on the current week had a significant contribution in predicting BDI-II scores. For the other variables, at least one of the two weeks was significant. (See Table 2 for details.)

The final model resulting from the backward elimination procedure is detailed in Table 2. Due to the complicated nature of the non-linear

Table 2
Posterior means and 95% credible intervals (ci) for the final model. All variables have a p-value < .001.

Variable	Mean	95% ci
Lagged: BDI-II score	0.197	(0.116, .274)
Contemporaneous: Sunshine	0.116	(0.059, .170)
Contemporaneous: Cloud cover	0.091	(0.049, .128)
Contemporaneous: Air temperature	− 0.246	(− 0.393, −0.106)
Contemporaneous: Humidity	0.322	(0.193, .462)
Lagged: Sunshine	0.469	(0.410, .532)
Lagged: Global radiation	− 0.961	(− 1.03, − 0.876)
Lagged: Mist probability	0.054	(0.035, .074)
Lagged: Humidity	0.094	(0.060, .123)
Lagged: Atmospheric pressure	− 0.041	(− 0.060, − 0.022)

statistical model employed, it is difficult to directly interpret the numerical values of the estimators (and their credible intervals); although the relative magnitude of the coefficients is informative. Furthermore, the sign of the values – informing about the direction of the location – and the *p*-value – informing about the significance of the relation – can be interpreted directly.

From Table 2 it can be seen that weather has a contemporaneous and a lagged effect on depression symptoms, as four remaining weather variables are included in a contemporaneous way, and five variables are included as lagged effects. Apart from air temperature, global radiation and atmospheric pressure, the relations are positive: higher scores on the weather variables are related to higher depression symptoms. The largest effect on depression symptoms, in magnitude, is the lagged effect of global radiation (− 0.961). This is followed by the lagged effect of sunshine (0.469), the contemporaneous effect of humidity (0.322) and the contemporaneous effect of air temperature (− 0.246). All other weather variables have small magnitudes, below 0.20.

4. Discussion

In this paper, we studied eight weather variables and their influence – both contemporaneous and lagged – on SAD symptoms. Our analyses show that depression symptoms are not influenced by only one or a limited set of weather variables, but by a complicated mix of meteorological ingredients. We did not collect SAD symptom scores in summer months (weeks 18–26) so cannot assess how depressive symptoms evolved in other seasons outside winter. Symptom scores were collected weekly and were analysed against weekly measures of the weather. The weekly nature of the data means that it was not possible to assess within week (e.g. daily) variations of symptoms or how these are affected by within week variations in weather.

There are significant links between SAD symptoms and luminance-related weather variables. The relationships between weekly variations of symptoms and of weather variables show that short term fluctuations in weather variables influence SAD symptoms in addition to seasonal changes.

There is a strong suggestion that the serotonin levels play a role in the existence of especially seasonal depression. Sunlight has a direct influence on serotonin levels (Lambert et al., 2002), and a seasonal variation of the serotonin transporter binding is described (Praschak-Rieder et al., 2008). Seasonal factors as for example daily sunshine and global radiation influence the serotonin 1A receptor binding in the limbic brain regions (Spindelegger et al., 2012). The hyperactive serotonin transporter (5-HTT) in SAD sufferers could be normalized after 4 weeks of light treatment and was comparable to summer levels (Willeit et al., 2008). In our studies, the mood of most SAD sufferers improved after 5-10 days of light treatment (Meesters and Gordijn, 2016).

The results of the final multivariate model (Table 2) suggest that more sunshine leads to higher depression scores. However, it is clear that on its own, the more sunshine the lower the depression scores as is measured by the Spearman correlation coefficient of − 0.22 (Table 1). The multivariate model includes other variables and, as such, quantifies semi-partial correlation, rather than bivariate correlations. With strong bivariate correlation between predictor variables, these semi-partial correlations can be distinctively different from the corresponding bivariate correlations. In this case, these results can be explained by the high correlation between sunshine and global radiation. A hypothesis may be that it is better to have strong sunlight over longer periods (same global radiation but longer sunshine duration). This could indicate that it is the strength of the sunlight that is linked to depressive symptom rather than its duration. It also indicates that there may be an interaction effect between sunshine and global radiation but adding the interaction variables to the model would add to its complexity.

Contrary to the study of Huibers et al. (2010) who found no influences of the effects of weather variables on mood in the general population, we found influence of some weather variables on mood in people diagnosed with SAD, a group of patients who are normally, by definition, sensitive to the effects of the seasons. Our results are in line with those of Molin et al. (1996). However, in our study we have demonstrated that there is also a relationship between cloud cover and mood in a population of people with SAD. McWilliams et al. (2014) describe that daily meteorological patterns do not affect overall hospital admissions for mania and depression (only a weak trend for barometric pressure in relation to mania admission was found). Our study shows the opposite for SAD, which suggests that people with SAD may be more vulnerable to these changes than people with other mood disorders. Our study offers new insight over and above that offered from cross-sectional studies of the assessment of hospital admissions, as we have assessed the longitudinal development of the course of mood in the same patients, related to weather conditions. This provides new understanding of the relationships between weather and the symptoms of people with SAD. The results in this study are in line with those described by O'Hare et al. (2016) who described that areas of Ireland with higher levels of rainfall in the preceding or current calendar month have greater incidence of depressive symptoms compared to areas with sunnier climates.

These findings demonstrate that the health of people with SAD in Groningen may be impacted by weekly changes in weather in addition to seasonal changes. Further studies will be necessary to check if these still hold true for sufferers in other climates. It has previously been demonstrated that administration of light treatment at the development of the first signs of SAD appears to prevent it from developing into a full-blown depression (Meesters et al., 1993). The findings in this study suggest that forecasting sunshine duration or cloud cover might improve the possibilities of early treatment (Met Office, 2010) which should be investigated by future research.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.psychres.2017.08.019.

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