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What is the relationship between risk attitudes and ambient temperature? Evidence from a large population-based cohort study

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ABSTRACT

Rising temperatures affect human behavior and risk-taking in several domains. However, it is not yet well understood just how ambient temperature shapes risk attitudes. Using data from the large population-based KORA-Fit study (Cooperative Health Research in the Region of Augsburg) of older people (N=2454), we identify a statistically significant, but very small, positive association between short-term ambient temperature changes and individuals' general willingness to take risks. Health-related risk attitudes, however, show no significant relationship with temperature. These findings support a domain-specific view of risk attitudes, with results remaining consistent for vulnerable individuals with the chronic conditions diabetes, hypertension, and asthma. Overall, our findings suggest that risk attitudes are somewhat stable towards changes in ambient temperature.

1. Introduction

Over the past decades, climate change has increased the likelihood of natural disasters, including extreme heat events and rising global temperatures (e.g., Karl et al., 2015; Horton et al., 2016; Otto et al., 2016; IPCC, 2023) with a variety of far-reaching consequences leading, for instance, to human migration (Cattaneo et al., 2019) and interpersonal or intergroup conflicts (Evans, 2019). More generally, temperatures and changes therein may be associated with human behavior in several domains. Links between temperature and behavior under risk and uncertainty have been established, for example, in financial or health-related decision-making (Cao and Wei, 2005; Chang et al., 2006; Tucker and Gilliland, 2007; Floros, 2011; Ventura-Cots et al., 2019; Shafi and Mohammadi, 2020). How temperatures relate to risk *attitudes*, however, is not well-understood. This is somewhat surprising, as risk attitudes are "one core dimension of individual preferences" (Schildberg-Hörisch, 2018, p.135) to model the behavior of economic agents under risk and uncertainty. It can therefore be summarized that evidence highlights the link between temperature and (health) behavior and that economic theory relies on preferences to model behavior, but the link between risk attitudes and temperature is missing.

In this paper, we contribute to filling this gap by analyzing the link between ambient temperature and self-reported risk attitudes. Ambient temperature is defined as outdoor temperature. We use a large sample of older adults born between 1945 and 1964 from the region of Augsburg, Germany (N= 2454). Besides general risk attitudes, we also analyze how temperature is associated with risk attitudes in the health domain. This is evidently an important domain, since risk attitudes relate to, for example, smoking (Dohmen et al., 2011; Falk et al., 2018), heavy drinking (Beauchamp et al., 2017; Szrek et al.,

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2012), unhealthy eating (Anderson and Mellor, 2008), and preventive activities (Szrek et al., 2012). To account for the domain specificity of risk preferences (e.g., Anderson and Mellor, 2008; Einav et al., 2012; Galizzi et al., 2016), we elicit both self-reported general and health-related risk attitudes using established survey questions (Dohmen et al., 2011).

In addition, we analyze the link between ambient temperature and risk attitudes in individuals with chronic illnesses that may be particularly sensitive to temperature changes. It is well-known that temperature changes are associated with health outcomes in several chronic diseases, as evidenced by increased visits to the emergency department for cardiovascular diseases, diabetes, and blood pressure (e.g., Basu et al., 2012; Lavigne et al., 2014). Higher temperatures are also known to lead to changes in blood pressure (Halonen et al., 2011; Modesti et al., 2006) and increase respiratory disease mortality (Rai et al., 2023). Lower temperatures are related to more respiratory symptoms and functional disability in patients with allergic rhinitis and asthma (Hyrkäs-Palmu et al., 2018) as well as a higher risk of myocardial infarction (Wolf et al., 2009). Thus, chronically-ill patients are already at higher risk of a health deterioration based on temperature changes compared to healthy individuals and might aggravate their conditions based on their altered risk attitudes.

We link our two measures of risk attitudes to ambient temperatures. We focus on daily changes in ambient temperature, as variations in the temperature seem likely to be exogenous in the short run and are easily perceived by individuals. In the longer run, people may move to different climate zones or successively adjust to changes. However, the ability of individuals to deal with ambient temperature might correlate with their risk attitudes. We thus measure in some sense the residual variation in temperature and its effect on risk attitudes. We also explore whether the link between risk attitudes and temperature is heterogeneous for patients with different chronic diseases. In addition, we control for demographics (sex, age, income, education, region) and individuals' optimism in our analyses.

