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CHAPTER 3

The influence of weather conditions on joint pain in older people with osteoarthritis: results from the European Project on OSteoArthritis


ABSTRACT

Objectives:
This study examined whether daily weather conditions, 3-day average weather conditions and changes in weather conditions influence joint pain in older people with osteoarthritis (OA) in 6 European countries.

Methods:
Data from the population-based European Project on OsteoArthritis were used. American College of Rheumatology classification criteria were used to diagnose OA in older people (65-85 years). After the baseline-interview, at six months, and after the 12-18 months follow-up interview, joint pain was assessed using two-week pain calendars. Daily values for temperature, precipitation, atmospheric pressure, relative humidity and wind speed were obtained from local weather stations. Multilevel regression modelling was used to examine the pain-weather associations, adjusted for several confounders.

Results:
The study included 810 participants with OA in knee, hand and/or hip. After adjustment, there were significant associations of joint pain with daily average humidity (B=0.004; p<0.01) and 3-day average humidity (B=0.004; p=0.01). A significant interaction effect was found between daily average humidity and temperature on joint pain. The effect of humidity on pain was stronger in relatively cold weather conditions. Changes in weather variables between 2 consecutive days were not significantly associated with reported joint pain.

Conclusions:
The associations between pain and daily average weather conditions suggest that a causal relationship exist between joint pain and weather variables, but the associations between day-to-day weather changes and pain do not confirm causation. Knowledge about the relationship between joint pain in OA and weather may help individuals with OA, physicians and therapists to better understand and manage fluctuations in pain.
INTRODUCTION

Osteoarthritis (OA) is a process or condition affecting the joint cartilage and subchondral bone and is frequently accompanied by pain, stiffness and disability [1,2]. Persons with OA frequently report that weather conditions affect their pain levels. In particular, damp/rainy and cold weather conditions are perceived to affect joint pain in people with OA [3,4]. However, previous studies investigating the relationship between objective meteorological conditions and joint pain in OA have been inconclusive and contradictory [5,6]. The objective of this study is to examine whether weather conditions influence joint pain in older people with OA in 6 European countries.

Various mechanisms have been suggested to explain the effects of certain weather conditions on joint pain in OA [6-8]. Because tendons, muscles, bones and scar tissues are of varied densities, differential expansions and contractions attributable to the changes in humidity and temperature may result in pain at sites of microtrauma [6,8]. Alterations of atmospheric pressure and temperature may increase stiffness in joints and make joints more sensitive to the pain of mechanical stresses. Changes in atmospheric pressure may also cause a transient disequilibrium in body pressure that may sensitise nerve endings [6,8]. Empirical evidence on these mechanisms is lacking and large-scale epidemiological research is needed to examine whether the association between joint pain in OA and weather exists.

Previous studies have examined the relationship between meteorological conditions [5,6], such as temperature [9-14], precipitation [9-11,14,15], atmospheric pressure [7,9-14,16], humidity [9,11-13,16,17] and wind speed [9,11,15], and joint pain in OA and show conflicting results [5,6]. Several methodological limitations are presented among the body of current evidence [5,6]. Particular problems include disclosure of the study hypothesis to participants and the small study size. Further, many studies focused on static 24-hour average conditions, instead of changes in weather. Individuals with OA often report that their joint pain becomes worse during weather changes [3,6]. However, most studies focused on effects of weather conditions in the short term instead of ambient weather conditions and weather changes immediately preceding each pain report. Further, most stud-
ies were performed at single geographical sites, resulting in limited geographic and meteorological variability. An exception is a study [18] that investigated the relationship between meteorological variables and joint pain in 200 individuals with knee OA. Participants were geographically dispersed within the United States of America and were informed about the study hypotheses only after the data collection concluded. The findings revealed that both an increase in atmospheric pressure and a decrease in ambient temperature (the average temperature in the three days prior to a pain report) were associated with increased pain in OA.

This population-based study extended previous research by including a large sample of older persons with OA in knee, hand, and/or hip, living across 6 European countries. The association between 3-day average weather conditions and pain has never been studied in persons with OA across Europe. The present study aims to examine whether average daily weather conditions, 3-day average weather conditions and changes in weather conditions were associated with (day-to-day changes in) joint pain in older people with OA in 6 European countries. In addition, the effects of combinations of daily and 3-day average weather variables on joint pain in OA were examined. It was hypothesized that cold and humid weather conditions as well as changes in atmospheric pressure led to more pain in older people with OA.

METHODS

Design and study sample
Data from the European Project on OSsteoArthritis (EPOSA) were used. The EPOSA study focuses on the personal and societal burden and its determinants of OA in older persons. A detailed description of the study design and data collection of the EPOSA study is described elsewhere [19]. In summary, random samples were taken from existing population-based cohorts in five European countries (Germany, the Netherlands, Spain, Sweden and the United Kingdom (UK)). In Italy, a new sample was drawn. A total of 2,942 respondents (response rate, ranging from 64.6% to 82.2%, averaging 72.8%) were included at baseline. The age-range was 65-85
years in most countries except for the UK, which had an age-range of 71-79 years. All participants were interviewed by a trained researcher at home or in a clinical center, using a standardized questionnaire and a clinical exam. The baseline and follow-up interview lasted about one and a half hours. All participants completed an informed consent. For all 6 countries, the study design and procedures were approved by the Medical Ethics committee of the respective centers.

The clinical classification criteria, developed by the American College of Rheumatology (ACR) [20], were used to determine OA. The ACR criteria for knee, hand or hip OA were satisfied in 889 participants (31.7%) at baseline. At the end of the baseline interview (t0), all 889 participants with OA were invited to complete a pain calendar on which they were asked to score per day the level of joint pain for the following two weeks. In total, 784 participants (88.3%) returned the baseline pain calendar and 750 baseline pain calendars (84.3%) were included in the analyses (e.g., these pain calendars had no missing data on all dates). Six months after the baseline interview (t1), 681 participants received a pain calendar. Of those people, 506 (74.4%) returned the pain calendar at t1. In total, 490 (72.1%) pain calendars at t1 were used in the analyses. After the 12-18 months follow-up interview (t2), 697 participants received a pain calendar. Of those participants, 636 (91.3%) returned the pain calendar at t2. In total, 606 (87.0%) pain calendars at t2 were used in the analyses.

Of all 889 participants with OA at baseline, 810 persons had data available on at least 2 days of the 3 pain calendars. These participants were included in the final study sample. The proportions of women and depressed persons were higher in the excluded group (n=79) compared with the included group (n=810). Further, the excluded persons were older and used pain medication on fewer days compared with the persons included.

**Measures**

**Dependent variables:**

**Joint pain**

After the baseline-interview, six months later, and after the 12-18 months follow-up interview, participants were asked to complete a two-week pain calendar. The pain...
calendars were completed by the participants in the period between December 2010 and February 2013. Per day, respondents indicated how much joint pain they experienced on an 11-point rating scale from 0 to 10 with 0 representing no pain and 10 representing the greatest pain intensity. The number of pain reports per respondent ranged from 2 to the maximum of 42. For each participant, change in pain was calculated as the difference in perceived joint pain intensity between 2 consecutive days. The number of measures on changes in joint pain ranged from 0 to a maximum of 39 across respondents.

