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Cold season air temperature as predictor of psychological well-being and mental health

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The effects of climate change on mental health are far from being fully understood. The aim of this study was to investigate potentially beneficial effects of warm ambient temperatures on psychological well-being and mental health during cold seasons. High-resolution data from 156 meteorological stations were matched with representative survey data on stress, loneliness, affect, life satisfaction, and self-reported health of *N* = 8,017 individuals. The analyses revealed that higher ambient temperatures were associated with lower perceived stress levels (14-day lag: ß=-0.151, *p* = .033; 30-day lag: ß=-0.238, *p* = .018) and better self-reported health (7-day lag: ß=0.178, *p* = .013). Moreover, intermediate ambient temperatures were linked with less loneliness (14-day lag: ß=-0.147, *p* = .033), greater life satisfaction (7-day lag: ß=-0.195, *p* = .002; 14-day lag: ß=-0.176, *p* = .011), and better self-reported health (same day: ß=-0.171, *p* = .001; 14-day lag: ß=-0.138, *p* = .041). These findings shed more nuanced light on the impact of climate change on mental health.

Keywords Affect, Climate, Health, Loneliness, Mood, Stress, Temperature

According to the World Meteorological Organisation (WMO), 2023 was the warmest year on record with the global average near-surface temperature at 1.45 °C ± 0.12 °C above the pre-industrial baseline[1]. The consequences of rising temperatures for human health are manifold. They can occur both directly, for example through acute weather events such as wild fires or floods, and indirectly, through agricultural losses or the challenges of increasing conflicts and migration[2]. In addition, high temperatures have repeatedly been demonstrated to be a risk factor for waterborne, vector-borne, and nutrition-related diseases as well as for cardiovascular and respiratory diseases[3].

In view of the significant impact of high temperatures on somatic health, researchers have also begun to investigate potential links with mental health. Several studies have found that higher ambient temperatures were associated with more mental health-related hospitalisations and suicides[4,5]. A much smaller body of research has examined direct measures of mental health: One study found that temperatures above 30 °C were associated with more mental health difficulties compared to 10 °C to 15 °C[6]; another study found that temperatures above 15 °C to 20 °C were related to more days with poor mental health[7]; and yet another study found that higher temperatures corresponded with more days with poor mental health across a spectrum from − 1 °C to over 26 °C[8].

Interestingly, these findings appear to contrast with other studies that have reported positive psychological effects of warmth and heat[9]. For instance, experimental research has repeatedly found that brief exposures to indoor temperatures between 22 °C and 24 °C were followed by a more relational focus and feeling closer to others compared to cooler room temperatures[10]. Moreover, an international study found that countries where the coldest month was relatively warm were, on average, happier than countries where the coldest month was relatively cold[11]. A third study found that, in cooler countries, warm temperatures were associated with increased life satisfaction[12]. These findings raise the question of whether high ambient temperatures might exert positive psychological (and health) effects in cooler conditions, particularly in cold seasons.

The aim of this study was to comprehensively investigate the relationship between ambient temperature during cold seasons, psychological well-being, and mental health. To this end, high-resolution meteorological data from weather stations across Switzerland were combined with data from a large representative sample of the general population. Given that the average cold season temperatures in Switzerland are between − 10 and + 25 degrees Celsius, we hypothesised a negative association between air temperature in the autumn and winter months and stress, loneliness, anger, sadness, worry, blues, depression, and anxiety, and a positive association between

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air temperature and joy, optimism, strength, energy, and general life satisfaction. These hypotheses referred to same-day and several lagged associations (see statistical analyses). Additionally, we explored a potential positive association between air temperature in the autumn and winter months and self-reported health. The study was part of a two-part project on cold and warm season ambient temperature on mental health, respectively, that was pre-registered on the Open Science Framework (https://osf.io/49nb5).

Results

Sample characteristics

A total of 13,151 individuals took part in the survey. Of these, 1,925 completed a proxy questionnaire for another person and 2,386 respondents only answered a household questionnaire. This left a total of 8,840 people who completed the individual questionnaire. Further exclusions due to missing meteorological data resulted in a final sample size of $N = 8{,}017$.

The socio-demographic and psychological characteristics of the sample are shown in Table 1. The participants ranged in age from 14 to 99 years, with an average age of 50.9 years (SD = 19.4). The gender distribution was roughly balanced with 46.8% of male and 53.2% female participants.