Our main findings are the following: We find a very small positive, statistically significant relationship between temperature and the general willingness of individuals to take risks. Individuals are slightly more risk-seeking in the general risk domain with rising temperatures. A temperature increase by one degree Celsius is associated with a 0.013 increase in an individual's willingness to take risks (on an 11-point scale). We observe a similar pattern for health-related risk attitudes, but the difference is not statistically significant. This result provides some support for the domain specificity of risk attitudes. These findings are not significantly different for older adults with diabetes, asthma, and hypertension. Overall, our results suggest that the willingness of individuals to take risks remains relatively stable despite changes in temperature.

The rest of the paper is organized as follows. Section 2 describes how our study relates to the existing literature. In Section 3, we describe the data set and our different variable specifications. The econometric approach is specified in Section 4. In Section 5, we present our estimation results. Section 6 discusses limitations, as well as policy implications, and concludes.

2. Related literature

Our study contributes to several streams of the literature. First, we add to studies analyzing how different weather conditions relate to decision-making under risk, and using weather conditions as an instrumental variable to link an individual's mood to decision-making under risk.[2] While several weather conditions have been investigated in the context of decision-making under risk, the majority of the literature does not focus on ambient temperature as we do. For example, cloud coverage has been associated with stock-market returns (Hirshleifer and Shumway, 2003; Saunders, 1993). Bassi et al. (2013) assessed the relationship between three weather conditions, precipitation, cloudiness, or subjective weather assessments, and risk preferences in a financial context with an experimental approach. They report that good weather increased risk-taking.

In fact, several studies argue that weather-induced mood, such as aggression or upbeat mood, is responsible for observed weather-related effects (e.g., Cao and Wei, 2005; Hirshleifer and Shumway, 2003; Bassi et al., 2013). In line with this argumentation, some research used weather-related variables as instruments or proxies for mood. Shafi and Mohammadi (2020) showed that on cloudy days investments in crowdfunding campaigns were smaller than on sunny days. The authors hypothesized that sunshine induced a positive mood which, in turn, increased risk-taking. This was supported by more investments in campaigns with equity involving more risk on sunny days, compared to cloudy ones. In contrast, investments in campaigns with venture loans (i.e., less risky projects) were smaller on sunny compared to cloudy days. Cortés et al. (2016) found that sunshine or less cloud coverage were associated with higher loan-approval rates.

Second, we contribute to the scarce literature on the link between temperature and risk attitudes. Only very few studies from psychology directly examined this relationship. Stroom et al. (2021) used a laboratory experiment to study the effect of high indoor temperature on risk-taking in an incentivized lottery task, and on self-reported risk attitudes. Stroom et al. (2021) report no significant differences between the temperature conditions for the behavioral risk measure or self-reported risk attitudes. In a similar study, Syndicus et al. (2018) did not find a difference in behavioral risk-taking, measured in a lottery task, between high and normal temperature conditions. Using the Balloon Analogue Risk Task (BART), Lejuez et al. (2002) report that participants were more willing to take risks in the high-temperature condition. One might argue, however, that the BART evaluates decision-making under uncertainty rather than under risk (De Groot and Thurik, 2018).

Finally, we contribute to the literature analyzing the formation of risk attitudes. Our focus is not on the stability of risk attitudes, as we are not considering a longitudinal data set. Most studies on the stability of risk preferences in panel data document moderate correlations of an individual's risk preferences across time (e.g., Chuang and Schechter, 2015; Schildberg-Hörisch, 2018). We contribute to the evidence on what forms risk attitudes by assessing the relationship between self-reported risk attitudes and the whole ambient temperature spectrum. Further, we explore the heterogeneity in the association with risk attitudes for vulnerable populations which could be assumed to be most influenced by temperature changes. More specifically, we analyze the association of temperature and risk attitudes for several chronic diseases (i.e., asthma, diabetes, and hypertension).

3. Data

To investigate the relationship between temperature and risk attitudes, we used data from the Cooperative Health Research in the

[2] More specifically, mood, emotions, and feelings associated with temperature could suggest a possible behavioral mechanism for the positive relationship between general risk attitudes and higher temperature. For example, higher temperature levels are accompanied by more aggression (Anderson, 2001; Bushman et al., 2005). While some researchers also suggest lower levels of aggression after reaching a peak at moderately high temperatures (Cohn and Rotton, 1997), others support a rather linear relationship between temperature and aggression (Bushman et al., 2005). Higher aggressive feelings due to higher temperature levels could be related to a greater willingness to take risks. A similar mechanism is proposed by Cao and Wei (2005) in the context of stock-market returns. In addition, Loewenstein et al. (2001) also emphasized the role of emotions for risk attitudes.