**Independent variables:**

*Meteorological data and meteorological exposure definitions*

Data-collecting weather stations provided local daily average values for temperature (in degrees Celsius (°C)), precipitation (in millimeters (mm)), atmospheric pressure (in hectopascals (hPa)), relative humidity (in percentages), and wind speed (in meters per second (m/s)) for every participant, for each day of their participation in the study period. The maximum distance between a weather station and a participants’ residence was within 80 kilometres. From the daily average values, 3-day average values and change values were derived for each participant. The 3-day average values consisted of the means of the daily averages over the 3-day periods before each pain report. Change in weather variables was computed as the difference in each meteorological parameter between the day before each pain report and the day of the pain report itself [18].

**Potential confounders:**

*Socio-demographic variables*

Socio-demographic information was obtained on participants’ age, sex and country of residence. To account for minor sampling differences across cohort studies, the analyses are adjusted for country of residence. Participants were living in six European countries, including Germany, Italy, the Netherlands, Spain, Sweden and the UK. This variable was dummy coded with Sweden as the reference category, because the Swedish respondents reported, on average, the lowest joint pain intensity.
**Depression**

At \( t_0 \) and \( t_2 \), depressive symptoms were examined using the 7 four-point Likert scaled items of the Hospital Anxiety Depression Scales that are related to depression (HADS-D) [21]. The HADS-D has a range from 0-21. The HADS-D was used as categorical variable with cut-off level of 8 or more for presence of depression (yes/no).

**Medication use**

Simultaneously with the pain calendars, participants were asked daily to indicate changes in medication use. This was assessed by asking participants whether they used additional pain medication because of joint pain (yes/no).

**Statistical analyses**

One-way ANOVA analyses and Kruskal-Wallis tests were performed to examine differences in joint pain and meteorological exposure across countries and seasons. All descriptive statistics, except sex, age, country and the weather variables, were weighted to the European standard population in 2010. The weights were calculated per sex and per five-year age category, using the formula:

\[
W = \frac{N_{\text{exp}}}{N_{\text{obs}}}
\]

The \( N_{\text{obs}} \) was the number of persons in a specific age/sex category in the cohort, and \( N_{\text{exp}} \) was the number of persons in a specific age/sex category in the European standard population in 2010 [22].

Multilevel regression modelling was used to examine the associations between the weather variables and (day-to-day changes in) joint pain. In these models, the joint pain intensity measures and the measures of the weather parameters (level-1) were nested within 810 participants (level-2) who completed at least two individual pain reports of the three pain calendars. Participants with some missing data can remain in the analysis, thereby increasing the precision of the estimates and the power of the statistical tests [23].

A number of associations were tested: (1) whether each of the weather variables was associated with joint pain on the same day; (2) whether 3-day average weather
variables were associated with joint pain on the next day; (3) whether changes in weather variables between 2 consecutive days were associated with reported joint pain on the second day; and (4) whether changes in weather variables between 2 consecutive days were associated with differences in pain report between these 2 days. This study focused on the associations between joint pain and weather parameters in the full sample to maximise the variation in weather parameters.

All of these associations were examined in models constructed step by step. The dependent variable in each of the models was either joint pain or day-to-day changes in joint pain. Model 1 tested the univariate effects of the weather variables. Model 2 tested the effects of the weather variables, adjusted for potential confounders sex, age, country, depression and medication use. Subsequently, we tested pain-weather associations in Model 3, including all weather variables that reached a p-value below 0.20 in Model 2 and all potential confounders. To examine the effects of combinations of weather parameters on joint pain, all possible two-way interaction terms between weather parameters were assessed separately in a fully adjusted model. The interaction effects were considered significant at a p-value below 0.10 [24]. For each pain-weather association, the effect size (ES) was calculated as described in Tymms [25]. Effect sizes ≤0.10 were considered as small, ES>0.10 to ≤0.30 were considered as medium, and ES≥0.50 were considered as large [26]. Statistical analyses were performed in IBM SPSS Statistics (version 20.0).

RESULTS

The characteristics of participants are presented in Table 1. At baseline, the mean age of all 810 participants with OA was 74.0 (SD=5.0) years. Of the participants, 556 (68.6%) were female. Two hundred and forty (29.4%) participants had hand OA only and 367 (45.0%) persons had knee and/or hip OA, but no hand OA. Of all 810 included participants, 203 (25.6%) persons had hand OA as well as knee and/or hip OA. In total, 25,891 (76.1%) of the possible 34,020 individual pain reports (810 x 42) were completed. Further, 23,616 (74.8%) of the possible 31,590 (810 x 39) measures on differences in joint pain between 2 consecutive days were available.
### Table 1: Characteristics of the study sample (n=810).*

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Count (Percentage)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age in years (Mean (SD))</td>
<td>74.0 (5.0)</td>
</tr>
<tr>
<td>Sex (female) (n (%))</td>
<td>556 (68.6)</td>
</tr>
<tr>
<td>Country</td>
<td></td>
</tr>
<tr>
<td>Germany (n (%))</td>
<td>84 (10.4)</td>
</tr>
<tr>
<td>Italy (n (%))</td>
<td>167 (20.6)</td>
</tr>
<tr>
<td>the Netherlands (n (%))</td>
<td>127 (15.7)</td>
</tr>
<tr>
<td>Spain (n (%))</td>
<td>162 (20.0)</td>
</tr>
<tr>
<td>Sweden (n (%))</td>
<td>158 (19.5)</td>
</tr>
<tr>
<td>United Kingdom (n (%))</td>
<td>112 (13.8)</td>
</tr>
<tr>
<td>Depression (HADS-D score≥8 at baseline and/or at 12-18 months follow-up) (n (%))</td>
<td>198 (24.3)</td>
</tr>
<tr>
<td>Number of days of medication use (Median (IQR))</td>
<td>19.0 (10.0-28.0)</td>
</tr>
</tbody>
</table>

* Descriptive statistics are weighted (except age, sex and country). The numbers of participants are non-weighted. IQR=interquartile ranges.

### Joint pain

On 17.3% of all completed days, the participants did not experience joint pain at all (pain score=0). The participants experienced mild joint pain (pain score=1-3) and moderate to severe joint pain (pain score=4-10) on 29.6% and 53.1% of all completed days respectively. Overall, the average joint pain intensity was 3.7 (SD=2.7), range=0-10) across countries. Significant differences in joint pain across countries and seasons were found (Table 2). Joint pain intensity was highest in Spain (Mean=5.1, SD=2.9) and lowest in Sweden (Mean=2.5, SD= 2.3). Overall, joint pain intensity was highest in winter (Mean=3.9, SD=2.8) and lowest in autumn (Mean=3.6, SD=2.6). However, the season in which most pain was reported differed across countries (Table 2).

### Weather conditions

The distribution of the meteorological exposures in the study sample showed significant differences in daily weather conditions and 3-day average weather conditions between the 6 countries (Data supplement). No significant differences in weather changes between countries were observed (data not shown).
Average daily temperature and atmospheric pressure were highest in Spain. Further, precipitation and humidity were lowest in Spain. In Germany, daily temperature was lowest and humidity was highest. In Sweden, daily precipitation and atmospheric pressure were highest and lowest respectively. Daily wind speed was highest in the Netherlands and lowest in Italy (Data supplement).

