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Review

Does rain really cause pain? A systematic review of the associations between weather factors and severity of pain in people with rheumatoid arthritis

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A B S T R A C T

Objective: To examine the association between weather and pain in rheumatoid arthritis (RA).
Methods: Systematic review of longitudinal observational studies (up to September 2009) with data on the association between weather variables and severity of pain in RA. The methodological quality was rated independently by the two authors according to an adapted Newcastle–Ottawa Scale. We analyzed the data on an aggregated (group) level with a meta-analysis of correlations between pain and weather, and at an individual level as the proportion of patients for whom pain was significantly affected by the weather.
Results: Nine studies were included. Many different weather variables have been studied, but only three (temperature, relative humidity and atmospheric pressure) have been studied extensively. Overall group level analyses show that associations between pain and these three variables are close to zero. Individual analyses from two studies indicate that pain reporting in a minority (<25%) of RA patients is influenced by temperature, relative humidity or atmospheric pressure. We were not able to relate the findings to methodological quality or other aspects of the studies.
Conclusion: The studies to date do not show any consistent group effect of weather conditions on pain in people with RA. There is, however, evidence suggesting that pain in some individuals is more affected by the weather than in others, and that patients react in different ways to the weather. Thus, the hypothesis that weather changes might significantly influence pain reporting in clinical care and research in some patients with RA cannot be rejected.

1. Introduction

Many patients with rheumatic diseases claim that they feel worse before or during weather changes. Jamison et al. (1995) gave a weather and pain questionnaire to 558 patients with chronic pain and found that 68% believed that changes in weather affected their pain. Of these patients, 53% stated that their pain was affected before weather changes, 62% that their pain was affected during weather changes, while only 11% said that their pain was affected after weather changes. Shutty et al. (1992) had 70 chronic pain patients complete another weather and pain questionnaire and found that only 3% of the patients reported no association between weather and their pain. Hendler et al. (1995) found that between 50% and 100% of patients with various diagnoses of chronic pain reported that they their pain always got worse with changing weather.

Since the time of Hippocrates the medical literature has referred to relations between weather and human diseases (Lowry and Lowry, 2001). The Asian symbol for rheumatism (Fong Shi) is literally translated as 'wind' and 'wet' (Ng et al., 2004), and the disease is known as "wind wet disease" in Chinese (Tsai et al., 2006). The first study on the association between pain and atmospheric conditions was published in 1879 (Everett, 1879), and since the 1930s the phenomenon has been studied using increasingly sophisticated scientific methods. However, there are a number of methodological challenges when studying this. First, subjective variables like pain are likely to be affected by expectations, weather–mood associations and misattributions. In a study of exposure variables that are directly perceived by the individual, the outcome is pain and the participants know that the study is about pain-weather relations, any result can be interpreted as a sum of three different effects, (bio-physiological effects, cognitive misattribution and mood-mediated effect).

One way to avoid confusing these psychological effects with a bio-physiological one is to use data recorded for other purposes. In such cases, patients would not think about the weather while reporting their degree of pain. The relationship between experienced pain and objective external variables could also be highly individual. A study should therefore preferably report data both

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for each individual patient and for the whole group. Finally, any weather variable has an auto-correlated structure. This means that for example today's temperature is dependent on yesterday's temperature. When analysing the co-variation of pain and temperature, this dependency should be taken account of.

A number of previous reviews have tried to sum up the literature on weather and symptoms in patients with rheumatic diseases (Cimmino, 1999; Harlfinger, 1991; Jamison, 1996; Latman, 1987; Lawrence, 1977; Patberg and Rasker, 2004; Quick, 1997). Some of these reviews looked at patients with chronic non-cancer pain without limiting their focus to rheumatic diseases. But no systematic review (i.e. with a comprehensive literature search, methodological quality appraisal, and a transparent reporting of methodological considerations) has been undertaken.

The aim of the present review was to locate, critically appraise, and synthesize results from studies that have reported data on how pain levels are affected by weather variables in patients with RA.