Table 1
Sample characteristics ($N = 2454$).

Variable	Descriptives
Age (mean, s.d.)	63.1 (5.5)
Share of females (in %)	52.1
Education in years (mean, s.d.)	12.0 (2.6)
Monthly household income in Euro (*n*, %)	
<875	167 (6.8)
875 to 1749	967 (39.4)
1750 to 2624	868 (35.4)
2625 to 3499	304 (12.4)
≥3500	148 (6.0)
Region (*n*, %)	
Rural	1552 (63.2)
Urban	902 (36.8)
Optimism (mean, s.d.)	16.4 (3.6)

Notes: Data from the KORA-Fit study conducted from January 2018 to June 2019; age and education in years; household income in Euro per month. Regions are defined as "rural" if they are located in the district (*Landkreis*) of Augsburg, or as "urban" if they are located within the city of Augsburg. Optimism is a questionnaire item based on the overall score achieved in the German version of the Life Orientation Test (Glaesmer et al., 2008); for more details, see Section 3.4.

Table 2
Risk measures and weather-related variables.

Variables	Descriptives
A. Risk attitudes	
General risk attitudes (mean, s.d.)	4.1 (2.1)
Health risk attitudes (mean, s.d.)	3.3 (2.2)
B. Weather-related variables	
Temperature in °C (mean, s.d.)	10.7 (8.4)
Temp6DayAvg in °C (mean, s.d.)	10.5 (7.9)
ΔTemp in °C (mean, s.d.)	1.5 (3.4)
Barometric pressure in hectopascals (mean, s.d.)	1018.1 (7.6)
Relative humidity in % (mean, s.d.)	70.1 (11.8)
Season (*n*, %)	
Six warmest months	1080 (44.0)
Six coldest months	1374 (56.0)

Notes: To account for longer periods of high or low temperature, we calculated six-day averages labeled Temp6DayAvg. ΔTemp is the difference between the daily temperature and the monthly average temperature at the study center.

Region of Augsburg (KORA) Fit study. KORA is a regional research platform for population-based studies in Bavaria, southern Germany. It consists of four population-representative cross-sectional baseline surveys between 1984 and 2001; see Holle et al. (2005) for an overview.

KORA-Fit is a follow-up study conducted from January 2018 to June 2019. All living participants of the four KORA baseline surveys born between 1945 and 1964 were invited for a re-examination ($N = 3059$; 64.4% of all eligible persons). The investigations were carried out in accordance with the Declaration of Helsinki, including written informed consent of all participants. All study methods were approved by the Ethics Committees of the Bavarian Chamber of Physicians (KORA-Fit EC No 17040).

Due to missing values, our analysis is based on a sample containing 2454 observations. Most missing values were found for self-reported risk attitudes, income, and optimism. Table 1 provides an overview of the sample characteristics.

3.1. Measures of risk attitudes

We consider two self-reported measures of risk attitudes: general risk attitudes and health-related risk attitudes. Following Dohmen et al. (2011), participants were asked to indicate their willingness to take risks in general and in the health domain. The 11-point Likert scale ranged from "not willing to take risks" to "very willing to take risks".[3] Table 2 shows descriptive statistics for the two risk measures in our sample. For the distribution of general and health-related risk attitudes, see Figs. A.1 and A.2 in Appendix A.1. In the health domain, subjects tend to be more risk-averse (mean: 3.3) compared to the general risk domain (mean: 4.1).

3.2. Temperature

Temperature was measured in degrees Celsius (°C) in Augsburg and was reported as a 24-h average on a given day by the Bavarian Environment Agency (*Landesamt für Umwelt*). This is the main ambient temperature measure we use in our analyses. Fig. A.3 in the Appendix shows the distribution of temperature levels in days. These refer to the temperature level occurring on the day a study participant visited the study center. All data including risk attitudes were collected for a participant on this respective day.

