Original Article

The Influence of the Weather on Affective Experience

An Experience Sampling Study

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Abstract. This study examined the relationship between affective experiences and weather variables using an experience-sampling method. The moderating effects of personality and age on the relationship were also investigated. Two age groups of participants (students and elderly people) recorded their moods when signalled during 14 consecutive days on 7 randomly determined occasions per day. Hourly weather data (temperature, relative humidity, barometric pressure, and luminance) for the same period were obtained from the local weather station. Previously participants had completed the Estonian versions of the Revised NEO Personality Inventory (Kallasmaa, Allik, Realo, & McCrae, 2000) and the Positive and Negative Affect Schedule (Allik & Realo, 1997). Multilevel random coefficient modeling analyses showed that momentary ratings of positive and negative affect were weakly related to temperature, positive affect was also related to sunlight. However, momentary ratings of fatigue showed a distinct tendency for greater incidence of sleepiness in the cold and dark. Age group was one of the most important moderators of the weather-emotion models. The influence of weather on emotions interacted with being outdoors. Personality traits also explained a small portion of variance in the influence of weather on affective states.

Keywords: weather, affective experience, personality

It is common knowledge that people's mood can vary widely from day to day or even from hour to hour. Our mood is influenced by a large number of factors, including external factors as well as biological or sociocultural rhythms (Watson, 2000). One external factor strongly believed to have an impact on mood fluctuations is weather: Most people believe that sunshine makes them happy, whereas rain brings sadness. In reality, the relation of mood to various aspects of weather is far from clear. Previous research has managed to establish weather effects mostly on several features of behavior and cognition–judgments of life-satisfaction (e.g., Schwarz & Clore, 1983), investor behavior and stock market moves (e.g., Hirshleifer & Shumway, 2003; Saunders, 1993), restaurant tipping behavior (e.g., Rind, 1996), helping behavior (e.g., Cunningham, 1979), and cognitive performance (Keller et al., 2005). This effect is often assumed to be mediated by mood – there is indeed empirical evidence that mood influences decision-making.

There is some credible reason to assume that weather affects emotions. At the physiological level there are processes through which this influence could come about. Systolic blood pressure has been found to decrease immediately on more humid days (Schneider et al., 2008). However, in colder temperatures blood pressure is usually higher (Barnett, Sans, Salomaa, Kuulasmaa, & Dobson, 2007), because then catecholamine secretion may occur, which leads to vasoconstriction (Jehn, Appel, Sacks, Miller, & DASH Collaborative Research Group, 2002). But naturally, blood pressure does not reflect emotion directly, nor is it synonymous with emotion. Sunlight can affect feelings through the impact on brain serotonergic activity; the rate of production of serotonin by the brain rises rapidly with increased luminosity (Lambert et al., 2002). Nevertheless, finding any direct impact of weather on affective experience in empirical research has proven to be difficult, not to mention all the controversial results.

In this study we use "affective experience" in a broader sense – in addition to positive and negative affect we have also included fatigue in our analyses, because in most folk taxonomies it features among emotion-related terms (Allik & Realo, 1999; Watson & Clark, 1992). However, unlike Watson, Clark, and Tellegen (1988), we analyze fatigue separately from positive affect (PA) and negative affect (NA). Fatigue is more a physiological state than a prototypical affect. It demands separate attention also because whether fatigue is a marker of low PA (Watson & Tellegen, 1985), or one of the factors of NA (Allik & Realo, 1997) appears to be culture-specific.

Journal of Individual Differences 2011; Vol. 32(2):74–84
DOI: 10.1027/1614-0001/a000037

Previous Research on the Relationship Between Weather Indices and Affective Experience

Negative Affect (NA)

NA is a general dimension of subjective distress and unpleasant engagement that subsumes a variety of aversive mood states, including anger, contempt, disgust, guilt, fear, and nervousness (Watson et al., 1988). Different aspects of negative mood have been related to hours of sunshine (Cunningham, 1979; Denissen, Butalid, Penke, & van Aken, 2008; Howarth & Hoffmann, 1984), temperature (Denissen et al., 2008; Howarth & Hoffmann, 1984), rain (Clark & Watson, 1988), wind power (Denissen et al, 2008); or NA has been entirely unrelated to weather (Sanders & Brizzolara, 1982; Watson, 2000).

Positive Affect (PA)

Evidence by prominent mood researchers (Diener & Emmons, 1985; Watson & Tellegen 1985) has shown that PA is a dimension independent from NA, although the notion of complete independence has been challenged (see Green, Goldman, & Salovey, 1993; Russell, 1979 for alternative approaches). PA reflects the extent to which a person feels enthusiastic, active, and alert (Watson et al., 1988). Aspects of positive mood have been found to be associated with higher barometric pressure (Goldstein, 1972), with high (Howarth & Hoffman, 1984) or low levels of humidity (Goldstein, 1972; Sanders & Brizzolara, 1982), and negatively with rain (Schwartz & Clore, 1983). Keller et al. (2005) found that higher barometric pressure and temperature were related to higher mood, but only as the time spent outside in spring increased. Drawing on this conflicting and somewhat obscure previous research, we expected a small but nevertheless unsystematic effect of weather on PA and NA.