The meteorological data included daily records collected from September 2nd, 2019 to March 3rd, 2020. During this period, the temperature ranged between −6.9 degrees Celsius and +22.6 degrees Celsius, with an average of 7.5 ± 5.2 degrees Celsius (see also Fig. 1a). The relative humidity was relatively high, averaging 81.4 ± 8.6%, with a range from 26.1 to 100%. There was an average of 3.6 ± 3.3 h of sunshine per day, with a minimum of 0 h and a maximum of 12.6 h. Precipitation varied from 0 to 86.4 millimetres per day with a mean of 2.96 ± 4.46 millimetres per day. For an overview of these parameters, please see Supplement 1. For an overview of the spatial distribution of the weather stations across Switzerland and of the respondent and population density, please see Supplement 2.

	N (%)	M (SD)
Age (years)		50.89 (19.39)
Gender		
Male	3751 (46.79)	
Female	4266 (53.21)	
Diverse	0 (0)	
Body Mass Index		24.68 (4.53)
Education		
No completed education	260 (3.24)	
Compulsory school or equivalent	1097 (15.77)	
Apprenticeship or equivalent	2688 (33.53)	
A-levels	804 (10.03)	
Job-specific further education	1294 (16.14)	
University/university of applied sciences degree	1854 (23.13)	
Not indicated	20 (0.25)	
Gross income		
Up to 30,000 CHF	1796 (22.4)	
30,001 to 50,000 CHF	1155 (14.41)	
50,001 to 100,000 CHF	2636 (32.88)	
100,001 to 150,000 CHF	1050 (13.1)	
150,001 to 200,000 CHF	309 (3.85)	
More than 200,000 CHF	186 (2.32)	
Not indicated	885 (11.04)	
Stress (score range: 1–5)		2.68 (1.07)
Loneliness (score range: 0–10)		1.86 (2.30)
Anger (score range: 0–10)		3.75 (1.87)
Sadness (score range: 0–10)		3.35 (1.96)
Worry (score range: 0–10)		3.09 (2.27)
Joy (score range: 0–10)		7.45 (1.26)
Blues, depression, anxiety		2.17 (2.11)
Optimism, strength, energy (score range: 0–10)		7.03 (1.75)
Satisfaction with life (score range: 0–10)		8.07 (1.32)
Self-reported health (score range: 1–5)		4.03 (0.64)

Table 1. Sample characteristics. Data presented as means and standard deviations.