To check the robustness of our results, we used several measures of temperature. First, to investigate differences due to longer periods of high or low temperatures, we calculated six-day averages labeled Temp6DayAvg. For this purpose, the average temperatures across the study day and the five days before was determined. Second, the impact of the current temperature likely depends on the difference to the usual temperature at this time of year. We thus also used a *deseasonalized* measure of temperature denoted as ΔTemp, similar to Cortés et al. (2016) and Hirshleifer and Shumway (2003). We calculated the difference between the daily temperature and the monthly average temperature. Data on the monthly average temperature in Augsburg were retrieved from the German Weather Service (*Deutscher Wetterdienst*). Third, we controlled for warm and cold seasons with a binary variable Season, which equals 1 if the daily temperature belonged to one of the six warmest months in a given year, and 0 otherwise. Finally, we categorized the 24-h average temperature in deciles to decrease the influence of temperature outliers and to simplify the temperature-data distribution.

3.3. Health variables

Our unique sample offered the possibility to control for individuals with different chronic diseases. We included the chronic diseases hypertension, diabetes, and asthma, since these conditions largely contribute to the global burden of disease (Naghavi et al., 2017; Stanaway et al., 2018) and were reported by a sufficient number of individuals in our sample; see Table A.1 in Appendix A.1. Variables were included in our statistical models to indicate corresponding chronic health conditions.

Hypertension was defined as having a blood pressure ≥140/90 mmHg or having a medically-controlled known hypertension. The presence of diabetes was based on self-reports or indicated medications. The presence of asthma was based on self-reports regarding a prior diagnosis by a doctor. We also defined a dummy variable labeled ChronicDisease, which equals 1 if one or more of the three health conditions were present, and 0 otherwise.

3.4. Covariates

In our analyses, we considered several covariates: age (in years), sex, education (in years), and income (equivalized household income in Euro per month). To capture temperature differences between rural and urban areas, we included a dummy variable Region, which equals 1 for the district of Augsburg (rural, suburban area) and 0 for the city of Augsburg (urban area). We also controlled for two other weather conditions: barometric pressure and relative humidity. Barometric pressure

[3] The exact German wording for general risk attitudes was: "*Sind Sie im Allgemeinen ein risikobereiter Mensch, oder versuchen Sie, Risiken zu vermeiden?*" and the exact German wording for health-related risk attitudes reads: "*Wie würden Sie Ihre Risikobereitschaft in Bezug auf Ihre Gesundheit einschätzen?*"

was measured in hectopascals (hPa), and relative humidity in percent (%). Data were received from the Bavarian Environment Agency (*Landesamt für Umwelt*).

To account for the suggested relationship between weather and mood (e.g., Cao and Wei, 2005; Hirshleifer and Shumway, 2003), we included a measure for the individuals' optimism (serving as a proxy for mood) in our regression analyses. The measure is based on the overall score achieved in the German version of the Life Orientation Test (ranging from 0 to 24, with higher levels indicating higher optimism; Glaesmer et al., 2008).

4. Econometric approach

We used ordinary least square (OLS) regression to estimate a set of different regression models. All analyses were conducted in R (R Core Team, 2021). We first employed a univariate regression model with temperature on the study day as the independent and either general risk attitudes or health-related risk attitudes as the dependent variables. In a second model, we controlled for sex and added further demographic controls for age, education, income, and region. Our third model accounted for the presence of a chronic disease, and the fourth model considered interactions between chronic disease and temperature.

Another set of models provides further sub-group analyses of subjects with chronic diseases: diabetes, asthma, and hypertension. All of these models also included an interaction term of the chronic disease and temperature.

To assess the robustness of our main estimation results, we conducted several analyses including different temperature measures. We re-estimated the second model with six-day-average temperature, Temp6DayAvg, and the *deseasonalized* temperature measure, ΔTemp, instead of the temperature measured on the study day as the main independent variable. Furthermore, we included temperature on the study day as a squared and also as a cubic variable to assess potential non-linear patterns. Further re-estimated models contained either an additional control for season, indicators for two other weather conditions (i.e., barometric pressure and relative humidity), or a measure of temperature in deciles. Finally, we controlled for optimism.

To reflect the ordered nature of our dependent variable, we also used ordinal logistic regression to evaluate the robustness of our results with respect to the statistical models used. We specified our ordinal logistic regression model assuming proportional odds. We then tested this assumption and re-specified those models as partial proportional odds (ppo) models when the assumption was not met. Following this approach, we estimated ppo models for self-reported general and health risk attitudes and temperature on the study day. To avoid an interpretation of the log odds, we exponentiated the coefficients to get odds.

In addition, we aggregated several response levels of the risk-attitudes measure to create a three-leveled measure for self-reported risk attitudes: low, medium, and high risk attitudes. Response levels 0 to 3 were condensed to the category low-risk attitudes, reflecting high risk aversion. Response levels 4 to 6 indicated medium-risk attitudes. Accordingly, response levels 7 to 10 referred to high-risk attitudes reflecting high risk tolerance; see Table A.2 in Appendix A.2 for frequencies in each category.