Fatigue

Low activity and sleepiness have been reported to be correlated with a high level of humidity and low barometric pressure (Goldstein, 1972; Howarth & Hoffman, 1984). Additionally, while sunlight has been found to have a significant main effect on tiredness in one study, it might also mediate the effect of precipitation and air pressure on tiredness (Denissen et al., 2008). As there is general agreement in the literature that the human body and health are related to weather (Rusticucci et al., 2002), we expected fatigue to be significantly more related than PA and NA to weather. Nevertheless, while finding a direct and systematic influence of weather on mood has previously been challenging, we also included potential moderators in our study.

The Current Study

We used experience-sampling methodology (ESM), because it allows for a contextual analysis of behavior (Barret & Barret, 2001) and intrapersonal as well as interpersonal comparisons (Hektner, Schmidt, & Csikszentmihalyi, 2007). The hierarchical structure of ESM data, with a varying number of responses nested within participants, is not compatible with the assumptions underlying many traditional statistical procedures (Hektner et al., 2007), because relationships at the between- and within-subject levels are, to some degree, independent (Nezlek, 2001). In this study, we used a multilevel random coefficient modeling (MRCM) procedure, more specifically a hierarchical linear modeling (HLM) technique, which is considered to provide the most accurate account of multilevel data structures (Nezlek, 2001).

The main goal of this study was to investigate if affective experience was affected by weather. Additional aims, relying on literature, were to find out whether elderly people were more sensitive to weather than young, and if personality moderated the effect of weather on affect. We also wanted to test whether any relationships found between weather and momentary affect could be moderated by more permanent mood, or the general positive and negative affect experienced by the participants during the 2 weeks of the experiment. Based on the literature cited above, we chose to examine the effect of temperature, relative humidity, barometric pressure, and sunlight on affective experience, as these weather indicators have been shown to be the most promising. Finally, we also analyzed whether the effect of weather was greater when participants were outside at the time of the measurement. Unfortunately our study was limited by being done during mostly winter months.

Method

Participants

The sample consisted of 110 participants (70 women and 40 men) with age ranging from 19 to 84 years. Participants received EEK 520 (about EUR 33) for taking part in the study. Data were collected in Tartu, Estonia (58 °23’ northern latitude). The high latitude means that the rotation of seasons and the interchange of light and dark periods in the year are well-pronounced in Estonia – the maximum length of a summer day is about 18.5 hours, whereas during the shortest day in winter, the sun appears for a mere 6 hours. The average annual temperature in Estonia is 5.4 °C.

The first group of participants (n = 55; 42 women and 13 men) was recruited from two day centers in Tartu that provide activities (exercises, dancing, singing, etc.) and lunches for elderly people. The age of participants in this group ranged from 61 to 84 years with a mean age of 68.2

(*SD* = 5.5). The majority (73%) of the respondents were retired; about one third (36%) of the elderly respondents had higher education. Data were collected between September 30 and December 15, 2004.

The second group of participants (*n* = 55; 28 women and 27 men) was made up of undergraduate students from the University of Tartu and was recruited via advertisements placed in university academic buildings and residence halls. Students came from different faculties of the university and those majoring in psychology were not eligible to participate. The mean age of students was 21.3 (*SD* = 1.0), ranging from 19 to 23 years. Data were collected between February 23 and April 20, 2005.

Procedure

Participants visited the laboratory three times during the course of the study. During the introductory session, participants were assigned a palm-top computer *(Handspring Visor Neo)* and received instructions regarding the experience-sampling portion of the study. The experience sampling experiment was programmed and conducted with iESP software (http://seattleweb.intel-research.net/projects/ESM/iESP.html), which was built at Intel Research Seattle Lab from existing software called ESP (the Experience Sampling Program), developed by Dr. Lisa Feldman Barrett and Daniel Barrett (http://www.experience-sampling.org/esp/). Participants were told that they would be beeped randomly 7 times per day (from 8:00 am to 8:00 pm) for a 14-day period. They were told to answer the questions as quickly as possible, without compromising accuracy. Participants went through a practice trial of the experiment on the palm-top computer and received a written set of instructions about the experience-sampling procedure before leaving the laboratory. In addition, participants completed the Estonian version (Allik & Realo, 1997) of the Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988) asking the extent to which they had experienced different emotions during the previous 2 weeks. Finally, they were given a copy of the Estonian version (Kallasmaa, Allik, Realo, & McCrae, 2000) of the Revised NEO Personality Inventory (NEO PI-R; Costa & McCrae, 1992) that they were asked to complete at home and return at the beginning of the second session.