**Joint pain intensity and daily average weather parameters**

After adjustment for all confounders (Table 3; Model 2), the association between joint pain and daily average humidity ($B=0.004$, $p<0.01$, $ES=0.063$) was statistically significant. In a multivariable model including daily average precipitation, relative humidity, wind speed and all confounders (Table 3; Model 3), the associations between joint pain and precipitation ($B=-0.006$, $p=0.03$, $ES=-0.034$) and relative humidity ($B=0.005$, $p<0.01$, $ES=0.068$) were significant. A significant humidity by temperature interaction effect on joint pain was found ($p=0.01$). In the highest quartile of daily average temperature ($>16.9^\circ C$), no significant association was found between joint pain and relative humidity ($B=0.002$, $p=0.44$, $ES=0.044$), whereas the association between pain and relative humidity was statistically sig-

![Figure 1](image)

**Figure 1**: The association between joint pain and daily average humidity in older persons with osteoarthritis in relatively cold and warm weather conditions.
### Table 2: Average joint pain in older people with osteoarthritis across countries and seasons.

<table>
<thead>
<tr>
<th>Season</th>
<th>All countries (n=810)</th>
<th>Germany (n=84)</th>
<th>Italy (n=167)</th>
<th>the Netherlands (n=127)</th>
<th>Spain (n=162)</th>
<th>Sweden (n=158)</th>
<th>United Kingdom (n=112)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>Joint pain intensity (0-10) (Mean (SD)) (based on n participants / n pain reports)</td>
<td>3.7 (2.7) (810 / 25,891)</td>
<td>3.3 (2.2) (84 / 2,882)</td>
<td>4.3 (2.8) (167 / 5,203)</td>
<td>3.9 (2.3) (127 / 4,165)</td>
<td>5.1 (2.9) (162 / 3,900)</td>
<td>2.5 (2.3) (158 / 5,893)</td>
<td>3.8 (2.6) (112 / 3,848)</td>
</tr>
<tr>
<td>Spring</td>
<td>3.8 (2.7) (561 / 7,895)</td>
<td>3.1 (2.1) (63 / 815)</td>
<td>4.3 (2.8) (118 / 1,620)</td>
<td>4.0 (2.3) (92 / 1,259)</td>
<td>5.1 (2.8) (119 / 1,816)</td>
<td>2.5 (2.3) (117 / 1,781)</td>
<td>3.0 (2.7) (52 / 604)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Summer</td>
<td>3.8 (2.7) (479 / 6,884)</td>
<td>3.0 (2.1) (54 / 592)</td>
<td>4.3 (2.8) (88 / 1,227)</td>
<td>4.0 (2.2) (77 / 1,012)</td>
<td>4.8 (2.9) (82 / 966)</td>
<td>2.4 (2.3) (83 / 1,188)</td>
<td>4.0 (2.7) (95 / 1,899)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Autumn</td>
<td>3.6 (2.6) (442 / 6,983)</td>
<td>3.7 (2.4) (61 / 884)</td>
<td>4.4 (2.8) (103 / 1,615)</td>
<td>4.3 (2.5) (69 / 858)</td>
<td>4.8 (2.9) (26 / 314)</td>
<td>2.6 (2.2) (126 / 2,576)</td>
<td>3.8 (2.6) (57 / 736)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Winter</td>
<td>3.9 (2.8) (316 / 4,129)</td>
<td>3.4 (2.2) (50 / 591)</td>
<td>4.0 (3.0) (68 / 741)</td>
<td>3.4 (2.4) (59 / 1,036)</td>
<td>5.5 (3.0) (62 / 804)</td>
<td>2.7 (2.5) (31 / 348)</td>
<td>4.0 (2.5) (46 / 609)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

*a The number of participants and pain reports are non-weighted. Descriptive statistics are weighted.*
significant (B=0.006, p<0.01, ES=0.086) in the lowest three quartiles of daily average temperature (≤16.9 °C) (Figure 1). No associations were found between joint pain and the other daily average weather parameters (Table 3; Model 2).

Table 3: Associations between daily average weather parameters and joint pain intensity in older persons with osteoarthritis.

<table>
<thead>
<tr>
<th>Models</th>
<th>B</th>
<th>95-% Confidence Interval</th>
<th>p-value</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1#</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature (in °C)</td>
<td>-0.006</td>
<td>-0.010 -0.003</td>
<td>&lt;0.001</td>
<td>-0.060</td>
</tr>
<tr>
<td>Precipitation (in mm)</td>
<td>-0.001</td>
<td>-0.003-0.003</td>
<td>0.98</td>
<td>-0.003</td>
</tr>
<tr>
<td>Atmospheric pressure (in hPa)</td>
<td>-0.002</td>
<td>-0.004-0.001</td>
<td>0.14</td>
<td>-0.022</td>
</tr>
<tr>
<td>Relative humidity (in %)</td>
<td>0.004</td>
<td>0.003-0.006</td>
<td>&lt;0.001</td>
<td>0.089</td>
</tr>
<tr>
<td>Wind speed (in m/s)</td>
<td>0.011</td>
<td>-0.004-0.027</td>
<td>0.15</td>
<td>0.025</td>
</tr>
<tr>
<td>Model 2*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature (in °C)</td>
<td>0.002</td>
<td>-0.003-0.007</td>
<td>0.45</td>
<td>0.009</td>
</tr>
<tr>
<td>Precipitation (in mm)</td>
<td>-0.004</td>
<td>-0.009-0.002</td>
<td>0.18</td>
<td>-0.018</td>
</tr>
<tr>
<td>Atmospheric pressure (in hPa)</td>
<td>-0.003</td>
<td>-0.007-0.002</td>
<td>0.21</td>
<td>-0.023</td>
</tr>
<tr>
<td>Relative humidity (in %)</td>
<td>0.004</td>
<td>0.002-0.007</td>
<td>&lt;0.01</td>
<td>0.063</td>
</tr>
<tr>
<td>Wind speed (in m/s)</td>
<td>-0.020</td>
<td>-0.046-0.006</td>
<td>0.13</td>
<td>-0.032</td>
</tr>
<tr>
<td>Model 3#</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precipitation (in mm)</td>
<td>-0.006</td>
<td>-0.012 -0.001</td>
<td>0.03</td>
<td>-0.034</td>
</tr>
<tr>
<td>Relative humidity (in %)</td>
<td>0.005</td>
<td>0.002-0.008</td>
<td>&lt;0.01</td>
<td>0.068</td>
</tr>
<tr>
<td>Wind speed (in m/s)</td>
<td>-0.012</td>
<td>-0.040 -0.017</td>
<td>0.42</td>
<td>-0.027</td>
</tr>
</tbody>
</table>

# Abbreviations: °C: degrees Celsius; B: unstandardized coefficient; hPa: hectopascals; mm: millimetres; m/s: meters per second.

* Model 1: unadjusted model.

* Model 2: adjusted for sex (reference category: men), age, country (reference category: Sweden), depression (reference category: not depressed (Hospital Anxiety Depression Scales-Depression<8) and medication use (reference category: no medication use).