2. Literature search and methods

2.1. Inclusion criteria

We included longitudinal observational studies with daily reported data on degree of pain and atmospheric or solar variables in patients with RA. Studies including several rheumatic diagnoses were only included if data on RA were reported separately. Studies of pain episodes (attacks), studies of pain levels in different months of the year, studies that compared the incidence of pain-related disorders in different climates, studies of climatic therapy, studies using controlled environments such as climate chambers, studies lacking objective exposure data, theoretical articles, letters to editors, editorials, and opinion papers were excluded. By "atmospheric variables" we mean the data that are typically recorded by meteorological stations. By "solar variables" we mean ultraviolet radiation from the sun and solar radio flux. We searched for studies from all geographical locations and written in all languages. Google Translate (http://translate.google.com/translate_t#) was used for determining whether articles not in English or Scandinavian would be included. For some articles (in Russian, Bulgarian, Polish and Czech) experts who were fluent speakers of these languages were contacted (see acknowledgements).

2.2. Search strategy

We searched PsycINFO (1806 – Week 25, 2009), Medline (1950 – August Week 2, 2009), EMBASE, (1966 – Week 25, 2009), AMED (search date: June 19th 2009) and CINAHL (1989–2009). The search strategy for Medline is listed in Appendix. The search strategies for the other databases are available on request from the first author. Reference lists from relevant studies were checked for additional references, and ISI Web of Knowledge was searched for references citing the included studies (September 23rd, 2009).

2.3. Inclusion process

Titles and abstracts were checked against the inclusion criteria by GS. Data from included articles were extracted by GS and checked by KBH.

2.4. Quality assessment

The methodological quality of the included studies was scored independently by the two authors using a checklist modified from the *Newcastle – Ottawa Quality Assessment Scale for Cohort Studies* (Wells et al., 2009). The Newcastle–Ottawa Scale deals with selection, comparability and outcome. Selection is about whether the study sample was representative of the population of interest, and whether the exposure was adequately measured. Comparability is about whether exposed and non-exposed cohorts were comparable. This was not relevant for our review, and this is why we had to adapt it. Finally, outcome is about how the outcome was recorded and whether the follow-up time was long enough.

2.5. Description of studies and data analysis

For each study we describe the study sample (number of participants, percent women, and mean age). We list the weather variables that was studied and information about the data collection (number of days of reporting, time of day). We report correlations between pain and weather variables for each study. In our own study (Smedslund et al., 2009) we had access to the raw data, but none of the other studies had reported a correlation. In cases where the original studies did not report a correlation, we estimated one. If a study (Gorin et al., 1999; Janus et al., 2005) reported an *F*-ratio from an ANOVA, we used a formula listed by Lipsey and Wilson (2001, formula no. 6 in Table B11). In a study (Verges et al., 2004) that reported odds ratios, we used formulas for conversion from odds ratios to correlations (Borenstein et al., 2009). In one study, only "$p < .05$" was reported. We used $p = .03$ (being the midpoint between $p = .05$ and $p = .01$ and employed an on-line calculator (http://faculty.vassar.edu/lowry/tabs.html#r) to estimate a correlation. In one study (Janus et al., 2005), we received the *F*-ratios from the first author. We analyzed the data in two ways; (1) on an aggregated (group) level with a meta-analysis of correlations between pain and the three most studied variables (temperature, relative humidity, atmospheric pressure) and (2) at an individual level as the proportion of patients for whom pain was affected by the weather (i.e. with significant associations between pain and weather). Random effects models were chosen a priori because we expected large variation among studies in patients, climates, study durations, and study designs.

