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ORIGINAL ARTICLE

Does the Weather Really Matter? A Cohort Study of Influences of Weather and Solar Conditions on Daily Variations of Joint Pain in Patients With Rheumatoid Arthritis

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Objective. **To explore how reported joint pain in patients with rheumatoid arthritis (RA) relates to weather and solar variables.**

Methods. **A prospective cohort study was conducted in Norway on 36 patients with stable RA. Daily reports of pain in the morning on a visual analog scale for 84 consecutive days were correlated (using time-series methodology) with records of atmospheric and solar variables for the same days.**

Results. **Pain was significantly associated with 3 or more external variables in 6 (17%) of the patients, with 1 or 2 external variables in 16 (44%) of the patients, and no associations were observed in 14 (39%) of the patients. The multivariate model explained between 19% and 64% of the variance in pain (R^2) in the patients with associations to at least 3 weather/solar variables. The patients differed in the variables they responded to and in which direction, except for consistent negative associations between pain and ultraviolet light dose, and between pain and solar radio flux/sunspot count. The associations were mostly with same-day weather, but also lagged up to 3 days. We were not able to fit a statistically significant model at the group level.**

Conclusion. **Weather sensitivity seems to be a continuum and a highly individual phenomenon in patients with RA. In the present sample, pain was significantly associated with 3 or more weather variables in 1 out of 6 patients, for whom the magnitude of weather sensitivity might significantly influence pain reporting in clinical care and research.**

INTRODUCTION

Since the time of Hippocrates, there has been a widespread belief that pain in the rheumatic diseases is somehow affected by external environmental exposures (1). Cold and wet changing weather are believed to be bad, and warm, dry, and stable conditions are believed to be good. The Asian symbol for rheumatism (Fong Shi) is literally translated as "wind" and "wet" (2), and the disease is known as "wind wet disease" in the Chinese language (3). When a weather front is moving through an area, it is preceded by a wave of positive ions in the surface air (4–7). Patients with rheumatism often report that they can sense changes in the air hours or days before a front approaches. The pain typically increases when the front is approaching, and reaches a maximum when the patient is situated at or near the center of the front. The speed of the front's movement is also believed to be positively associated with pain, but the scientific documentation for these claims is sparse (6,7).

An early study from the 1870s reported that periods of Aurora Borealis were associated with increased pain (4). Fifty years later, associations between pain and atmospheric pressure were reported (8). However, only a few of these studies (e.g., Hollander and Yeostros) employed modern scientific methods (9). More recently, significant associations with pain have been reported for temperature (10–15), relative humidity (11,14,15), cloudiness (10,14), water vapor pressure (15), and sunspots/solar radio flux (16). However, other studies reported small or nonsignificant associations with weather, solar, or atmospheric variables (17,18).

In a previous study, we observed that individual rheu-

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matoid arthritis (RA) patients reported large day-to-day variations in pain (19). This triggered our curiosity as to whether atmospheric conditions might explain some of this variation. The aim of the present study was to examine associations between reported joint pain in patients with RA and a large number of meteorological and solar variables.

PATIENTS AND METHODS

The study was a prospective cohort study and the recruitment and selection procedures have been previously described (19). Briefly, 38 patients were recruited from the Oslo Rheumatoid Arthritis Registry and signed an informed consent form. One patient did not report pain during the period of observation and was excluded from the present study. Another patient had only 24 days of pain reporting (60 missing days) and was also excluded. A total of 36 patients participated in the current analyses. The regional ethics committee evaluated the study.

Data collection. The data collection started on January 27, 2004 and ended on May 12, 2004. Patients started and ended on separate dates over a total period of 107 days. The data collection period for a single patient was 84 days. The first patients started on January 27 and ended on April 19, and the last group started on February 19 and ended on May 12.

For each participant, pain was determined every morning after waking. Each patient reported her or his joint pain for 42 days on a personal digital assistant (PDA) and for another 42 days using a paper-and-pencil (PP) form. Fifty percent of the patients started with the PP version and the other 50% started with the PDA. The randomization between PDA and PP was a block randomization performed by a computer algorithm. We employed a double crossover design in which each patient was subject to either PDA-PP-PDA-PP or PP-PDA- PP-PDA, with each of the 4 periods lasting for 21 days. The results for the PP and the PDA registrations were similar (although the pain levels for PDA were slightly higher) (20) and were treated together in the present analyses. The pain data were judged on a 100-mm visual analog scale. Since the primary purpose of the original study was to evaluate the PDA, the patients were not aware that the relationship between the pain reports and weather variables was to be investigated later.