* Model 3 includes all pain-weather associations that reached a p-value below 0.20 in Model 2. In addition, this model includes sex (reference category: men), age, country (reference category: Sweden), depression (reference category: not depressed (Hospital Anxiety Depression Scales-Depression<8) and medication use (reference category: no medication use).
Joint pain intensity and 3-day average weather conditions

After adjustment for all confounders (Table 4; Model 2), the association between joint pain and 3-day average relative humidity (B=0.004, p=0.01, ES=0.054) was significant. In a multivariable model including 3-day average atmospheric pressure, 3-day average relative humidity and all potential confounders (Table 4; Model 3), the association between joint pain and 3-day average relative humidity was statisti-

Table 4: Associations between 3-day average weather parameters and joint pain intensity in older persons with osteoarthritis.*

<table>
<thead>
<tr>
<th>Models</th>
<th>B</th>
<th>95%-Confidence Interval</th>
<th>p-value</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature (in °C)</td>
<td>-0.005</td>
<td>-0.009-0.002</td>
<td>&lt;0.01</td>
<td>-0.051</td>
</tr>
<tr>
<td>Precipitation (in mm)</td>
<td>0.003</td>
<td>-0.002-0.008</td>
<td>0.19</td>
<td>0.016</td>
</tr>
<tr>
<td>Atmospheric pressure (in hPa)</td>
<td>-0.003</td>
<td>-0.005-0.001</td>
<td>0.07</td>
<td>-0.025</td>
</tr>
<tr>
<td>Relative humidity (in %)</td>
<td>0.007</td>
<td>0.005-0.009</td>
<td>&lt;0.001</td>
<td>0.130</td>
</tr>
<tr>
<td>Wind speed (in m/s)</td>
<td>0.014</td>
<td>-0.007-0.034</td>
<td>0.18</td>
<td>0.028</td>
</tr>
<tr>
<td>Model 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature (in °C)</td>
<td>0.003</td>
<td>-0.002-0.008</td>
<td>0.29</td>
<td>0.021</td>
</tr>
<tr>
<td>Precipitation (in mm)</td>
<td>-0.001</td>
<td>-0.009-0.007</td>
<td>0.81</td>
<td>-0.002</td>
</tr>
<tr>
<td>Atmospheric pressure (in hPa)</td>
<td>-0.005</td>
<td>-0.009-0.001</td>
<td>0.05</td>
<td>-0.034</td>
</tr>
<tr>
<td>Relative humidity (in %)</td>
<td>0.004</td>
<td>0.001-0.007</td>
<td>0.01</td>
<td>0.054</td>
</tr>
<tr>
<td>Wind speed (in m/s)</td>
<td>-0.015</td>
<td>-0.046-0.017</td>
<td>0.36</td>
<td>-0.021</td>
</tr>
<tr>
<td>Model 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atmospheric pressure (in hPa)</td>
<td>-0.003</td>
<td>-0.008-0.002</td>
<td>0.29</td>
<td>0.018</td>
</tr>
<tr>
<td>Relative humidity (in %)</td>
<td>0.004</td>
<td>-0.001-0.007</td>
<td>0.02</td>
<td>0.052</td>
</tr>
</tbody>
</table>

* Abbreviations: °C: degrees Celsius; B: unstandardized coefficient; hPA: hectopascals; mm: millimetres; m/s: meters per second.

* Model 1: unadjusted model.

* Model 2: adjusted for sex (reference category: men), age, country (reference category: Sweden), depression (reference category: not depressed (Hospital Anxiety Depression Scales-Depression<8) and medication use (reference category: no medication use).

* Model 3 includes all pain-weather associations that reached a p-value below 0.20 in Model 2. In addition, this model includes sex (reference category: men), age, country (reference category: Sweden), depression (reference category: not depressed (Hospital Anxiety Depression Scales-Depression<8) and medication use (reference category: no medication use).
### Table 5: Associations of day-to-day differences in weather parameters between two consecutive days with joint pain on the second day and day-to-day differences in joint pain intensity in older persons with osteoarthritis.\(^a\)

<table>
<thead>
<tr>
<th>Models</th>
<th>B</th>
<th>95%-Confidence Interval</th>
<th>p-value</th>
<th>Effect size</th>
</tr>
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<tbody>
<tr>
<td><strong>Joint pain on the second day</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Model 1(^b)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature (in °C)</td>
<td>0.003</td>
<td>-0.013-0.018</td>
<td>0.73</td>
<td>-0.006</td>
</tr>
<tr>
<td>Precipitation (in mm)</td>
<td>0.001</td>
<td>-0.004-0.005</td>
<td>0.76</td>
<td>-0.008</td>
</tr>
<tr>
<td>Atmospheric pressure (in hPa)</td>
<td>-0.002</td>
<td>-0.009-0.005</td>
<td>0.56</td>
<td>-0.003</td>
</tr>
<tr>
<td>Relative humidity (in %)</td>
<td>&lt;0.001</td>
<td>-0.004-0.004</td>
<td>0.92</td>
<td>-0.010</td>
</tr>
<tr>
<td>Wind speed (in m/s)</td>
<td>0.002</td>
<td>-0.022-0.027</td>
<td>0.86</td>
<td>0.003</td>
</tr>
<tr>
<td><strong>Model 2(^c)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature (in °C)</td>
<td>-0.001</td>
<td>-0.017-0.015</td>
<td>0.91</td>
<td>-0.002</td>
</tr>
<tr>
<td>Precipitation (in mm)</td>
<td>-0.002</td>
<td>-0.007-0.002</td>
<td>0.29</td>
<td>-0.015</td>
</tr>
<tr>
<td>Atmospheric pressure (in hPa)</td>
<td>0.003</td>
<td>-0.004-0.009</td>
<td>0.44</td>
<td>0.012</td>
</tr>
<tr>
<td>Relative humidity (in %)</td>
<td>0.001</td>
<td>-0.003-0.005</td>
<td>0.59</td>
<td>0.008</td>
</tr>
<tr>
<td>Wind speed (in m/s)</td>
<td>-0.005</td>
<td>-0.034-0.023</td>
<td>0.72</td>
<td>-0.007</td>
</tr>
<tr>
<td><strong>Day-to-day differences in joint pain</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Model 1(^b)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature (in °C)</td>
<td>0.006</td>
<td>-0.003-0.014</td>
<td>0.21</td>
<td>0.001</td>
</tr>
<tr>
<td>Precipitation (in mm)</td>
<td>-0.001</td>
<td>-0.004-0.001</td>
<td>0.32</td>
<td>-0.002</td>
</tr>
<tr>
<td>Atmospheric pressure (in hPa)</td>
<td>-0.001</td>
<td>-0.004-0.003</td>
<td>0.84</td>
<td>0.008</td>
</tr>
<tr>
<td>Relative humidity (in %)</td>
<td>-0.002</td>
<td>-0.004-&lt;0.001</td>
<td>0.08</td>
<td>-0.004</td>
</tr>
<tr>
<td>Wind speed (in m/s)</td>
<td>-0.004</td>
<td>0.018-0.009</td>
<td>0.53</td>
<td>0.002</td>
</tr>
<tr>
<td><strong>Model 2(^c)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature (in °C)</td>
<td>0.004</td>
<td>-0.007-0.016</td>
<td>0.44</td>
<td>0.003</td>
</tr>
<tr>
<td>Precipitation (in mm)</td>
<td>-0.002</td>
<td>-0.005-0.001</td>
<td>0.14</td>
<td>-0.007</td>
</tr>
<tr>
<td>Atmospheric pressure (in hPa)</td>
<td>-0.001</td>
<td>-0.005-0.004</td>
<td>0.79</td>
<td>0.009</td>
</tr>
<tr>
<td>Relative humidity (in %)</td>
<td>-0.002</td>
<td>-0.005-&lt;0.001</td>
<td>0.08</td>
<td>-0.011</td>
</tr>
<tr>
<td>Wind speed (in m/s)</td>
<td>0.001</td>
<td>-0.008-0.002</td>
<td>0.90</td>
<td>0.001</td>
</tr>
<tr>
<td><strong>Model 3(^d)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precipitation (in mm)</td>
<td>-0.001</td>
<td>-0.004-0.002</td>
<td>0.49</td>
<td>-0.002</td>
</tr>
<tr>
<td>Relative humidity (in %)</td>
<td>-0.003</td>
<td>-0.006-&lt;0.001</td>
<td>0.08</td>
<td>0.015</td>
</tr>
</tbody>
</table>
Objective weather conditions, joint pain and osteoarthritis