3. Results

The electronic searches identified 386 studies of which 268 were clearly not relevant, and 118 were retrieved in full text. After reading the full texts, 109 publications were excluded. Reasons for exclusion were type of publication (review, editorial, letter to editor [$n = 24$], not patients with RA ($n = 9$), no weather data ($n = 18$), no pain data ($n = 28$), not time series ($n = 8$), or other aim of the study (e. g. incidence of disease, seasonal fluctuations in pain, controlled climate chamber, climate therapy [$n = 22$]). A table of excluded articles with reasons for exclusion is available on request from the first author. Nine studies with a total of 492 participants (range: 12–88) published between 1985 and 2009 were included in this review (Table 1). Because each patient reported their pain up to four times a day for up to 365 days, the number of observations ranged from 372 to 32,120. The studies were from Australia (Drane et al., 1997), Belgium (Dequeker and Wuestenraed, 1986), USA (Gorin et al., 1999), Israel (Guedj and Weinberger, 1990), Poland (Janus et al., 2005), the Netherlands (Patberg et al., 1985), Norway (Smedslund et al., 2009), Italy (Marson et al., 1989), and Spain (Verges et al., 2004). Two studies (Guedj and Weinberger, 1990; Verges et al., 2004) had participants from more than one diagnostic category. Fifteen different objective weather variables were studied in at least one of the included studies. However, quantitative data synthesis was only feasible for temperature, relative humidity and atmospheric pressure.

Table 2 shows how we judged the methodological quality of the included studies. No study came close to fulfilling all the quality

Table 1
Characteristics of included studies ($n = 9$).

Study identifier	Patients and data collection	Objective weather variables[a]	Approximate number of observations
Dequeker and Wuestenraed (1986)	19 patients (15 women and 4 men with mean age 58 years) registered pain four times a day for five times a week. Mean study period was 15.3 days (4 days to 5 weeks). All patients stayed indoors (hospital)	RH–P–CC–T–W	1140
Drane et al. (1997)	53 female patients with a mean age of 42 years registered pain in 14 day periods at 3–4 monthly intervals over 1–3 years	T–RH–P–CC–SS–R–TH	3614
Gorin et al. (1999)	75 patients (mean age: 53 years, 71% women) registered their daily pain for 75 consecutive days. No simultaneous scoring period for all subjects	T–P–RH–SS	5625
Guedj and Weinberger (1990)	51 patients (16 RA, 24 OA, 11 FM) reported pain every morning for four weeks. Mean age of the RA patients was 56 years	T-P-PR	448
Janus et al. (2005)	50 patients registered pain every evening for 14 consecutive days	T–RH–P	700
Marson et al. (1989)	16 patients (4 men and 12 women with mean age 51 years) registered their pain every evening for 123 days	T, P, RH, W, CC	1968
Patberg et al. (1985)	88 patients (43 men and 45 women ranging in age from 30–68 years) registered their pain daily for one full year	SS, T, VP, RH, P, W	32,120
Smedslund et al. (2009)	36 patients (mean age: 50 years, 69% women) registered pain daily for 84 consecutive days	T–RH–P–W–SS–CC–VP–PR–UV–NAO–SC–DP–SF	3024
Verges et al. (2004)	92 patients (12 with RA and 80 with OA) registered their pain daily for 1 month (31 days)	T–RH–P	372

[a] T = temperature, H = humidity, RH = relative humidity, DP = dew point (wet bulb), VP = vapour pressure, P = pressure, W = wind, SS = sunshine, TH = thunderstorms, CC = cloud cover, PR = precipitation, UV = ultra-violet radiation, SC = sunspot count, NAO = North-Atlantic Oscillation Index, SF = solar radio flux.

Table 2
Methodological quality of the included studies.