For each patient, the daily morning pain reports were linked to the same-day weather variables. The weather data were collected from the Norwegian Meteorological Institute (available at URL: www.met.no). The meteorological station is situated at 59° 46’ N and 10° 43’ E at 94 meters above sea level (centrally located in Oslo). The meteorological station at Blindern offers data on a total of 53 weather variables. We included only continuous variables about mean daily values. We excluded data on snow cover, sea waves, wind direction, extreme values, values at sea level, and categorical variables, which left us with 9 weather variables. We decided to include sun spots and solar radio flux after reading an article by Rozin et al (16) that studied the associations between solar activity and relapse onset in RA and spondylarthropathy. The North Atlantic Oscillation (NAO) Index was included after reading an article by Hubálek, who studied associations between a number of human infectious diseases and the NAO Index (21). Finally, we decided to include ultraviolet (UV) index data as another measure of solar activity.

The following 13 variables were employed as possible predictors: temperature (°C); atmospheric pressure (millibars); relative humidity (%), which is defined as the ratio of the partial pressure of water vapor in the mixture to the saturated vapor pressure of water at a given temperature; dew point (°C), which is the temperature to which a given parcel of air must be cooled, at constant atmospheric pressure, for water vapor to condense into water; water vapor pressure (millibars), which is the partial pressure of water in the atmosphere; hours of sunshine; amount of precipitation (mm); wind speed (meters/second); cloud cover (scale 0–9); NAO Index; number of sunspots; solar radio flux (10.7 cm); and UV index.

Statistical analysis. Time-series analysis was chosen since the reported pain and weather variables on subsequent days were dependent. All analyses were performed using the Statistical Package for the Social Sciences software, version 14.0 (22). The expert modeler in SPSS Trends searches for the best-fitting model among a large number of possible candidates, including autoregressive integrated moving averages and exponential smoothing. For each individual patient, we first entered joint pain as the dependent variable, and each of the 13 predictors previously mentioned as independent variables in bivariate analyses. This approach could produce many spurious significant associations, and for each patient we expected 1/20 (i.e., 0.65 out of 13) spurious significant correlations. Under the chi-square distribution with the true number of significant associations being 0, the probability of observing 3 or more significant associations was 0.2%. We therefore defined a weather-sensitive patient as one having a significant association with 3 or more variables. In a similar manner, a weather variable had to have significant associations in at least 5 patients in order for us to assume that this variable was not spuriously associated with pain. As a further check, we computed 2 variables consisting of random numbers. The first random variable had a mean $\pm$ SD normal distribution of 0 ± 1. The other random variable had a uniform distribution with a range of 0–100. For the multivariate models we entered all the significant variables (for each patient) from the bivariate analyses into 1 model. In this way we were able to estimate the independent effect of each weather and solar variable.

The models take into account not only the same-day weather, but also the weather on days before the pain was scored. The significance of a model is indicated by the Box-Ljung statistic. As additional indices of model fit, we reported the stationary R^2 and the R^2 (22). Time series have to be stationary in order to account for auto-correlated values and errors (22). The stationary R^2 is a measure that compares only the stationary part of the model with a simple mean model. This measure is preferable to ordinary R^2 when there is a trend or seasonal pattern. Since we

Table 1. Descriptive characteristics of the weather and solar variables (n = 107 days)*

Variable	Min/max	Mean ± SD
Temperature, °C	−8.4/19.8	3.19 ± 5.04
Relative humidity, %	36/95	67.5 ± 13.9
Dew-point temperature, °C	−11.4/8.4	−2.2 ± 4.42
Water vapor pressure, millibars	2.3/12.2	5.3 ± 1.94
Atmospheric pressure, millibars	970.8/1,029.5	1,002.2 ± 12.82
Precipitation, mm	0/12.8	1.2 ± 2.7
Sunshine, hours	0/12.7	4.8 ± 3.52
Cloud cover, scale 0–9	1/8	5.3 ± 2.01
Wind speed, meters/second	0.7/6.7	2.7 ± 1.17
SESC sun spot, no.	0/169	70.3 ± 29.8
Solar radio flux, 10.7 cm	85/129	106.3 ± 10.66
NAO	−1.449/1.866	0.49 ± 0.64
UV index	0.2/9.9	3.0 ± 2.1

* SESC = Space Environment Services Center; NAO = North Atlantic Oscillation Index; UV = ultraviolet.

could not rule out seasonal trends in the data, we emphasized the stationary R^2. Stationary R^2 can be negative with a range of negative infinity to 1. Negative values mean that the model under consideration is worse than the simple mean model. Positive values mean that the model under consideration is better than the simple mean model. The stationary R^2 can be interpreted as an estimate of the proportion of the total variation in the series that is explained by the model (22). After the individual patient analyses, we repeated the analyses at the group level.

RESULTS

The mean age of the participants was 50.4 years (range 22–77 years), 69% were women, and the mean disease duration was 14.9 years. A description of the weather and solar variables is shown in Table 1. The study period from January to May produced temperature recordings covering the entire annual mean normal range.