A week later, participants visited the laboratory for the second time. During this short session, an experimenter uploaded their data to a host personal computer. The participants were given immediate feedback regarding their level of experiment completion (i.e., response rate) during the first week of the study. They also returned the completed NEO PI-R questionnaires. The third and final session took place after the experiment had ended. Participants returned their palm-top computers to the laboratory where the experimenters had explained the purpose of the study. Participants were also given the opportunity to obtain feedback about the experiment. Finally, they were asked to complete the Estonian version of PANAS (Allik & Realo, 1997) for a second time, as well as a few other short questionnaires.

Experience-Sampling Ratings of Experienced Emotion

For each measurement, participants were asked to indicate on a 4-point Likert scale (1 – *not at all*, 4 – *to a large extent*) the extent to which each of seven basic emotions (anger, happy, contempt, disgust, fear, sad, and surprise) as well as five other emotion-related adjectives (disappointed, in physical pain, irritated, sleepy, and tired) described their current emotional and physiological state as quickly and accurately as possible by touching appropriate answers on the screen of the palm-top computer. Affect terms were presented in the same order at each trial. Both ratings of experience and response latencies were recorded.

In addition, participants were asked to indicate their whereabouts when the signal occurred by choosing one of the 17 alternatives (at home; visiting someone; on the street; in a car; in a public transport vehicle; at work; in a shop; in a restaurant; at a beauty parlor; in nature (including, in a garden); at a club or activity center; in a classroom; in a library; in a sports facility; in a student corporation; at a doctor's office; at some other place) on the screen of the palm-top computer. For later analyses, the variable was recoded to indicate whether the respondents were outdoors ("on the street" or "in nature"), in transit ("in a car" or "in a public transport vehicle"), or inside (all other options, except for "at some other place").

There were 10,667 measurement trials across all participants. For various reasons (including technical), the number of measurement trials per participant varied from 49 (on one occasion the first part of the database was lost because of a palm-top computer crash on the fifth day of the experiment) to 99 trials, with an average of 97 measurement trials per participant. The majority of participants (81.2%) had 98 trials. The response rate was within the normal range for such experience-sampling studies. Across all participants, the number of reports was 8,835 (82.8%) of 10,667 possible. The average response rate was very similar for the two groups of participants (83.0% and 82.7% for elderly people and students, respectively). The number of usable trials per participant ranged from 37 (of 49 possible) to 95 (of 98 possible) (*M* = 80.32, *SD* = 10.60).

Weather Data

We obtained data on temperature (°C), relative humidity (%), and barometric pressure (hPa), from the University of Tartu Institute of Environmental Physics weather station (http://meteo.physic.ut.ee/). The fully automated weather

Table 1. Descriptive statistics of the four weather indicators across data collection periods

	Elderly (September 15 – December 20, 2004)				Students (February 23 – April 20, 2005)			
Weather indicators	*M*	Min	Max	*SD*	*M*	Min	Max	*SD*
Temperature	4.4	–7.9	17.2	4.8	0.9	–14.8	17.7	7.5
Humidity	87.8	49.8	100.0	11.1	68.7	33.7	100.0	15.6
Barometric pressure	1008.2	979.4	1028.6	10.2	1005.2	985.7	1028.7	7.3
Luminance	6896.7	245.0	60358.0	9199.3	26203.4	186.0	78153.0	19965.3

Notes. Temperature = temperature in degrees (Celsius); humidity = relative humidity (%); barometric pressure (hPa); luminance (lx).

station is located on the roof of the Physics Department at the University of Tartu (58 °23' N, 26 °43' E). The sensors measure weather parameters every 10 s, but in our study we used the average data per hour.

In total, data on temperature and barometric pressure were available for 10,655 measurement trials. Information about relative humidity was available for 8,477 trials. The average temperature for the first data collection period (autumn/early winter; September 30 – December 15, 2004) was 4.39 °C (SD = 4.82), ranging from 17.2 °C to –7.9 °C. The average temperature of the second data collection period (winter/early spring; February 23 – April 20, 2005) was 0.88 °C, ranging from 17.7 °C to –14.8 °C. The average temperature in Estonia is normally 3.4 °C from September to December and –1.4 °C from February to April. The descriptive statistics of the three other weather indicators are given in Table 1. For the HLM analysis, Celsius temperature readings were converted to the Kelvin temperature scale (with a conversion value of 273.15). Kelvin is one of the Systeme Internationale (SI) units and the Kelvin scale is widely used in scientific measurements. Its advantage over Celsius is that it has an absolute zero point and, therefore, only positive values.