	Modified Newcastle–Ottawa Scale				Study-specific quality-coding		
	Selection		Outcome				
Study	Representativeness[a]	Ascertainment of exposure[b]	Subjects blinded to study aims[c]	Duration covering full range of weather variation[d]	Diagnosis[e]	Adequate use of statistics[f]	Attrition[g]
Dequeker and Wuestenraed (1986)	Not met	Not met	Not met	Met	Not met	Not met	Met
Drane et al. (1997)	Unclear	Unclear	Met	Met	Met	Met	Met
Gorin et al. (1999)	Unclear	Unclear	Met	Not met	Met	Met	Met
Guedj and Weinberger (1990)	Unclear	Unclear	Met	Met	Met	Not met	Not met
Janus et al. (2005)	Unclear	Unclear	Met	Not met	Met	Not met	Unclear
Marson et al. (1989)	Unclear	Unclear	Met	Not met	Met	Not met	Unclear
Patberg et al. (1985)	Met	Unclear	Met	Not met	Not met	Not met	Met
Smedslund et al. (2009)	Unclear	Unclear	Met	Met	Met	Met	Met
Verges et al. (2004)	Unclear	Unclear	Met	Not met	Not met	Not met	Met

[a] Sample is truly representative of the average patient with rheumatoid arthritis.
[b] The meteorological conditions were measured adequately and the participants have been exposed to them (e.g. have been outdoors).
[c] The participants were not informed that the study was about pain and weather.
[d] Recorded weather for a full year is preferred, but recordings covering winter, spring and summer, or summer, autumn and winter i.e. periods with a substantial variation more weather variables are acceptable.
[e] Participants have a formal diagnosis of RA according to validated diagnostic criteria.
[f] The researchers have taken account of autocorrelations in their data.
[g] Complete follow up of all subjects or subjects lost to follow up are unlikely to introduce bias: number lost less than or equal to 20%.

criteria. Eight of the nine studies had tried to blind the subjects to the study aims. Six studies had employed internationally accepted diagnostic criteria, and six studies had low attrition. None of the studies reported the degree to which the patients had actually been exposed to the weather conditions, except for Dequeker and Wuestenraed (1986). In this study the patients were hospitalised and were minimally exposed to outside weather conditions. It is mostly unclear how representative the study samples are for the typical RA patient.

3.1. Meta-analysis of group level (aggregated) analyses

Fig. 1 shows correlations between pain and temperature. Five studies were included in the statistical pooling. All studies show small correlations clustering around zero, and in sum no significant influence of temperature was found. The heterogeneity was judged to be high according to the criteria proposed by Higgins et al. (2003) [$Q(4) = 13.5$, $p = .009$, I-squared: 70.5]. The confidence intervals are very narrow because the studies have a large number of

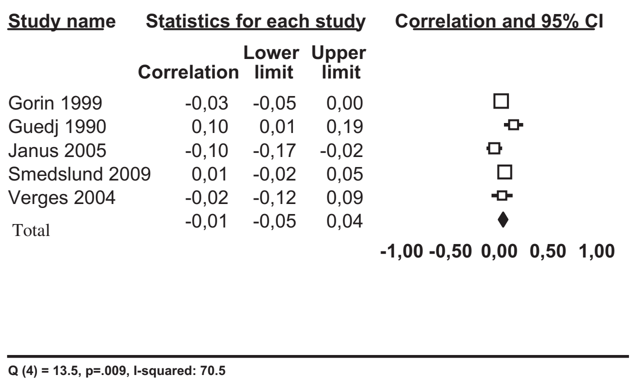

Fig. 1. Random-effects meta-analysis of correlations between pain and temperature.

observations. The studies by Dequeker and Wuestenraed (1986), Drane et al. (1997), and Marson et al. (1989) are not included because it was not possible to calculate a correlation. The study by Patberg et al. (1985) is omitted because it reported only monthly averages of pain, and not daily data (even though daily data were indeed recorded!). Patberg et al. (1985) reported a positive association between pain and temperature. Dequeker and Wuestenraed did not find a clear pattern, but Drane et al. and Marson et al. reported negative associations (i.e. higher temperature was associated with less pain). But we were not able to quantify the strength of the associations in these four studies.

Fig. 2 shows the same for pain and atmospheric pressure. The overall picture is much the same as for temperature, except that heterogeneity was low to moderate according to the aforementioned criteria [Q (4) = 6.5, p = .165, I-squared = 38.4]. None of the omitted studies found a positive association between pain and pressure. Dequeker and Wuestenraed, Drane et al. and Patberg et al. did not report any association, but Marson et al. reported a negative association.