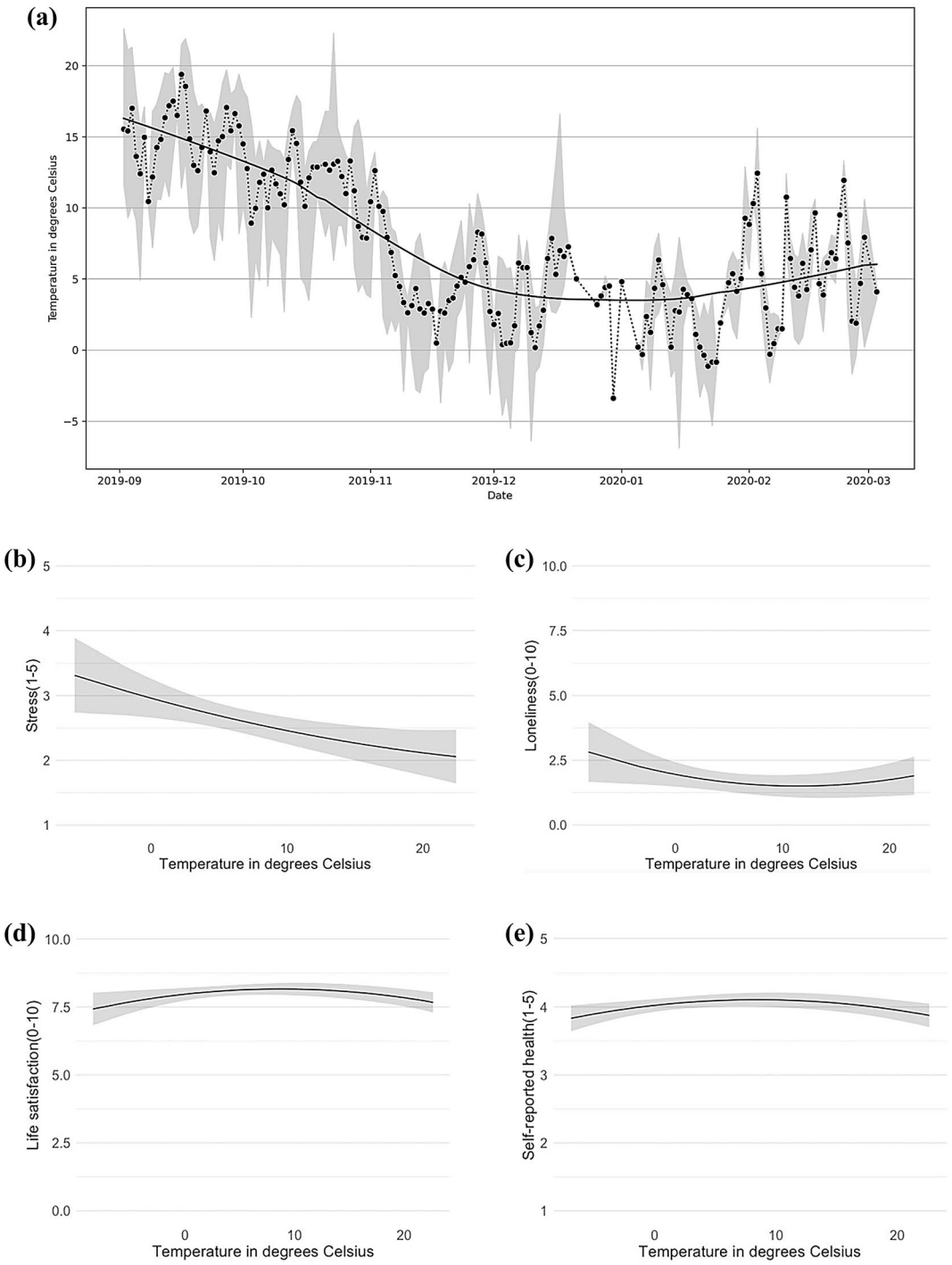

Fig. 1. (**a**) Mean daily air temperature for all stations during the study period (points and dashed line). The shaded area shows the range between minimum and maximum daily air temperature across all stations. The solid line represents the smoothed mean, illustrating the general trend of air temperature during the study period. (**b**) Average temperature over the past 30 days as a predictor of average stress over the past 30 days. The grey areas around the curve represent 95% confidence intervals. (**c**) Average temperature over the past 14 days as a predictor of loneliness. The grey areas around the curve represent 95% confidence intervals. (**d**) Average temperature over the past 7 days as a predictor of life satisfaction. The grey areas around the curve represent 95% confidence intervals. (**e**) Average temperature on the same day as a predictor of self-reported health. The grey areas around the curve represent 95% confidence intervals.

Air temperature and stress

Four regression models were calculated to predict stress, incorporating meteorological variables on the day of the survey, the average of the previous seven days, the average of the previous 14 days and the average of the previous 30 days (see Supplements 3 and 4). The analyses showed that both higher average temperatures over the past 14 days (ß=−0.151, p =.033) and over the past 30 days (ß=−0.238, p =.018; see also Fig. 1b) were associated with lower stress levels. These results were confirmed by bootstrapping, both for the 14-day (95% CI [−0.070, −0.002]) and for the 30-day time frame (95% CI [−0.112, −0.010]).

Air temperature and loneliness

Three regression models were calculated to predict loneliness (see Supplement 5). The analyses revealed that intermediate average temperatures during the past 14 days (ß=0.147, p =.033) were associated with less loneliness (see also Fig. 1c). These results were confirmed by bootstrapping (95% CI [0.000, 0.007]).

Air temperature and affect

Three regression models were calculated to predict anger, sadness, worry, and joy, respectively (see Supplements 6 to 9). None of the models was significant and these null findings were largely confirmed by bootstrapping 95% CI [anger: −0.030, 0.035; −0.016, 0.068; −0.009, 0.083; sadness: −0.015, 0.096; −0.018, 0.098; −0.036, 0.095; worry: 0.003, 0.099; −0.054, 0.085; −0.076, 0.073; joy: −0.049, 0.044; −0.044, 0.071; −0.051, 0.072]).

Air temperature and blues, depression, and anxiety

Three regression models were calculated to predict blues, depression, and anxiety (see Supplement 10). None of the models was significant and these null findings were confirmed by bootstrapping 95% CI [−0.009, 0.099; −0.049, 0.079; −0.052, 0.089]).