The first period of data collection (autumn/early winter) had a higher level of barometric pressure, $F(1, 10653) = 311.00$, and was also significantly warmer, $F(1, 10653) = 817.53$, and more humid $F(1, 8475) = 3836.73$, than the second data collection period in late winter/early spring (all differences significant at $p < .001$). The three weather indicators were all significantly related to each other (except for barometric pressure and luminance), correlations ranging from $r = –.03$ ($p < .01$) between temperature and barometric pressure, to $r = –.10$ ($p < .001$) between relative humidity and temperature, and $r = –.51$ ($p < .001$) between relative humidity and luminance. Because of the large number of measurement trials, even relatively minor correlations were statistically significant.

Across all measurement trials, our participants spent 85.35% of their time indoors (elderly people, 84.79%; students, 85.91%, respectively), 4.12% of their time in transit (elderly people, 4.36%; students, 3.88%), and only 8.25% of their time outdoors (elderly people, 10.34%; students, 6.14%, respectively). In the case of 2.3% of the measurement trials, respondents were at some other place (elderly people, 0.52%; students, 4.06%, respectively).

Possible Moderators of Affect-Weather Relationships

Age

Previous data about the importance of age in weather-emotion relationships are ambiguous. According to one study (von Mackensen et al., 2005) people over 60 were subjectively considerably more sensitive to weather than younger people. However, another study from the same year (DeCraen et al., 2005) showed no evidence of an association between time of the year, daylight, sunlight, or rain and emotions (depressive symptoms) in the elderly. With the intent of clarifying the possible mediating role of a person's age between affective experience and weather, we included age as a moderator in our analyses.

Basic Personality Dispositions

Another source of individual differences that might influence the relationship between mood and weather is personality. This addition is important as affective experience and personality have been found to be systematically related, especially PA with Extraversion and NA with Neuroticism (Allik & Realo, 1997; Costa & McCrae, 1980). There is also evidence in the literature about the relationship between NA and Agreeableness (Costa & McCrae, 1991; Martin et al., 1999; Watson, 2000). In addition, research has shown that individual differences in Openness can be related to seasonal variations in mood (for an overview see Murray, Allen, Rawlings, & Trinder, 2002; Williams, 1993). While personality is an important, although a somewhat incoherent factor, we assumed that personality traits moderate the possible relationship between affect and weather.

Analytic Strategy

We were interested in the impact of weather variables (i.e., temperature, barometric pressure, humidity, and luminance) on the affective and physiological states of the participants and in the mediating role of personality dispositions and age on this relationship. The present data had a hierarchically nested structure, with affect and different weather variables nested within persons. Three dependent variables – PA, NA, and Fatigue – were analyzed separately.

The intercepts and slopes of linear regressions of NA, PA, and Fatigue were predicted by weather indicators at Level 1 (measurement trials) of analysis and computed for each observation using the 6th version of the HLM program (Raudenbush & Bryk, 2002). HLM allows testing the relationship between affective and physiological states and weather variables (Level 1) while taking into account whether these relationships were moderated by personality traits, general affectivity or age (Level 2).

We started with totally unconditional (null) models before running other models as these models describe how much of the total variance of an outcome variable is at each level (Nezlek, 2001). The unconditional models of NA for Level 1 and Level 2, respectively, were as follows:

Level 1: $NA_{ij} = \pi_{0j} + e_{ij}$; Level 2: $\pi_{0j} = \beta_{00} + r_{0j}$

In the Level 1 model, NA_{ij} is the amount of NA at measurement trial *i* for person *j*. π_{0j} is a random coefficient representing the mean of NA for person *j* (across the *i* observations/signals for which the person *j* provided data); e_{ij} represents the error associated with each measurement of NA, and the variance of e_{ij} constitutes the measurement trial level residual variance. In the Level 2 model, β_{00} represents the grand mean of the person-level means (π_{0j}s) from the measurement level model, r_{0j} represents the error of π_{0j} and the variance of r_{0j} constitutes the Level 2 residual variance. The unconditional models of other affective states (i.e., PA and Fatigue) are identical, except for the outcome part.

On the basis of variability estimates, an intraclass correlation coefficient can be calculated. This coefficient measures the proportion of variance in the outcome that is between Level-2 units, which is between individuals in our analyses (Raudenbush & Bryk, 2002). The proportion of within-person to total variance was 69.9%, 74.2%, and 65.0% for NA, PA, and Fatigue, respectively. This shows that only a little less than one third of the variation of affective experiences is a result of individual differences. Next, we added weather indicators as predictors to Level 1 to find out whether they would have the effect of reducing the large within-person variance.

Subsequently, predictors of the person-specific intercept and slopes for positive and negative emotions and fatigue were added to Level 2. These were personality traits, general NA (GNA), and general PA (GPA)[1], and age. The Level 1 model remained unchanged with the exception of the omitted relative humidity. With the following Level 2 models, we estimated the possible moderating effect of personality and age on affective experience and weather relationships:

$\pi_{0j} = \beta_{00} + \beta_{01}$(Personality traits/Age/GNA, GPA) + r_{0j}

$\pi_{1j} = \beta_{10} + \beta_{11}$(Personality traits/Age/GNA, GPA) + r_{1j}.