Fig. 3 shows the same for relative humidity. Four studies were included in the analyses, and the picture is much the same as for temperature and pressure, but correlations are even smaller and the data are very homogeneous [Q (3) = 0.7, p = .861, I-squared = 0.0]. The study by Guedj and Weinberger (1990) is not included here because we could not compute a correlation. Marson et al. reported a positive association between pain and humidity. Drane et al. and Dequeker and Wuestenraed found no association, and Patberg et al. reported a negative association.

In summary we found no quantitative support for an association between pain and weather variables for patients with RA on

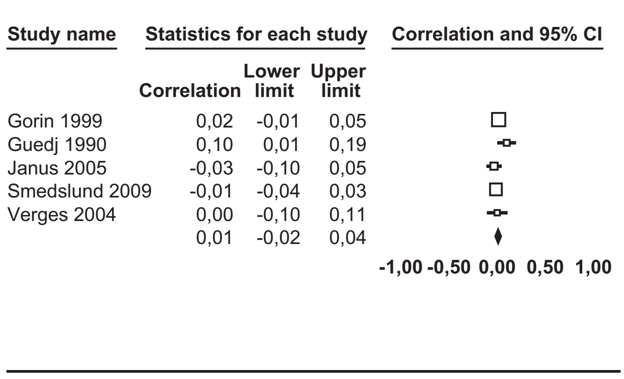

Fig. 2. Random-effects meta-analysis of correlations between pain and atmospheric pressure.

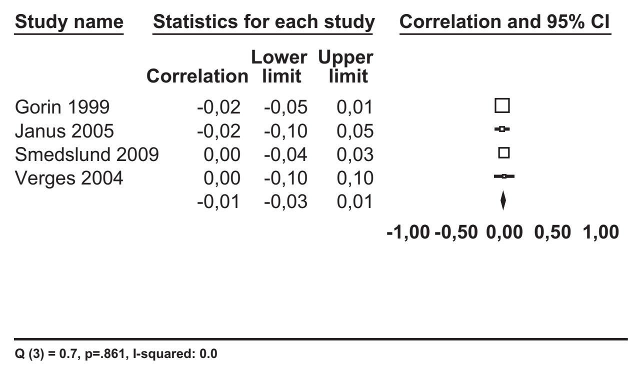

Fig. 3. Random-effects meta-analysis of correlations between pain and relative humidity.

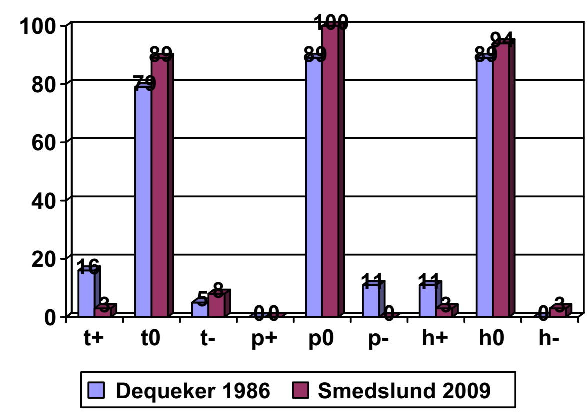

Fig. 4. Studies with reported individual data. Percent of patients with positive (+), zero (0), or negative (−) associations with temperature, (t) atmospheric pressure (p), and relative humidity (h). Thus, 't+' shows percent of patients with positive associations with temperature, 'p−' shows percent of patients with negative associations with pressure, etc.

a group level. Because there were only nine included studies, we did not perform meta-regression or any stratified analysis to try to explain variation in effect estimates.