Air temperature and optimism, strength, and energy

Three regression models were calculated to predict optimism, strength, and energy (see Supplement 11). None of the models was significant and these null-findings were confirmed by bootstrapping 95% CI [−0.074, 0.007; −0.080, 0.023; −0.071, 0.038]).

Air temperature and satisfaction with life

Three regression models were calculated to predict life satisfaction (see Supplement 12). The analyses showed that intermediate average temperatures during the past 7 days (ß=−0.195, p =.002; see also Fig. 1d) and 14 days (ß=−0.176, p =.011) were associated with higher life satisfaction. These effects were confirmed by bootstrapping (95% CI[−0.004, −0.001; −0.005, −0.000]).

Air temperature and self-reported health

Three regression models were calculated to predict self-reported health (see Supplement 13). The analyses showed that intermediate average temperatures on the same day (ß=−0.171, p =.001; see Fig. 1e) and during the past 14 days (ß=−0.138, p =.041) were associated with better self-reported health. Moreover, higher average temperatures over the past 7 days were associated with better self-reported health (ß=0.178, p =.013). These effects were confirmed by bootstrapping (95% CI[−0.001, −0.000; 0.004, 0.044; −0.002, −0.000]).

Discussion

The present study yielded the following main findings. First, the higher the average ambient temperature in cold seasons, the lower the stress levels. Second, intermediate temperatures were associated with less loneliness, better life satisfaction, and better self-reported health. Third, there was no relationship between temperature and affect, optimism, strength, and energy.

Our fist finding was that higher ambient temperatures during cold seasons in the 30 days prior to the survey were related to lower reported stress experienced over the past 30 days. This finding is novel in that, to the best of our knowledge, no previous studies have investigated the relationship between ambient temperatures and stress. However, emerging findings from experimental research suggest that warmth may potentially alleviate acute stress responses[13]. Given that stress is one of the most significant risk factors for mental health problems[14], warm temperatures might exert protective effects, above and beyond the well-established effects of light[15]. Indeed, one study has shown that ambient temperature was predictive of disorders treated with selective serotonin reuptake inhibitors (e.g., depression and anxiety), but not of substance use disorders[16].

Our second finding was that intermediate cold-season ambient temperatures in 14 days prior to the survey were associated with less loneliness, better life satisfaction, and better self-reported health. Regarding loneliness, cold-season outdoor temperatures above 0 °C and up to 20 °C appeared to be protective against loneliness, whereas outdoor temperatures below 0 °C appeared to exert the opposite effect. Again, we are not aware of any previous studies investigating associations between ambient temperatures and loneliness. However, our findings complement experimental work, which has demonstrated that indoor temperatures between 22 °C and 24 °C mapped onto a more relational focus and feeling closer to others when compared to cooler room temperatures[10]. Regarding life satisfaction, cold-season temperatures between 0 °C and 10 °C appeared to lead to higher levels of life satisfaction, whereas temperatures below 0 °C appeared to lead to lower levels. Our study adds to previous observations in climatically cooler countries, where warm temperatures were associated with increased life satisfaction[12]. Finally, temperatures above 0 °C and up to 20 °C appeared to exert beneficial effects on self-reported health. These findings extend previous research showing that heat is a demonstrable risk factor for waterborne, vector-borne, and nutrition-related diseases as well as for cardiovascular and respiratory diseases[3].

Our third finding was that cold-season ambient temperatures were neither related to affect nor to optimism, strength, and energy. These findings stand in contrast to prior research, which found that higher temperatures in colder months were associated with greater happiness[11]. However, this study relied on aggregated, country-level data, meaning that is not directly comparable to the present study, which used individual-level data. Moreover, it used happiness as a dependent variable, which is conceptually different from affect, optimism, strength, and energy. Interestingly, in contrast to stress, loneliness, life satisfaction, and self-reported health, affect, optimism, strength, and energy were operationalised as trait-like variables in the present study (i.e., "How often do you normally experience the following feelings?"; "How often are you full of strength, energy and optimism?"). This mismatch in time frames between our independent variable and our dependent variables is likely to have prevented us from detecting any significant relationships.