In this model, to the between-person level Neuroticism, Extraversion, Openness to Experience, Agreeableness, Conscientiousness, or Age Group was added to both the intercept and slope functions. Note that the coefficients π_0 and π_1 were again modeled as random effects; each had a random error term (r_{0j} and r_{1j}). Personality dimensions, GNA, GPA, and age were entered separately. While examining the change in variance component of Level 2 (random effects), the estimated proportion of variance between persons explained by the model with personality traits, general affectivity, or age was calculated (see Raudenbush & Bryk, 2002, p. 74 for the formula).

Results

Measurement of Emotions and Fatigue

A principal component analysis of the 12 adjectives describing mood and related physiological states resulted in a three-factor solution, which explained 49.48% of the total variance. The factor structure was very simple with all items except one ("in physical pain") loading above .40 on one factor only. On the basis of the three-factor solution of the 12 items, we developed three subscales for measuring Negative Affect (NA; anger, contempt, disappointed, disgust, fear, irritated, and sad), Positive Affect (PA; happy and surprised), and Fatigue (sleepy and tired). The Cronbach's α for the NA subscale was .76. The correlations between the two adjectives were $r = .21$ and $r = .64$ in the

Table 2. Descriptive statistics of mood scales

	Elderly (n = 55)			Students (n = 55)					
Affective state	*M*	*N*	*SD*	*M*	*N*	*SD*	*F*	*df*	*p*
NA	1.17	4,430	0.28	1.26	4,386	0.37	138.29	1,8814	< .001
PA	1.75	4,430	0.58	1.66	4,391	0.63	46.35	1,8819	< .001
Fatigue	1.42	4,430	0.53	1.99	4,386	0.91	1299.42	1,8814	< .001

Notes. NA = negative affect (anger, contempt, disappointed, disgust, fear, irritated, sad); PA = positive affect (happy, surprised); fatigue (sleepy, tired); *N* = Number of valid measurement trials.

[1] The impact of GNA and GPA was analyzed according to the PANAS, which the participants filled in at the end of the experiment (i.e., the second time during the study). This means that they evaluated their mood for the previous 2 weeks, which exactly corresponded to the period of their participation in the experience sampling experiment.

Table 3. Relations between NA, PA, fatigue, and weather. Fixed effects with robust standard errors

	NA		PA		Fatigue	
	Coefficient	T-ratio	Coefficient	T-ratio	Coefficient	T-ratio
Intercept	1.214	67.43**	1.692	55.36**	1.68	34.54**
Temperature	0.002	2.23*	0.006	2.41*	–0.012	–3.36**
Humidity	–0.014	–2.54*	–0.026	–2.37*	0.018	*ns*
Barometric pressure	–0.0005	*ns*	0.007	*ns*	0.008	*ns*
Luminance	0.002	*ns*	0.028	2.62*	–0.103	–7.86**

Notes. NA = negative affect (anger, contempt, disappointed, disgust, fear, irritated, sad); PA = positive affect (happy, surprised); Fatigue (sleepy, tired). $^{**}p < .001$, $^{*}p < .05$.

PA and Fatigue subscales, respectively (both correlations were significant at $p < .001$). The intercorrelations between the three subscales (defined as the sum scores of the items divided by the number of items in each subscale) were small: between NA and PA, $r = -.01$ (*ns*; i.e., $p > .05$); for NA and Fatigue, $r = .21$ ($p < .001$); and, for PA and Fatigue, $r = -.11$ ($p < .001$).

Table 2 shows the mean scores of the three subscales across the two groups of respondents. During the 2 weeks of the experiment, elderly people experienced significantly more positive and less negative emotions than students. Quite surprisingly, elderly people were also less tired than students.

Negative Affect (NA) and Weather Variables

First, we evaluated the independent contributions of the four weather variables to the frequency of NA. For this purpose, a multilevel model predicting NA on the basis of the weather conditions at Level 1 (measurement level), allowing for random (person-specific) intercept and slope values at Level 2 (person level), was estimated ($NA_{ij} = \pi_{0j} + \pi_{1j}$(temperature) + π_{2j}(barometric pressure) + π_{3j}(humidity) + π_{4j}(luminance) + e_{ij}). In other words, these two equations refer to the prediction of the slopes indicating the association between affective states, on the one hand, and weather variables, on the other. Here and below, all weather variables were added to the models grand mean centered (see Nezlek, 2001; Raudenbush & Bryk, 2002; Richter, 2006; for discussion about centering). Only temperature and humidity contributed independently to the frequency of NA: Temperature was positively and humidity negatively related to NA. As can be seen from the coefficients (see Table 3), the contribution of weather variables to NA was relatively low.