3.2. Individual level analyses

Only two studies reported individual associations between separate weather variables and pain (Dequeker and Wuestenraed, 1986; Smedslund et al., 2009). The studies by Gorin et al. (1999) and Guedj and Weinberger (1990) took account of individual differences in their analyses, but proportion of weather sensitivity was not reported for separate weather variables. Fig. 4 shows that, respectively 11% and 21% of the patients were sensitive to temperature, 0% and 11% to atmospheric pressure, and 6% and 11% to relative humidity in our own study (Smedslund et al., 2009) and that of Dequeker and Wuestenraed (1986). Thus, the proportion of patients who were *not* weather sensitive for these three weather variables varied between 79% and 100%.

4. Discussion

Aggregated analyses showed no relationship between three single weather variables (temperature, humidity and atmospheric pressure) and pain in patients with RA. However, individual level analyses suggest that a small proportion of patients are weather sensitive, but the patients differed as to which variables they responded to and which direction.

These findings might seem puzzling to some readers because it is well known that more than 60% of patients with RA believe that their pain is affected by the weather (Jamison et al., 1995). We have suggested that this could be caused by a cognitive misattribution. If a patient believes that rain causes pain, he or she will pay much attention to rainy days with much pain. Sunny days with pain and rainy days without pain will not be so much noticed. There might also be a mood–pain link such that rainy days will make the patient feel depressed, and that this depressed mood somehow will lower the pain threshold (Jamison et al., 1995; Shutty et al., 1992). Although these explanations may be true for some persons with RA, the data from this review certainly cannot rule out the possibility of a bio-physiological impact of weather factors on the body (in some individuals) which is independent of the aforementioned psychological explanations.

Strengths of this review are that it employs a systematic and transparent literature search, that it has explicit inclusion/exclusion criteria, that it has methodological quality appraisal of the included studies, and that it includes a meta-analysis. Weaknesses are that the number of included studies is small, that the included studies have poor reporting, and that the outcome (pain) is subjective.

Apart from Patberg and Rasker (2004), this is the first review on weather and pain that has performed a systematic literature search. But we searched five databases while Patberg and Rasker only searched Pub Med. The present review also is the first to perform a meta-analysis. Other reviews have used vote-counting methods (Patberg and Rasker, 2004; Quick, 1997) or are narrative reviews (Jamison, 1996; Latman, 1987). We are the first to employ methodological quality appraisal of the included studies using a validated instrument. The results are not directly comparable to those of other reviews because meta-analytical results are not comparable to those using cote counting. Our review is different from other reviews in that we found consistent results across studies, while other reviews have found conflicting results.

We have found that associations between weather and pain are close to zero at the group level, but that there are individual variations. This could be because individual associations cancel each other out.

There are a number of unanswered questions. Why did we not find any group effects of weather on pain when a large majority of persons with chronic pain experience such effects? Why are some people weather sensitive and others not? How does the weather cause variations in pain?

Many researchers have tried to isolate the effect of a single meteorological variable on pain. But meteorological variables are part of a complex pattern, which we call ‘‘weather’’. Hollander and colleagues (Hollander, 1961; Hollander and Yeostros, 1963) did not find a relation between any one variable and pain. However, they found that pain increased when barometric pressure was lowered and relative humidity was increased simultaneously (in a controlled chamber).

Maybe the studies by Mitchell (1877) and Everett (1879) from the late 18th century of ‘‘distance to storm front’’ represented a more adequate test of patients’ experiences than the current isolation of single variables. These pioneers wrote that when a weather front is moving through an area, it is preceded by a wave of positive ions in the surface air. Their patients claimed that they could sense changes in the air hours or days before a front approached. The pain typically increased when the front was approaching, and reached a maximum when they were situated at or near the centre of the front. The speed of the front’s movement was also believed to be positively associated with pain. In modern headache research, some authors (Vaitl et al., 2001; Walach et al., 2001) have recently taken up these ideas. *Sferics* are low frequency, low intensity electromagnetic pulses radiating from distant meteorological events and other yet unknown sources. It has been hypothesized that sferics are part of the purported sensitivity to weather changes reported by headache sufferers (Vaitl et al., 2001; Walach et al., 2001).