The bivariate individual analyses (36 patients × 13 variables) produced a number of significant models in 22 (61%) of the patients, whereas no significant associations with any of the external variables were observed in 14 (39%) of the patients. Table 2 shows the significant bivariate models predicting day-to-day pain for each of these 22 patients. For 16 patients (44%), pain was significantly associated with 1 or 2 variables, while significant associations with ≥3 weather variables were found for 6 patients (17%). Three variables (amount of precipitation, solar radio flux, and UV dose) had significant associations for 5 or more patients. Of the 22 weather-sensitive patients, 7 (32%) were men. This is similar to the proportion of men in the whole sample (31%).

Between 12% and 61% of the pain variation could be explained by one of the meteorological and solar factors (Table 2). The patients differed in the variables they responded to and in which direction. UV dose, solar radio

Table 2. Explained variance (R^2) in bivariate time-series models for the 22 patients with significant ($P < 0.05$) associations between pain and weather variables*

Patient, sex	Temp	DP	WVP	SRF	NAO	UV	PR	CC	RH	WS	SSC	SS	Total
1, female								0.21 (+)	0.22 (+)				2
4, female						0.44 (−)							1
5, female	0.24 (−)	0.27 (−)	0.28 (−)	0.31 (−)	0.26 (−)	0.29 (−)		0.33 (−)					7
8, female							0.50 (+)			0.45 (+)			2
10, female	0.01 (−)			0.14 (−)									2
11, female							0.47 (−)						1
12, female											0.64 (−)		1
13, male							0.48 (−)						1
14, female											0.59 (−)		1
16, female						0.42 (+)		0.44 (+)					2
17, male		0.40 (+)	0.40 (+)		0.36 (−)						0.43 (−)		4
18, female				0.57 (−)		0.59 (−)	0.61 (+)						3
20, female	0.44 (−)												1
21, female					0.48 (−)								1
26, female							0.52 (+)						1
27, female	0.19 (+)			0.12 (−)	1				0.27 (−)				3
28, male		0.51 (−)	0.53 (−)			0.55 (−)	0.57 (−)						4
29, male						0.58 (−)							1
33, male		0.32 (+)									0.32 (−)		2
35, female								0.21 (−)					1
37, male							0.35 (+)					0.44 (−)	2
38, male				0.21 (+)		0.18 (−)				0.21 (−)			3
Total	4	4	3	5	3	7	7	4	2	2	4	1	46

* (−) or (+) = direction of the association; Temp = temperature; DP = dew point; WVP = water vapor pressure; SRF = solar radio flux; NAO = North Atlantic Oscillation Index; UV = ultraviolet radiation index, PR = precipitation; CC = cloud cover; RH = relative humidity; WS = wind speed; SSC = sun spot count; SS = hours of sunshine.

Table 3. Multivariate time-series models for 6 patients with significant ($P < 0.05$) bivariate associations between pain and ≥3 weather variables*

Patient, sex	Stationary R^2	R^2	P†	Significant variables: UV dose	Significant variables: Water vapor	Significant variables: Dew point	Other variables
5, female	0.52	0.45	0.20	(−)			Solar flux (+)
17, male	0.40	0.40	0.62		(+)	(−)	
18, female	0.31	0.58	0.69				Precipitation (+)
27, female‡							
28, male	0.64	0.64	0.73	(−)	(−)	(+)	
38, male	0.29	0.18	0.59	(−)			

* UV = ultraviolet; (−) or (+) = direction of the association.
† Box-Ljung method.
‡ Not able to fit a significant model.

flux, and sunspot count showed a negative association with pain in almost all patients. Twelve of the 13 variables showed significant effects in at least 1 patient. Atmospheric pressure did not seem to have any effect on pain. The random normal variable was significantly associated with pain in 2 patients, but R^2 was only 0.05 (data not shown). The probability of this happening by chance is 87% under the null hypothesis. The uniform random variable was associated with pain in 3 patients (data not shown) and R^2 was 0.07. The chance probability of this finding is 36%. These associations are necessarily spurious, but the explained variance is much lower than for the real weather variables.

Table 3 shows the results of the multivariate analyses for the 6 patients with significant associations for 3 or more weather variables. We were not able to fit a significant model for patient number 27. The models explained between 19% and 64% of the variation in pain. The 3 variables with significant associations for 5 or more patients (UV dose, solar radio flux, and amount of precipitation) were retained in the multivariate analyses. Dew point and water vapor pressure were also retained. The following variables did not enter the multivariate analyses: temperature, cloud cover, NAO Index, sunspot count, relative humidity, and wind speed. Therefore, these variables did not seem to have independent effects on pain. When the data were analyzed at the group level, we were not able to fit a statistically significant model for any of the variables (data not shown).