Despite the small size of the observed effects, it is worth think about the various direct and indirect pathways through which warm ambient temperatures in cold seasons could positively influence psychological well-being and mental health. One possible mechanism of action involves the effect of μ-opioids[17]. Changes in skin temperature activate the contralateral dorsal posterior insula, where many μ-opioid receptors are located[18]. These have been shown to be both part of the thermoregulatory system and associated with feelings of social connectedness. Notably, μ-opioid receptors are located in several different parts in the brain and the evidence supporting this mechanism is experimental, which renders it unclear whether it also underlies the longer term and more diffuse ambient climate effects. Furthermore, neural pathways involved in the perception and regulation of temperature may be associated with affect[19]. For example, Rolls, Grabenhorst[20] found that warm stimuli deactivated the lateral orbitofrontal cortex, which is associated with numerous unpleasant sensations, such as unpleasant odours, images and touch, or losing money. Other studies have shown that low temperatures impair cognitive functions[21,22]. Moreover, the use of thermoeffectors such as vasoconstriction and shivering requires energy, which can lead to increased fatigue and a lack of energy. Finally, low temperatures can affect sleep quality[23] and hinder physical[24] and other leisure activities[25].

This study has several strengths. First, the study hypotheses were preregistered, which is in line with open science standards. Second, the sample size was relatively large and representative of the general population. Third, the study used a comprehensive network of weather stations that recorded numerous meteorological data, including the most important temperature-related confounders (e.g., humidity). Fourth, the data was collected under natural, everyday life conditions, which, in contrast to previous experimental research, comes with high levels of ecological validity. Fifth, air temperature was assessed over different time periods, which made it possible to explore time-lagged effects of ambient temperature on mental health. The present study also has some limitations. First, all dependent variables used were measured with a single item, for some of which no measures of reliability or validity were available. Moreover, the conflation of different constructs was unfortunate (i.e., assessing blues, depression, and anxiety with the same item). This might have prevented us from finding specific effects of temperature on depression versus anxiety. Distinguishing between the two conditions is particularly important, as individuals with depression[26] might respond differently to increases in temperature than individuals with anxiety[27]. Second, as mentioned above, the questions about affect and optimism, strength, and energy were operationalised as trait-like variables, which made it difficult to detect any relationships with momentary or recent ambient temperatures. Third, the participants' actual location during the study were unknown, which might have led to an underestimation of the relationship between ambient temperatures and well-being/mental health.

In sum, our study showed that, in cold seasons, intermediate and high temperatures exerted positive effects on psychological wellbeing and mental health. The identified effects were small. Nevertheless, they are relevant at the population level and shed a more nuanced light on the effects of climate change on mental health. Longitudinal studies combining high-resolution, spatially distributed meteorological data (e.g., via remote sensing or reanalysis datasets) with psychometrically sound measures of psychological well-being and mental health (e.g., disorders treated with selective serotonin reuptake inhibitors[16]) are warranted to replicate our findings. An excellent example is recent work by Bundo, Preisig[28], who used ecological momentary assessments to investigate the effects of ambient temperatures on momentary mood in a highly dynamic fashion. Ideally, such studies would also integrate biological measures (e.g., heart rate, hormones, immune markers), which would allow shedding further light on the mechanisms translating varying ambient temperatures into different mental health outcomes. Finally, more research at higher levels of the temperature spectrum is warranted to identify tipping points at which warmth/heat might translate into negative mental health outcomes.

Methods

Sample

The study was part of a two-part project on cold and warm season effects of ambient temperature on mental health. The participants for this study, which investigated cold seasons effects, were recruited from the Swiss Household Panel (SHP). The SHP is an ongoing, nationally representative survey conducted annually between September and March since 1999[29]. The surveys were initially conducted using computer-assisted telephone interviews (CATI), but since 2010, computer-assisted personal interviews (CAPI) and computer-assisted web interviews (CAWI) have increasingly been used as alternative methods[30]. For this study, we used data from survey wave number 21 from the year 2019, as it contained all variables required to answer our research questions.

All methods were carried out in accordance with relevant guidelines and regulations. The protocol of this study was exempt from approval by the Ethics Committee of the Canton of Zurich (Req-2023-01300). Informed consent was obtained from all subjects and/or their legal guardian(s).

Meteorological data

The relevant meteorological data was obtained from the Federal Office of Meteorology and Climatology MeteoSwiss. MeteoSwiss operates an extensive monitoring network of weather stations across all regions and altitudes in Switzerland[31]. Since 2015, around 157 weather stations have been in operation, comprehensively covering all of Switzerland's regional climate zones. The weather stations continuously measure air temperature at a height of two metres, along with other meteorological parameters such as wind strength and direction, precipitation, humidity, air pressure, and sunshine duration.