After adding weather variables to the unconditional NA model, we estimated the proportion of explained variance within persons (see Raudenbush & Bryk, 2002, p. 79 for the formula). We found that temperature, barometric pressure, and luminance explained about 2.2% of within-person variance. With each unit increase in temperature, NA rose 0.002 units, as shown in Table 3[2]. After adding the humidity variable to the model, the estimated reduction in variance was negative (and, therefore, could be considered as a potential artifact). It was also the case for PA and Fatigue; hence we omitted humidity from further analyses. Luminance and barometric pressure were not significantly related to NA.

Positive Affect (PA) and Weather Data

Adding absolute temperature, barometric pressure, and luminance as predictors of PA reduced the within-person variance by 5%. Table 3 shows that with each unit rise in absolute temperature, PA increased 0.006 units[3]. Changes in barometric pressure had no significant effect on PA. However, the weather variable that had the greatest impact on PA was luminance ($\pi_1 = 0.028$, $p < .05$).

Fatigue and Weather Data

Temperature, barometric pressure, and luminance reduced the within-person variance of Fatigue by 6.5%. One unit increase in temperature reduced the Fatigue score by 0.012 units. Barometric pressure did not account for any significant changes in Fatigue. Again, luminance was in greatest part related to Fatigue, reducing its score by 0.103 units.

Personality, General Negative and Positive Affect, and Age as Moderators

Thereafter we examined possible moderators of weather-emotion relationships at Level 2. The results of random effects are summarized in the form of percentages in Table 4.

For NA, the results indicate that an additional 4.2% of the true between-person variance, which is predicted by

[2] We also ran analysis for the specific emotion terms "sadness" and "happiness." The sadness-temperature slope was somewhat higher (compared to NA), that is 0.007 units ($p = .002$).

[3] The happiness-temperature slope was 0.010 units ($p = .01$), which is also slightly higher than for PA.

Table 4. Proportion of explained additional variance[1] after including moderators at level 2 (%)

Level 2 moderators	NA[2]	PA[2]	Fatigue[2]
Neuroticism	4.2	0.0	2.1
Extraversion	0.0	0.5	6.8
Openness	1.2	0.0	6.6
Agreeableness	2.5	0.0	10.1
Conscientiousness	2.5	1.6	6.4
Age group	2.5	0.2	20.9
General negative affect (GNA)	0.0	0.0	0.0
General positive affect (GPA)	0.0	0.0	0.0

Notes. NA = negative affect (anger, contempt, disappointed, disgust, fear, irritated, sad); PA = positive affect (happy, surprised); Fatigue (sleepy, tired). [1]The proportion of explained variance refers to between-person differences in slopes, not variance in general. [2]Affective states predicted by temperature, barometric pressure and luminance at Level 1.

three weather variables (i.e., temperature, barometric pressure, and luminance), was accounted for by Neuroticism. There was a tendency for the relationship between NA and barometric pressure to be moderated by Conscientiousness ($\beta_{11} = 0.0002$, $p = .065$), although this effect did not reach statistical significance. The only significant ($p < .05$) moderator of NA-weather models is, however, the age group – that dichotomous variable moderated the NA-Luminance relationship ($\beta_{11} = 0.023$). Adding neither GNA nor GPA to NA-weather model reduced any remaining between-person variance.

In the case of PA, Conscientiousness was the most important moderator of the relationship with weather; it reduced the between-subject variance by 1.6%. The aforementioned model also had the only near-significant slope coefficient ($\beta_{11} = -0.0013$, $p = .06$) mediating PA-Temperature relationships. However, the PA-Luminance slope was statistically significantly moderated by age group ($\beta_{11} = 0.053$, $p < .05$). However, adding Age Group to PA-weather model decreased the remaining between-person variance by only 0.2%. Neither GPA nor GNA had a significant impact on the relationship between PA and weather.

From the three affective states examined, Fatigue-Weather relationships were moderated in the greatest proportion by personality traits and age when compared with the other two affective states. For example, 20.9% and 10.1% of between-person variance was accounted for by participants' age group, and Agreeableness scores, respectively. In the case of fixed effects, it was found that only the Fatigue-Temperature slope had significant moderators at the between-subject level – these were Openness ($\beta_{11} = -0.004$, $p < .001$), Agreeableness ($\beta_{11} = 0.003$, $p < .05$), and Conscientiousness ($\beta_{11} = 0.003$, $p < .001$). But the strongest moderator of the relationship between Fatigue and temperature was age ($\beta_{11} = 0.209$, $p < .001$), showing that people in the elderly group were significantly more affected by temperature than young people.

Role of the Environment: Time Spent Outdoors

To find out whether the effect of weather on affective experience would be greater when the participants are outside at the time of the signal, we computed a series of general linear regression models at the within-person level. Affective experience (NA, PA, or Fatigue) was treated as a dependent variable, weather indicators (temperature, barometric pressure, or luminance) as continuous predictors; and location (outside or inside/elsewhere) as a categorical factor.