A significant 3-day average humidity by 3-day average temperature interaction effect on joint pain was found \((p=0.01)\). In the highest quartile of 3-day average temperature \( (>16.5 \degree C)\), no significant association was found between joint pain and 3-day average humidity \((B=0.004, p=0.30, ES=0.048)\), whereas the association between pain and 3-day average humidity was marginally significant \((B=0.004, p=0.07, ES=0.051)\) in the lowest three quartiles of 3-day average temperature \((\leq 16.5 \degree C)\). No associations were found between joint pain and the other 3-day average weather parameters (Table 4). Analyses on the associations of joint pain with 1-day average weather parameters and 2-day average weather conditions showed similar results.

**(Changes in) joint pain intensity and changes in weather conditions**

Changes in weather parameters between two consecutive days were not significantly associated with reported joint pain on the second day (Table 5). Further, changes in weather parameters between 2 consecutive days were not significantly associated with differences in experienced joint pain intensity between these 2 days (Table 5).

**DISCUSSION**

Our study showed that both daily average humidity and 3-day average humidity were positively associated with joint pain. Further, the results suggest that the effect of humidity on pain was stronger in relatively cold weather conditions.
significant associations were found between day-to-day changes in weather parameters and (day-to-day changes in) joint pain.

Humidity and temperature may have an effect on the expansion and contraction of different tissues in the affected joint that may elicit a pain response [3,8]. Further, low temperatures may increase the viscosity of synovial fluid, thereby making joints stiffer and perhaps more sensitive to the pain of mechanical stresses [3,8]. Our study showed that, compared with warm weather conditions, the effect of relative humidity on joint pain in OA is stronger in relatively cold weather conditions. This finding supports the common belief that joint pain in older adults with OA is influenced by damp and cold weather conditions and suggests that a causal relationship exists between joint pain and weather parameters. The pain response might be intensified more in cold weather conditions, because the viscosity of synovial fluid increases, which may lead to stiffer joints and more friction between tissues in the joint. The associations between joint pain and day-to-day changes in weather conditions did not confirm a causal relationship between joint pain and weather conditions. These findings suggest that there might be a momentaneous causal effect of relative humidity on joint pain that is restricted to the same day.

Our study did not replicate the findings of McAlindon et al. [18] that showed that day-to-day changes in atmospheric pressure were associated with joint pain. The inconsistency between results may be explained by differences in study sample. McAlindon et al. focused on pain-weather associations in patients with knee OA, whereas the present study focused on pain-weather associations in older persons with OA in the general population. It has been suggested that the impact of atmospheric pressure on joint pain may depend on specific joint conditions (e.g., effusions, defect of articular cartilage integrity, and presence of subchondral pseudocysts) [7,18]. Sample differences (patients versus general population) imply differences in OA severity, which might explain the inconsistencies between our findings and those of McAlindon et al. [18].

Our findings showed that there were differences between countries in terms of joint pain intensity. Differences in socio-cultural factors, such as attitudes and expressiveness, between countries could explain these differences in pain intensity.
In this study, the analyses were adjusted for country, however this variable do not cover all socio-cultural characteristics of a country.

To our best knowledge, this study is the first large-scale study that examines the relationship between joint pain and weather conditions in older people with OA across Europe. Another strength is the standardized assessment of OA across countries using the ACR classification criteria. Further, the participants were geographically dispersed and participated at different times, generating greater opportunity for weather exposure variability.

Some limitations of this study have to be acknowledged as well. It might be that seasonal weather patterns influence mood in older people with OA which may affect pain perception [3,6,8,30]. In our study, the associations between joint pain and weather conditions were adjusted for depression at baseline and follow-up. Although depression often has a chronic character [31], it would be better to adjust for emotional distress on each specific day of pain assessment.

Our study did not consider variation in weather variables in internal and external environments, nor exposure time in these environments. Persons with OA may often stay inside and may often be able to regulate the indoor environment by using central heating. These factors may attenuate the associations between joint pain and weather parameters in older people with OA. The finding that the effects of weather conditions on joint pain are small is in line with previous studies [9,18]. Small effects of weather conditions on joint pain in older people with OA may seem clinically unimportant, but are likely to make a substantial difference at a population level. It is important to pay attention to the impact of weather conditions on joint pain in older people with OA, because the prevalence of OA in older people is high [32] and this large group might be impaired in their daily functioning due to weather effects on their joint pain.

Future research should take the differences between indoor and outdoor climate into account and should also consider exposure time to both environments and housing conditions [5,33,34]. Future research should also focus on hour-to-hour weather changes, because this could be of more importance to pain than day-to-day changes. More research is needed to measure how weather effects on pain interfere with daily activity performance of older people with OA. Further research
is also needed to examine the possible underlying physiological mechanisms on how meteorological parameters influence joint structures that result in more pain. Many suggestions have been made [6-8], but empirical evidence is lacking.

In conclusion, the association between joint pain and daily average relative humidity suggests that weather conditions affect joint pain of older people with OA. The results show that the influence of daily average humidity on joint pain is stronger when the temperature is low. The associations between day-to-day weather changes and pain do not confirm causation. There might be a momentaneous causal effect of weather conditions on joint pain in OA that is restricted to the same day. Knowledge on the relationship between joint pain in OA and weather conditions may help individuals with OA, physicians and therapists to better understand and manage fluctuations in pain.