If weather causes pain, we don’t know whether this happens instantaneously or in a lagged fashion. The pain may change in a matter of minutes, hours or days after the change in weather. If pain changes occur 1 h after the weather change, daily averages in meteorological factors would not be adequate in order to detect an association. In our own study (Smedslund et al., 2009) we found that a patient’s pain was influenced by the solar flux level 3 days previously. Patberg (1997) even claimed that the lag was 30 days between ESR (erythrocyte sedimentation rate) and temperature over a three-year period.

One possibility is that the macro variables, which are recorded by meteorological institutes, are not important for pain and disease activity. People spend most of their time indoors. Why should they be affected by outdoor conditions? Some variables (temperature, humidity) are different inside and outside houses, while others (e.g. atmospheric pressure) are not. It might be that the microenvironment close to the skin is the most important factor (Quick, 1997). Clothing creates a warm and humid environment, which might in some way be harmful. Patberg and Rasker (2004) concluded that high humidity close to the skin is correlated with worsening of RA symptoms. Clothes worsen symptoms by stopping the humidity from leaving the skin. High temperatures worsen disease activity since it (usually) increases absolute humidity. Most patients experience weather–pain associations regardless of what clothes they are wearing or whether they are indoors or outdoors, but the data in the present review can neither strengthen nor weaken the hypothesis about the microenvironment close to the skin. New studies that specifically address this hypothesis are needed.

Another proposed mechanism for temperature-pain associations is that much of the body is made up of tendons, and any changes in atmospheric pressure would have a tendency to expand or contract these tissue and adversely affect sensitized nerve pain (Jamison et al., 1995).

An ideal future study should record weather data covering the full annual variation. In other words, researchers should include at least one winter and one summer in their study period. It is also important that weather and pain is assessed at the exact same time. The microenvironment close to the skin could be assessed, perhaps using ambulatory measurement devices worn on a 24-h basis. A proxy might be to report the extent to which study participants have been outdoors and what clothing they have been wearing. The effects of single weather variables as well as multivariate analyses should be undertaken. Both levels of and change in exposure variables should be studied. As for pain scoring, we suggest that researchers consider the method described by Patberg (2005) which involves assessing pain in 21 joints and groups of joints. Pain is assessed in the morning immediately after getting up. This is the time of day when RA complaints are maximal. Evening pain scores are less reliable since variable daytime circumstances, like tiredness, might influence the scoring more than the in general more stable nighttime period (Patberg, 2005). Patberg also scored pain during the execution of standardized exercises because joint pain strongly depends upon positioning and movement of the joints. Patbergs scoring system involves 21 pain scores ranging from 0 (no pain) to 9 (very severe pain) for the hands, wrists, elbows, shoulders, temporomandibular joints, hips, knees, ankles, feet, and the neck, back, and costosternal joints (Patberg, 2005). In addition to pain, which is inherently subjective, an ideal future study might also measure other, more objective, disease-related variables such as grip strength, morning stiffness, ESR (erythrocyte sedimentation rate), and CRT (c-reactive protein). Unfortunately, it is not practical to measure these objective measures of disease on a daily basis.

The task of performing a systematic review turned out to be difficult. The weather data have high reliability and validity and are recorded in the same way worldwide, but all the included studies have shortcomings. Because of this, we cannot draw strong conclusions from the present review, but the studies to date do not show any consistent group effect of single weather variables on pain in people with RA. There is, however, evidence from two independent studies suggesting that pain in some individuals is affected by the weather. But we certainly cannot exclude the possibility that accurate and quantitative assessment of this subjective relationship is simply not obtainable. We have suggested some directions for how future research should deal with the shortcomings of the earlier studies.

Conflict of interest

Both authors declare that the answer to the questions on your competing interest form are all No and therefore have nothing to declare. However, one of the included studies was conducted by us.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.ejpain.2010.05.003.

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