It can be seen in Table 5 that the interaction between temperature outside and participants' whereabouts during the signal was statistically significant only for NA. Barometric pressure had no main effect on affective experience, but still interacted with being outdoors – in the case of PA and Fatigue. The interaction of luminance and participants' location was significant only in the case of PA, although main effects of luminance were also significant for NA and fatigue (see Table 5).

Table 5. General linear models of affective experience: Interactions between location and weather

	Beta coefficients (β)		
	NA	PA	Fatigue
Location × Temperature	1.91**	*ns*	*ns*
Location × Barometric pressure	*ns*	2.24*	–2.63*
Location × Luminance	*ns*	–0.13**	*ns*

Note. **$p < .001$; *$p < .05$; NA = negative affect (anger, contempt, disappointed, disgust, fear, irritated, sad); PA = positive affect (happy, surprised); Fatigue (sleepy, tired). Participants' location at the time of the signal was coded 1 for outdoors and 0 for anywhere else.

Discussion

This study examined the relationship between affective experience and weather variables using an experience-sampling method. There have been only a few solid studies about this topic with similar methodology. First, David Watson (Clark & Watson, 1988; Watson, 2000), who has conducted the most reliable research to date, showed that the effect of weather on daily mood fluctuations is almost nonexistent, and that mood is related neither substantially nor systematically to any weather indicator. Only sunshine was related to both negative and positive affect in his longitudinal data – it acted primarily on the intensity of the experienced affect. Second, Denissen and colleagues (2008) more recently conducted an online diary study, also linked to weather station data, and analyzed by means of multilevel analysis. Results revealed main effects of some weather variables on NA and tiredness, although weather explained only a small proportion of mood variance. Moreover, they found that individual differences in weather sensitivity could not be explained by the Five Factor Model personality traits, gender, or age. However, they failed to consider time spent outside by participants – although evidence from another outstanding study by Keller and colleagues implies that being outdoors is a causal factor that increases the weather-mood relationship (Keller et al., 2005).

The present study elaborated upon the research of Watson (2000) in several aspects. First, our study took place at a high northern latitude (i.e., 58 °23'), one which allows for substantial variation between the four seasons. Second, our sample consisted of two distinct age groups, enabling us to test the effect of age. Third, the trial period was relatively long, permitting reliable within-subject analyses. Fourth, we measured affect several times a day and linked this data on an hourly basis with weather data, obtained from the local weather station. Fifth, we studied the moderating role of personality traits. Additionally, we took into account the time that participants spent outside.

In the current study we used HLM to model participants' changes in affective states over different weather conditions; our data was gathered by means of ESM. We also examined possible individual differences in these affective changes. Several important findings emerged, suggesting that a small influence of weather on mood exists, but that this relationship is far from straightforward. Most of the relationships were microscopic, nonetheless, the effect became statistically significant because of the large sample size. Luminance had the most noticeable influence on affective experience.

The Impact of Weather on Mood

An increase in temperature was, in our study, related to a small rise in both negative and positive affect. In other words, in warmer temperatures individuals' feelings tended to be more intense. This is consistent with the findings of Denissen and colleagues (2008) who reported a positive main effect of temperature on negative affect. Watson (2000) observed that sunshine had a similar intensifying effect on feelings. In our data, sunlight (luminance) considerably intensified PA, but was unrelated to NA. However, most of the effects that we found were extremely small. Emotional experience is, indeed, far more complex than feelings brought on by the weather. Interpersonal tensions, work overload, sleep derivation, social and physical activities, not to mention spontaneous neurochemical processes in the brain, influence subjective positive and negative emotions (Kahneman, Krueger, Schkade, Schwarz, & Stone, 2004).

However, weather had a significantly greater impact on the physiologically-based feelings of sleepiness and tiredness. This represents one of the most important outcomes of our study. Specifically, as temperature or luminance rose, the scores of Fatigue decreased. This result is inconsistent with the popular belief that warmth makes people sleepy, as well as with the finding of Howarth and Hoffman (1984), who reported sleepiness to be related to higher temperatures. Our results are partly consistent with the results of Denissen et al. (2008) as well – they found that sunlight prevented tiredness.

This study was conducted in a relatively cold region in a period of cold weather, with an average temperature in the range of 1–4 °C. For warm-blooded species like humans, there is a comfort optimum, and deviation toward colder or hotter than optimum can cause physiological and psychological stress. This is related to the idea of the Scholander curve (Scholander, Hock, Walters, Johnson, & Irving, 1950): In a moderate temperature range, metabolic rate is constant at a low level. At lower or higher temperatures, metabolic rates increase, reflecting increased demands for active thermoregulation. For humans 22 °C, or about 72 °F, is the approximate midpoint of the range of comfortable temperatures (see Van de Vliert, 2007). Thus, in our study the increase in temperature may mean movement toward the thermal optimum accompanied by decrease in sleepiness and fatigue. However, we have to take into account the fact that in our study people spent most of their time indoors and at many times they were not exposed to the 1–4 °C temperatures.