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REFERENCES

1. Brooks PM. Impact of osteoarthritis on individuals and society: how much disability? Social con-
2. Jinks C, Jordan K, Croft, P. Measuring the population impact of knee pain and disability with the
Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC). Pain 2002;100:55-64.
APLAR J Rheumatology 2004;7:204-206.
perceived weather sensitivity and joint pain in older people with osteoarthritis in six European
countries: results from the European Project on OSteoArthritis (EPOSA). BMC Musculoskelet
5. De Figueredo ECQ, Figueiredo, GC, Dantas RT. Influence of meteorological elements on osteo-
8. Jamison RN, Anderson KO, Slater MA. Weather changes and pain: perceived influence of local
between weather conditions and clinical symptoms in patients with hip osteoarthritis: a 2-year
12. Strusberg I, Mendelberg RC, Serra HA, Strusberg AM. Influence of weather conditions on rheu-
13. Vergés J, Montell E, Tomás E. Weather conditions can influence rheumatic diseases. Proc West
1986;23:549-554.
16. Hollander JL, Yeostros, SJ. The effect of simultaneous variations of humidity and atmospheric
17. Clarke AM, Nicholl J. Does the weather affect the osteoarthritic patient? Br J Rheumatol
18. McAlindon T, Formica M, Schmid CH, Fletcher J. Changes in atmospheric pressure and ambient
project on osteoarthritis: design of a six-cohort study on the personal and societal burden of
**Data supplement:** Distribution of meteorological exposures in the study sample.\(^{a,b}\)

<table>
<thead>
<tr>
<th>Season</th>
<th>All countries</th>
<th>Germany</th>
<th>Italy</th>
<th>the Netherlands</th>
<th>Spain</th>
<th>Sweden</th>
<th>United Kingdom</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average daily weather conditions</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature (in °C) (Mean (SD)) (Range)</td>
<td>Overall</td>
<td>11.9 (7.6)</td>
<td>7.7 (7.0)</td>
<td>15.1 (7.8)</td>
<td>10.5 (6.2)</td>
<td>18.3 (7.1)</td>
<td>7.9 (6.1)</td>
<td>12.5 (5.2)</td>
</tr>
<tr>
<td></td>
<td>Spring</td>
<td>14.1 (5.9)</td>
<td>10.2 (4.2)</td>
<td>17.7 (4.4)</td>
<td>12.9 (3.7)</td>
<td>19.6 (4.5)</td>
<td>8.8 (4.7)</td>
<td>13.2 (2.5)</td>
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<tr>
<td></td>
<td>Summer</td>
<td>18.3 (5.2)</td>
<td>16.1 (3.2)</td>
<td>24.0 (2.9)</td>
<td>16.3 (2.7)</td>
<td>25.6 (2.7)</td>
<td>14.0 (4.1)</td>
<td>15.9 (2.4)</td>
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<td></td>
<td>Autumn</td>
<td>7.8 (5.8)</td>
<td>4.4 (5.4)</td>
<td>9.8 (5.5)</td>
<td>8.9 (5.0)</td>
<td>15.8 (4.4)</td>
<td>5.7 (5.0)</td>
<td>9.9 (4.1)</td>
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<tr>
<td></td>
<td>Winter</td>
<td>4.1 (5.0)</td>
<td>0.8 (4.4)</td>
<td>6.0 (3.3)</td>
<td>3.5 (4.7)</td>
<td>8.3 (3.1)</td>
<td>-1.4 (4.8)</td>
<td>4.5 (4.4)</td>
</tr>
<tr>
<td>Precipitation (in mm) (Median (IQR))</td>
<td>Overall</td>
<td>0.0 (0.0-1.8)</td>
<td>0.1 (0.0-2.1)</td>
<td>0.0 (0.0-0.5)</td>
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<td>1.3 (0.3-4.8)</td>
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</tr>
<tr>
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<td>Spring</td>
<td>0.0 (0.0-1.6)</td>
<td>0.0 (0.0-1.4)</td>
<td>0.0 (0.0-2.3)</td>
<td>0.0 (0.0-1.5)</td>
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<tr>
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<td>Summer</td>
<td>0.0 (0.0-2.2)</td>
<td>0.2 (0.0-3.6)</td>
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<td>0.3 (0.0-2.3)</td>
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</tr>
<tr>
<td></td>
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<td>0.0 (0.0-1.5)</td>
<td>1.3 (0.0-3.0)</td>
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<tr>
<td>Atmospheric pressure (in hPa) (Mean (SD)) (Range)</td>
<td>Overall</td>
<td>1,015.1 (8.8)</td>
<td>1,016.7 (7.7)</td>
<td>1,016.4 (6.6)</td>
<td>1,016.8 (9.2)</td>
<td>1,016.8 (5.3)</td>
<td>1,010.9 (10.9)</td>
<td>1,015.2 (8.7)</td>
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<tr>
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<td>1,015.0 (7.6)</td>
<td>1,016.3 (7.8)</td>
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<td>1,017.0 (8.4)</td>
<td>1,017.0 (4.5)</td>
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<td>1,015.5 (7.3)</td>
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<tr>
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<td>Summer</td>
<td>1,013.6 (6.0)</td>
<td>1,017.0 (3.9)</td>
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<td>1,013.5 (5.8)</td>
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<td>1,009.8 (7.5)</td>
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<tr>
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<td>Autumn</td>
<td>1,013.7 (10.3)</td>
<td>1,015.9 (8.1)</td>
<td>1,018.4 (6.8)</td>
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<td>1,015.3 (5.2)</td>
<td>1,010.1 (12.1)</td>
<td>1,012.2 (9.5)</td>
</tr>
<tr>
<td></td>
<td>Winter</td>
<td>1,020.4 (9.9)</td>
<td>1,018.0 (9.3)</td>
<td>1,020.0 (7.2)</td>
<td>1,021.9 (9.6)</td>
<td>1,017.4 (7.9)</td>
<td>1,021.7 (16.2)</td>
<td>1,024.0 (9.6)</td>
</tr>
</tbody>
</table>
## Data supplement (continued): Distribution of meteorological exposures in the study sample.

<table>
<thead>
<tr>
<th>Season</th>
<th>All countries</th>
<th>Germany</th>
<th>Italy</th>
<th>the Netherlands</th>
<th>Spain</th>
<th>Sweden</th>
<th>United Kingdom</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Relative humidity (in %) (Median [IQR])</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td>79.0 (67.5-88.0)</td>
<td>86.0 (76.0-93.0)</td>
<td>74.0 (66.0-83.0)</td>
<td>82.0 (74.0-88.0)</td>
<td>48.0 (36.0-63.0)</td>
<td>83.9 (73.7-91.5)</td>
<td>82.0 (75.0-89.0)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Spring</td>
<td>69.0 (58.1-79.0)</td>
<td>73.0 (65.0-85.0)</td>
<td>67.0 (61.0-77.0)</td>
<td>74.0 (66.0-80.0)</td>
<td>47.0 (37.0-56.0)</td>
<td>75.8 (65.3-86.3)</td>
<td>73.0 (68.0-81.0)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Summer</td>
<td>76.0 (68.0-84.0)</td>
<td>79.0 (75.0-85.0)</td>
<td>68.0 (63.0-75.0)</td>
<td>81.0 (75.0-85.0)</td>
<td>32.0 (26.0-37.0)</td>
<td>82.5 (76.0-90.4)</td>
<td>80.0 (74.0-86.0)</td>
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</tr>
<tr>
<td>Autumn</td>
<td>87.0 (79.7-93.0)</td>
<td>93.0 (88.0-97.0)</td>
<td>83.0 (75.0-89.0)</td>
<td>87.0 (82.0-91.0)</td>
<td>62.0 (57.0-71.0)</td>
<td>88.7 (81.6-94.5)</td>
<td>88.0 (82.0-93.0)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Winter</td>
<td>84.3 (73.0-91.0)</td>
<td>89.0 (84.0-94.0)</td>
<td>77.0 (69.0-87.0)</td>
<td>86.0 (80.0-92.0)</td>
<td>65.0 (57.0-79.0)</td>
<td>86.1 (75.4-93.0)</td>
<td>89.0 (86.0-92.0)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>Wind Speed (in m/s) (Median [IQR])</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Overall</td>
<td>1.9 (1.1-3.1)</td>
<td>1.2 (0.9-1.9)</td>
<td>0.8 (0.6-1.1)</td>
<td>3.8 (2.5-5.4)</td>
<td>2.5 (1.9-3.6)</td>
<td>2.3 (1.6-3.3)</td>
<td>1.9 (1.1-2.5)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Spring</td>
<td>1.9 (1.2-3.1)</td>
<td>1.4 (1.1-2.2)</td>
<td>1.1 (0.8-1.1)</td>
<td>3.3 (2.4-4.8)</td>
<td>2.5 (1.9-3.3)</td>
<td>2.3 (1.8-3.1)</td>
<td>1.7 (1.1-2.5)</td>
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<tr>
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<td>1.8 (1.1-2.8)</td>
<td>1.0 (0.9-1.4)</td>
<td>0.8 (0.6-1.1)</td>
<td>3.7 (2.5-5.4)</td>
<td>2.8 (1.9-3.6)</td>
<td>2.4 (1.6-3.3)</td>
<td>1.9 (1.4-2.5)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Autumn</td>
<td>1.7 (0.8-3.0)</td>
<td>1.2 (0.8-1.9)</td>
<td>0.3 (0.3-0.6)</td>
<td>4.3 (2.3-6.3)</td>
<td>1.4 (1.1-2.8)</td>
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<tr>
<td>Winter</td>
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<td>1.3 (0.0-2.6)</td>
<td>0.8 (0.5-1.1)</td>
<td>4.1 (2.9-5.5)</td>
<td>2.8 (1.9-4.7)</td>
<td>2.1 (1.3-3.3)</td>
<td>1.9 (1.1-3.3)</td>
<td>&lt;0.001</td>
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</tbody>
</table>