DISCUSSION

In the present study we found that 6 (16%) of the 36 participating patients were weather sensitive according to our criteria for avoiding spurious associations; however, there does not seem to be distinct groups of weather sensitivity. The proportion of men among those who were weather sensitive was similar to the proportion in the whole sample. Rather, the data are in accordance with a continuum from no weather sensitivity to high weather sensitivity. The time-series analyses suggest that between 19% and 64% of the pain variation in the 6 weather-sensitive patients can be explained by the weather, but the patients differed in the variables they responded to and in which direction. Three solar variables (UV dose, solar radio flux, and sunspot count) showed consistent negative associations with pain (Tables 2 and 3). Sunspot count and solar radio flux had high intercorrelations (Pearson's r = 0.82), but UV dose had small correlations with sunspot count (r = 0.07) and with solar radio flux (r = 0.04). Therefore, there is a negative association between pain and UV dose and a separate negative association between pain and sunspot count/solar radio flux. The fact that we were not able to fit a statistically significant model at the group level indicates that weather sensitivity is an individual phenomenon in patients with RA.

Previous research in this field has produced conflicting results. The fact that many researchers have used simple correlation analyses and not a time-series approach may overestimate the influence of weather variables. On the other hand, other researchers have employed aggregated analyses, therefore treating important individual differences as noise and possibly underestimating the influence.

We have identified only 1 previous study that analyzed individual RA patients using time-series methodology and compared pain diaries with objective weather data. Gorin et al studied 75 patients (mean age 52.7 years, 71% female) and compared daily pain severity for 75 consecutive days with temperature, barometric pressure, relative humidity, and percentage of sunlight (17). As in our study, Gorin and colleagues found significant variability between patients in their weather sensitivity patterns. However, weather variables accounted for only a small amount of change in pain scores. This pattern was true even for patients with the most pronounced pain-weather relationships. Therefore, although weather sensitivity was found, the effect sizes were not clinically meaningful. In general, Gorin et al found that patients with higher levels of self-reported pain demonstrated more weather sensitivity, whereas we found the opposite to be true. The 6 weather-sensitive patients in our study had a mean pain level of 31.0 compared with 35.2 for the 30 patients who were not weather sensitive, which translated into a 4.1 mean difference in pain (95% confidence interval 1.9–6.5).

We consider the comprehensive data set (pain reporting for 84 consecutive days) as a strength of the present study. Another strength is that the patients were not aware of the subsequent focus on weather conditions when the initial pain data were collected. Even if the patients were aware of factors such as temperature and precipitation, they could not possibly have sensed the variation in solar radio flux or the number of sunspots. Our patients had stable RA, i.e., there were no substantial changes in medication and no surgical interventions in the 4 weeks prior to and during the study period. Finally, as compared with other studies, it is a strength of our study that we analyzed each patient separately with time-series modeling. However, some of the patients may have traveled to the south of Europe to receive climate therapy during the study period. We do not know how many patients traveled, but this is a potential weakness. Another weakness is that patients might have taken pain medication on painful days, and this use was not recorded during the study. However, both these potential sources of bias would decrease the observed association between pain and weather.

The patients in the present study probably had beliefs about if and how the weather affected their pain. Some aspects of the weather are more likely to give rise to such beliefs, such as temperature, precipitation, wind, sunshine, cloudiness, and humidity, but sunny days with pain and rainy days without pain will not be noticed to the same degree (20). However, the participants in our study could not have any beliefs about nonobservable variables like solar radio flux. Therefore, our findings regarding this particular variable might reflect biophysiologic mechanisms, whereas the associations between pain and precipitation might be explained by psychological mechanisms triggered by observable weather conditions.

One of the reviewers wondered if combinations of logically fitting concepts of solar and meteorological variables might have reduced the number of independent variables, and therefore offered a different analytical value. In fact, combinations of "cold and wet" or "wind and wet" conditions have been thought by some to associate with joint pain. This association is a possible limitation of our study. However, a factor analysis was considered but not performed since our objective was to explore associations between pain and standard weather variables, which made it easier to compare our results with other studies. Reducing data into a small number of weather factors makes it difficult to assign meaning to each factor. Although we started with a rather large number of variables, the multivariate analyses we performed should have effectively excluded variables with too much shared variance.

In conclusion, we found that 1 in 6 patients were weather sensitive according to our criteria for avoiding spurious associations. The fact that weather variables explained between 19% and 64% of the variance in pain in these individuals indicates that the magnitude of weather sensitivity might significantly influence pain reporting in clinical care and research for some patients. However, these results have limited generalizability regarding geographic region, season, and patient sample and need replication.

AUTHOR CONTRIBUTIONS

All authors were involved in drafting the article or revising it critically for important intellectual content, and all authors approved the final version to be submitted for publication. Dr. Smedslund had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Study conception and design. Smedslund, Heiberg, Kvien, Hagen.

Acquisition of data. Smedslund, Heiberg, Hagen.

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