Psychological data

Stress The question "How often have you experienced stress during the past month?" was rated on a Likert scale from (1) "never" to (5) "very often". The development of this item was based on a proposal by the Swiss National Centre of Competence in Research "Lives"[32].

Loneliness The question "Do you feel lonely in your life?" was answered on a Likert scale from (0) "not lonely at all" to (10) "extremely lonely". This item was developed by the SHP.

Mood The question "How often do you normally experience the following feelings?" enquired about various affects, such as anger, sadness, worry, and joy. Answers were given on a scale from (0) "never" to (10) "always". The item was inspired by a representative study which examined the frequency and experience of various emotions[33].

Blues, *depression*, *and anxiety* The question "Do you often have negative feelings such as having the blues, being desperate, suffering from anxiety or depression, if 0 means "never" and 10 "always"?" was based on the Positive and Negative Affect Schedule[34].

Optimism, *strength*, *energy* The question "How often are you full of strength, energy and optimism?" was used and answered on a 10-point Likert scale from (0) "never" to (10) "always". This item was also based on the Positive and Negative Affect Schedule[34].

Satisfaction with life The question "Generally speaking, how satisfied are you with your life?" was answered on a scale between 0 and 10, where (0) meant "not at all satisfied" and (10) meant "completely satisfied". This item was based on the Satisfaction with Life Scale[35].

Self-reported health The question "I would now like to talk to you about various aspects of your health. How is your health at the moment?" was answered on a scale from (1) "very good" to (5) "very bad". This item was adapted from the Swiss Health Survey[36] and originated from the European Health Interview Survey[37].

Data matching

Based on the commune numbers listed in the official commune register of the Swiss Federal Statistical Office, the subjects of the SHP survey were assigned to their respective locations. The commune centre was determined for each municipality number by weighting based on the population density data[38]. To determine a representative measuring station, a maximum distance of 15 km from the municipality was defined. If multiple weather stations were located within this radius, the station with the smallest difference in altitude to the population-weighted commune centre was selected. Using this method, the meteorological data of the corresponding weather stations were assigned to the respective participants based on the municipality number and the date of the survey, which linked the respondents' answers to the prevailing weather conditions in the corresponding period.

Statistical analysis

Multiple polynomial regression models were calculated to answer our research questions. Models were created for each dependent variable, incorporating meteorological variables at three different time frames: the day of the survey, the average of the previous seven days, and the average of the previous 14 days. For the variable stress, which referred to the past 30 days, meteorological data from the 30 days prior to the survey were also included in the analysis. Several covariates were integrated into the models to control for possible confounding influences, including sociodemographic and lifestyle characteristics such as age, gender, and Body Mass Index (BMI). These characteristics influence thermoregulation and could therefore have an impact on the relationship between ambient temperature and psychological well-being. In addition, the month of the survey and the day of the week were included in the models as dummy variables. Bootstrapping was used to control for multiple testing. All statistical analyses of the data in this study were carried out using R software (version 4.3.3; R Core Team, 2024) and all Figures were created using R software (version 4.4.1; R Core Team, 2024). Deviations from the pre-registration: Canton was excluded as a predictor before undertaking the analyses to improve comparability with previous research in other countries and to reduce multicollinearity and model complexity.

Data availability

The data of this study is not publicly available since it belongs to the Swiss Household Panel (SHP) and Federal Office of Meteorology and Climatology MeteoSwiss and the authors are contractually obligated to delete the data after the dissemination of the findings. The full psychological and meteorological data sets are available upon request from the Swiss Household Panel (SHP; https://forscenter.ch/projects/swiss-household-panel/data/) and from the Federal Office of Meteorology and Climatology MeteoSwiss (https://github.com/MeteoSwiss/opendata-ground-based-measurements/blob/main/README.md#1-automatic-weather-stations), respectively.

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Author contributions

KN and SF conceived and designed the study. KN, PR, and XS, PR prepared the data. AM and XS analysed the data, and AM, KN, PR, SF, and XS interpreted the data. KN, SF, and XS drafted the article and AM and PR revised it critically for important intellectual content. All authors approved the final version of the article.

Declarations

Competing interests

The authors declare no competing interests.

Additional information

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