### 3-Day average weather conditions

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<tr>
<th>Season</th>
<th>All countries</th>
<th>Germany</th>
<th>Italy</th>
<th>the Netherlands</th>
<th>Spain</th>
<th>Sweden</th>
<th>United Kingdom</th>
<th>p-value</th>
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</thead>
<tbody>
<tr>
<td><strong>Temperature (in °C) (Mean [SD]) (Range)</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td>11.9 (7.4)</td>
<td>7.8 (6.8)</td>
<td>15.0 (7.7)</td>
<td>10.5 (6.1)</td>
<td>18.1 (6.9)</td>
<td>8.0 (5.9)</td>
<td>12.6 (4.9)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>(-17.1-31.7)</td>
<td>(-15.4-23.3)</td>
<td>(-3.0-29.0)</td>
<td>(-9.8-24.8)</td>
<td>(-1.7-31.7)</td>
<td>(-17.1-20.3)</td>
<td>(-3.3-21.7)</td>
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</tr>
<tr>
<td>Spring</td>
<td>13.9 (5.7)</td>
<td>10.2 (3.5)</td>
<td>17.4 (4.2)</td>
<td>12.7 (3.6)</td>
<td>19.3 (4.2)</td>
<td>8.4 (4.6)</td>
<td>13.0 (2.1)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>(-1.5-27.0)</td>
<td>(3.2-20.3)</td>
<td>(7.3-27.0)</td>
<td>(3.8-21.2)</td>
<td>(9.0-25.7)</td>
<td>(-1.5-19.3)</td>
<td>(6.0-17.7)</td>
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</tr>
<tr>
<td>Summer</td>
<td>18.3 (5.0)</td>
<td>16.3 (2.6)</td>
<td>24.2 (2.6)</td>
<td>16.4 (2.2)</td>
<td>25.4 (2.3)</td>
<td>14.1 (3.9)</td>
<td>15.9 (1.9)</td>
<td>&lt;0.001</td>
</tr>
<tr>
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<td>(-12.9-31.7)</td>
<td>(10.2-23.3)</td>
<td>(17.7-29.0)</td>
<td>(10.7-24.8)</td>
<td>(19.0-31.7)</td>
<td>(-12.9-20.3)</td>
<td>(11.3-21.7)</td>
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</tr>
<tr>
<td>Autumn</td>
<td>8.1 (5.6)</td>
<td>4.6 (5.1)</td>
<td>10.1 (5.5)</td>
<td>9.2 (4.7)</td>
<td>16.3 (4.5)</td>
<td>6.1 (4.8)</td>
<td>10.2 (3.7)</td>
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<tr>
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<td>(-12.9-23.3)</td>
<td>(-8.3-14.9)</td>
<td>(-0.7-21.0)</td>
<td>(-6.2-18.0)</td>
<td>(1.7-23.3)</td>
<td>(-12.9-15.0)</td>
<td>(1.3-19.0)</td>
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</tr>
<tr>
<td>Winter</td>
<td>4.0 (4.6)</td>
<td>0.7 (3.9)</td>
<td>5.7 (3.0)</td>
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<td>8.3 (2.8)</td>
<td>-1.0 (4.0)</td>
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<td>(-17.1-13.7)</td>
<td>(-15.4-8.0)</td>
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<td>(1.7-13.7)</td>
<td>(-17.1-6.6)</td>
<td>(-3.3-10.0)</td>
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</tbody>
</table>
Data supplement (continued): Distribution of meteorological exposures in the study sample.a,b