We assume that the effect of weather on mood is not linear. Although we found that an increase in temperature somewhat decreased the feelings of fatigue in spring and autumn, people's response to extremely hot weather in midsummer could result in exactly the opposite. At the beginning of spring and at the end of autumn, warmth is longed-for and novel, while in summer extreme heat produces an unwanted decline in outside activities, which, in turn, probably brings lethargy. Likewise, although we found no systematic effect of barometric pressure and humidity on mood, we do not contend that in other time periods or different seasons the outcome would have been the same.

There is one more important factor that deserves to be pointed out. Most studies have failed to consider the location of the participant at the time of measurement; although it is known that time spent outdoors enhances the influence of weather, at least during spring (Keller et al., 2005). The design of our study enabled us to know the whereabouts of the participants for every time they completed the palmtop questionnaire about their momentary feelings. We found that it is important to take into account the whereabouts of the participants when examining the effect of weather on mood, although unlike Keller and his colleagues we conducted our study mostly during the cold winter months. Being outdoors significantly interacted with temperature in predicting NA; it also interacted with sunlight while predicting PA. One plausible mediator could be here physical activity. According to Watson (2000), physically active events are associated with high levels of positive mood, and being outdoors usually demands greater physical activeness than spending time inside. And as we know, physical activity in open-air settings is related to meteorological conditions (Suminski, Poston, Market, Hyder, & Sara, 2008).

The Effect of Age on the Relationship between Weather and Mood

Although we found that most of the variance in affective states was within persons, we still could detect some important individual differences. In the case of Fatigue, age accounted for almost a quarter of the remaining variance between persons. As described above, we found for the whole sample that with increasing temperature the scores of Fatigue decreased. However, taking age group into account showed us that this effect was reversed in the case of the elderly group. They felt more tired when the temperature was rising. Age also moderated the influence of luminance on NA. Therefore, our data suggest that younger and older people tended to be somewhat differently affected by sunlight as well. This is consistent with previous research showing that older people are more sensitive to weather, at least subjectively (Von Mackensen et al., 2005).

The Effect of Personality Traits on the Relationship between Weather and Mood

As expected, in the NA-Weather relationship with Neuroticism explained the greatest part of the residual between-person variance. This result is consistent with many reports relating NA to Neuroticism (Allik & Realo, 1997; Costa & McCrae, 1980; Watson, 2000). We found that people who generally felt more negative feelings during the study also tended to be more influenced by warmer temperature. However, individual differences concerning PA–Weather relationships were very small in this study. This may be accounted for the fact that PA also had the smallest between-person variance to begin with.

Once again, Fatigue differed from the other two affective states in its considerable individual differences in participant response to weather conditions. Extraversion, Openness to Experience, Agreeableness, and Conscientiousness all explained as much as 6 to 10% of the residual between-person variance in feeling fatigued under the influence of weather. Further, we discovered that with increasing Openness, feelings of fatigue were slightly less susceptible to the influence of temperature. This is inconsistent to previous findings, where people high in Openness, for example patients with SAD, have been reported to be more susceptible to their environment (Enns et al., 2006). However, being high in Openness certainly does not imply that people are susceptible to every kind of mood affliction, such as SAD.

Limitations and Summary

The greatest limitation of our study is the inability to differentiate between the effects of season and the participant age. For practical reasons, the current study was conducted in two waves; the first was carried out in late autumn and the other in early spring. In spring, the sample consisted of students, and in autumn, of elderly people. Hence, our data was obtained mostly during colder winter months, and additionally, it did not allow us to determine if different age groups were similar in their reactions to weather conditions in spring and in autumn, or if the effects of age and season interacted. Nevertheless, we believe that the relationship between weather and mood would stay modest, regardless of the level of sophistication of the research methodology or design used.

To sum up, we found that weather has a relatively small impact on people's feelings, but different types of affective states change in diverse patterns in response to weather conditions. We assume that, as far as prototypical emotions are concerned, our study does lend support to Watson's (2000) contention. Namely, it seems that, despite the solid belief held in folklore and popular culture, the association between emotion and weather is merely an illusory correlation. This urban myth probably has its roots deep in the past when people's lives depended much more on the forces of nature.

Acknowledgments

This project was supported by a grant from the Estonian Science Foundation (#5384) and a Primus grant (3-8.2/60) from the European Social Fund to Anu Realo and by grants to Jüri Allik from the Estonian Ministry of Education and Science (SF0182585s03 and SF0180029s08). Portions of this article were presented at the 14th European Conference on Personality, July 2008, Tartu, Estonia. We are grateful to Gerli Laine and Tiit Mogom for their assistance in gathering the data. We also thank Talvi Kallasmaa, Iven Van Mechelen, and Kätlin Konstabel for their input during the early stages of this project and Delaney Michael Skerrett for his helpful comments on earlier drafts of this article.

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Accepted for publication: August 22, 2010

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