<table>
<thead>
<tr>
<th>Season</th>
<th>All countries</th>
<th>Germany</th>
<th>Italy</th>
<th>the Netherlands</th>
<th>Spain</th>
<th>Sweden</th>
<th>United Kingdom</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation (in mm) (Median (IQR))</td>
<td>Overall</td>
<td>0.8 (0.0-3.2)</td>
<td>0.9 (0.1-3.1)</td>
<td>0.3 (0.0-3.8)</td>
<td>0.8 (0.0-3.3)</td>
<td>0.0 (0.0-0.8)</td>
<td>2.2 (0.7-4.6)</td>
<td>0.8 (0.1-2.1)</td>
</tr>
<tr>
<td></td>
<td>Spring</td>
<td>0.6 (0.0-3.0)</td>
<td>0.1 (0.0-2.7)</td>
<td>0.8 (0.0-5.3)</td>
<td>0.6 (0.0-2.3)</td>
<td>0.0 (0.0-0.8)</td>
<td>2.3 (0.8-4.6)</td>
<td>0.5 (0.0-1.8)</td>
</tr>
<tr>
<td></td>
<td>Summer</td>
<td>0.9 (0.0-3.8)</td>
<td>1.7 (0.3-4.9)</td>
<td>0.8 (0.0-3.6)</td>
<td>2.5 (0.4-5.3)</td>
<td>0.0 (0.0-0.0)</td>
<td>2.1 (0.8-5.0)</td>
<td>0.9 (0.1-3.0)</td>
</tr>
<tr>
<td></td>
<td>Autumn</td>
<td>0.9 (0.1-4.0)</td>
<td>0.3 (0.0-2.0)</td>
<td>0.2 (0.1-4.0)</td>
<td>0.6 (0.0-3.9)</td>
<td>0.8 (0.0-3.4)</td>
<td>2.3 (0.6-5.1)</td>
<td>0.9 (0.3-1.8)</td>
</tr>
<tr>
<td></td>
<td>Winter</td>
<td>0.6 (0.0-2.2)</td>
<td>1.7 (0.7-3.0)</td>
<td>0.1 (0.0-1.6)</td>
<td>0.5 (0.0-1.7)</td>
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<td>1.3 (0.6-2.0)</td>
<td>0.5 (0.1-2.0)</td>
</tr>
<tr>
<td>Atmospheric pressure (in hPa) (Mean (SD)) (Range)</td>
<td>Overall</td>
<td>1,015.2 (8.0)</td>
<td>1,016.9 (7.0)</td>
<td>1,016.3 (6.1)</td>
<td>1,016.9 (8.4)</td>
<td>1,016.9 (4.9)</td>
<td>1,010.8 (9.6)</td>
<td>1,015.4 (7.9)</td>
</tr>
<tr>
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<td>Spring</td>
<td>1,015.1 (7.1)</td>
<td>1,017.5 (7.4)</td>
<td>1,015.0 (6.1)</td>
<td>1,017.0 (7.8)</td>
<td>1,017.2 (4.0)</td>
<td>1,010.4 (7.4)</td>
<td>1,015.9 (6.4)</td>
</tr>
<tr>
<td></td>
<td>Summer</td>
<td>1,013.5 (5.2)</td>
<td>1,016.9 (3.2)</td>
<td>1,013.4 (2.5)</td>
<td>1,013.3 (4.9)</td>
<td>1,016.5 (2.6)</td>
<td>1,009.6 (6.5)</td>
<td>1,013.5 (5.5)</td>
</tr>
<tr>
<td></td>
<td>Autumn</td>
<td>1,013.9 (9.2)</td>
<td>1,015.5 (7.3)</td>
<td>1,018.3 (6.4)</td>
<td>1,014.8 (8.8)</td>
<td>1,015.4 (4.3)</td>
<td>1,010.4 (10.7)</td>
<td>1,012.9 (8.4)</td>
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<tr>
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<td>Winter</td>
<td>1,020.3 (9.0)</td>
<td>1,018.1 (8.6)</td>
<td>1,019.7 (6.2)</td>
<td>1,021.8 (8.9)</td>
<td>1,017.4 (7.7)</td>
<td>1,020.1 (13.6)</td>
<td>1,024.2 (8.8)</td>
</tr>
<tr>
<td>Relative humidity (in %) (Median (IQR))</td>
<td>Overall</td>
<td>78.8 (69.0-86.3)</td>
<td>84.7 (77.3-91.0)</td>
<td>73.7 (66.7-81.3)</td>
<td>81.0 (75.3-86.7)</td>
<td>49.0 (36.7-62.0)</td>
<td>83.3 (75.1-89.6)</td>
<td>82.3 (73.3-87.3)</td>
</tr>
<tr>
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<td>Spring</td>
<td>70.0 (60.4-78.3)</td>
<td>72.0 (67.7-80.0)</td>
<td>68.0 (61.7-75.3)</td>
<td>74.7 (67.7-79.0)</td>
<td>46.0 (39.0-57.7)</td>
<td>75.9 (66.8-84.3)</td>
<td>75.3 (69.0-80.3)</td>
</tr>
<tr>
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<td>Summer</td>
<td>77.2 (69.0-82.8)</td>
<td>80.0 (75.7-82.7)</td>
<td>69.0 (64.6-74.7)</td>
<td>80.7 (76.7-83.8)</td>
<td>31.7 (27.3-35.3)</td>
<td>83.3 (77.0-88.8)</td>
<td>79.3 (75.7-83.7)</td>
</tr>
<tr>
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<td>Autumn</td>
<td>86.3 (80.1-91.7)</td>
<td>92.7 (87.8-96.3)</td>
<td>82.3 (76.0-87.7)</td>
<td>86.0 (82.0-90.0)</td>
<td>64.3 (55.7-70.8)</td>
<td>88.2 (82.4-93.0)</td>
<td>87.7 (84.0-90.7)</td>
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<tr>
<td></td>
<td>Winter</td>
<td>84.7 (75.0-84.7)</td>
<td>89.0 (85.7-92.3)</td>
<td>75.7 (68.7-84.7)</td>
<td>87.0 (80.0-91.0)</td>
<td>65.0 (56.0-79.3)</td>
<td>83.7 (75.8-92.0)</td>
<td>89.0 (85.3-91.0)</td>
</tr>
</tbody>
</table>
**Data supplement (continued):** Distribution of meteorological exposures in the study sample.$^{a,b}$

<table>
<thead>
<tr>
<th>Season</th>
<th>All countries (Median [IQR])</th>
<th>Germany (Median [IQR])</th>
<th>Italy (Median [IQR])</th>
<th>the Netherlands (Median [IQR])</th>
<th>Spain (Median [IQR])</th>
<th>Sweden (Median [IQR])</th>
<th>United Kingdom (Median [IQR])</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind Speed (in m/s)</td>
<td>Overall 2.0 (1.2-3.1)</td>
<td>1.3 (1.0-1.8)</td>
<td>0.8 (0.6-1.1)</td>
<td>3.8 (2.8-5.2)</td>
<td>2.8 (2.0-3.5)</td>
<td>2.4 (1.8-3.1)</td>
<td>1.9 (1.4-2.4)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>Spring 2.1 (1.3-3.1)</td>
<td>1.5 (1.2-1.9)</td>
<td>1.0 (0.8-1.2)</td>
<td>3.5 (2.6-4.7)</td>
<td>2.6 (2.0-3.3)</td>
<td>2.4 (1.9-3.0)</td>
<td>1.9 (1.4-2.2)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>Summer 1.9 (1.2-2.8)</td>
<td>1.1 (0.9-1.4)</td>
<td>0.9 (0.7-1.1)</td>
<td>3.8 (2.7-5.2)</td>
<td>2.6 (2.1-3.5)</td>
<td>2.3 (1.8-3.1)</td>
<td>1.8 (1.4-2.3)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>Autumn 1.8 (0.9-2.9)</td>
<td>1.3 (1.0-1.8)</td>
<td>0.5 (0.3-0.7)</td>
<td>4.2 (2.7-5.9)</td>
<td>1.8 (1.1-2.7)</td>
<td>2.4 (1.7-3.3)</td>
<td>2.0 (1.5-2.8)</td>
<td>&lt;0.001</td>
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<tr>
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<td>Winter 2.5 (1.2-3.9)</td>
<td>1.5 (0.6-2.6)</td>
<td>0.8 (0.5-1.1)</td>
<td>4.2 (3.2-5.4)</td>
<td>3.4 (2.1-4.5)</td>
<td>2.2 (1.4-3.2)</td>
<td>2.0 (1.2-3.1)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

$^a$ Abbreviations: °C: degrees Celsius; hPa: hectopascals; mm: millimetres; m/s: meters per second.

$^b$ Descriptive statistics are unweighted. Means and standard deviations (SD) and p-values for country-differences tested with ANOVA are presented for normally distributed continuous variables. Medians and interquartile ranges (IQR) and p-values for country-related differences tested with Kruskal-Wallis test are presented for skewed continuous variables.

$^c$ Average of within participant means over the 3-day period before each pain report.