5. Results

5.1. Main analyses

We find that individuals' *general* risk attitudes increase with rising temperatures. Estimation results in Model (1) of Table 3 showed that a one-unit increase in temperature was associated with an increase of 0.013 points in individuals' willingness to take risks on the 11-point Likert scale ($p = 0.012$). While being statistically significant, the magnitude of the relationship is very small. This association between temperature and general risk attitudes remained when we included sex and a set of demographic controls; see Model (2) of Table 3. Women, however, were significantly less willing to take risks. This finding adds to the ongoing debate about sex differences in risk preferences (e.g., Croson and Gneezy, 2009; Filippin and Crosetto, 2016).

The statistically significant, albeit very small, positive association between temperature and general risk attitudes was stable towards including chronic illness controls. Including a dummy for individuals with chronic disease did not change this association; see Models (3) and (4) of Table 3. In addition, accounting for the type of chronic illness such as diabetes, asthma, or hypertension did not relate significantly to individuals' general risk attitudes. The positive relationship between temperature and a general willingness to take risks remained, however; see Models (5) to (8) of Table 3.

In contrast, individuals' health risk attitudes did not significantly relate to temperature; see Model (1) of Table 4. Females were, on average, also more risk-averse in the health domain; see Model (2) of Table 4. The presence of any chronic illness had a positive relationship with health-risk attitudes only; see Model (3) of Table 4. However, controlling for the type of the chronic disease, either diabetes, asthma, or hypertension, showed no significant link to health risk attitudes; Models (5) to (8) of Table 4. The differences in the association between temperature and general or health risk attitudes emphasizes the domain specificity of risk preferences.

5.2. Robustness

We used several specifications to assess the robustness of our results. First, our results are robust towards different measures of temperature. Temperature as a six-day average, Temp6DayAvg, was associated with a statistically significant increase of 0.013 points ($p = 0.012$) in general risk attitudes; see Model (1) of Table A.3 in Appendix A.2. We did not find systematic evidence for a non-linear relationship between temperature and general risk attitudes; see Models (2) and (3) of Table A.3 in Appendix A.2.[4] Temperature defined as the deviation from the monthly average, ΔTemp, was associated with general risk attitudes as well; see Model (4) of Table A.3 in Appendix A.2. A one-unit increase in temperature difference related to an increase of 0.020 points ($p = 0.092$) in general risk attitudes. When controlling for season in Model (5) of Table A.3, a one-unit increase in temperature was associated with an increase of 0.019 points ($p = 0.020$) in general risk attitudes. Also, when controlling for barometric pressure and relative humidity in Model (6) of Table A.3, a one-unit increase in temperature was associated with an increase of 0.011 points ($p = 0.075$) in general risk attitudes. For health risk attitudes, analogously to the main results, we observed no association with temperatures; see Models (1) to (6) in Table A.4 in Appendix A.2. It is quite noteworthy that barometric pressure was significantly negatively associated with health-related risk attitudes; see Model (6) Table A.3 in Appendix A.2.

Second, when controlling for individuals' optimism, the association between temperature and general risk attitudes persisted. A one-unit increase in temperature was related to an increase of 0.014 points ($p = 0.005$) in risk attitudes. Also, the non-significant result for health-related risk attitudes remained; see Model (7) in Tables A.3 and A.4 in Appendix A.2.

Third, Table A.5 in Appendix A.2 expresses temperatures in deciles. Compared to the reference level (1st decile), temperatures in the 6th, 8th, and 10th decile were associated with an increase in general risk

[4] Including temperature as a squared or cubic term did not improve model fit. The significant temperature coefficient disappeared when including temperature as a squared term. However, when including a cubic term, temperature was still significantly associated with general risk attitudes. A one-unit increase in temperature related to an increase of 0.025 points ($p = 0.076$) in general risk attitudes.

Table 3
Self-reported general risk attitudes.

Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Temperature	0.013**	0.013***	0.013***	0.014*	0.012**	0.015***	0.014**	0.014**
	(0.005)	(0.005)	(0.005)	(0.007)	(0.005)	(0.005)	(0.007)	(0.007)
Chronic			−0.079	−0.057				
			(0.086)	(0.137)				
Chronic × Temperature				−0.002				
				(0.010)				
Diabetes					0.032			0.050
					(0.243)			(0.246)
Diabetes × Temperature					0.018			0.020
					(0.017)			(0.017)
Asthma						0.295		0.280
						(0.235)		(0.235)
Asthma × Temperature						−0.011		−0.009
						(0.017)		(0.018)
Hypertension							−0.136	−0.134
							(0.136)	(0.138)
Hypertension × Temperature							−0.001	−0.004
							(0.010)	(0.010)
Female		−1.030***	−1.042***	−1.042***	−1.024***	−1.032***	−1.055***	−1.056***
		(0.083)	(0.085)	(0.085)	(0.084)	(0.083)	(0.085)	(0.085)
Controls	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	3.966***	3.805***	3.781***	3.774***	3.838***	3.783***	3.736***	3.728***
	(0.069)	(0.549)	(0.549)	(0.551)	(0.549)	(0.549)	(0.551)	(0.552)
Adjusted R^2	0.002	0.074	0.074	0.073	0.074	0.074	0.074	0.075
N	2454	2454	2454	2454	2454	2454	2454	2454

Notes: This table reports estimates from OLS regressions, standard errors in brackets. "Temperature" in Models (1) to (8) is the 24-h average ambient temperature in degrees Celsius (°C) in Augsburg. "Chronic" is a dummy being equal to 1 if individuals have asthma, diabetes, or hypertension, and 0 otherwise. $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

Table 4
Self-reported health risk attitudes.

Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Temperature	0.001	0.001	0.001	−0.001	−0.0001	0.0007	0.002	0.002
	(0.005)	(0.005)	(0.005)	(0.008)	(0.006)	(0.006)	(0.007)	(0.008)
Chronic			0.214**	0.166				
			(0.092)	(0.146)				
Chronic × Temperature				0.004				
				(0.010)				
Diabetes					0.201			0.144
					(0.259)			(0.262)
Diabetes × Temperature					0.008			0.009
					(0.018)			(0.018)
Asthma						0.167		0.152
						(0.251)		(0.251)
Asthma × Temperature						0.002		0.001
						(0.019)		(0.019)
Hypertension							0.219	0.212
							(0.145)	(0.147)
Hypertension × Temperature							−0.001	−0.003
							(0.010)	(0.011)
Female		−0.703***	−0.668***	−0.669***	−0.694***	−0.706***	−0.668***	−0.668***
		(0.089)	(0.090)	(0.090)	(0.089)	(0.089)	(0.090)	(0.090)
Controls	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	3.288***	4.354***	4.417***	4.433***	4.386***	4.328***	4.436***	4.422***
	(0.072)	(0.585)	(0.585)	(0.587)	(0.585)	(0.586)	(0.588)	(0.588)
Adjusted R^2	0.000	0.026	0.028	0.028	0.027	0.026	0.028	0.027
N	2454	2454	2454	2454	2454	2454	2454	2454

Notes: This table reports estimates from OLS regressions, standard errors in brackets. "Temperature" in Models (1) to (8) is the 24-h average ambient temperature in degrees Celsius (°C) in Augsburg. "Controls" comprise age, education, income, and region. "Chronic" is a dummy being equal to 1 if individuals have asthma, diabetes, or hypertension, and 0 otherwise. $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

attitudes. Temperatures in the 6th decile (10.6 to 13.2 °C) were related to an increase of 0.488 points (p = 0.008), temperatures in the 8th decile (16.4 to 19 °C) to an increase of 0.378 points (p = 0.044), and temperatures in the 10th decile (21.8 to 28.2 °C) to an increase of 0.446 points (p = 0.016) in general risk attitudes. As before, temperature was not associated with health-related risk attitudes.

Finally, to evaluate our statistical approach, we re-estimated Model (2) of Table 3 as *ppo* models. For a one-unit increase in temperature, the odds of having higher general risk attitudes increased by 1.2% (OR: 1.012, p = 0.004). Temperature showed no significant relationship with health-related risk attitudes. Using a three-leveled risk-attitude measure, the odds of having higher risk attitudes increased by 0.9% for a one-unit increase in temperature (OR: 1.009, p = 0.049). Again, no association became evident for health risk attitudes; see Tables A.6 and A.7 in Appendix A.2.

6. Discussion

This paper analyzes the relationship between ambient temperature and self-reported risk attitudes in a population of older adults in southern Germany. We found a statistically significant, albeit very small, positive association between temperature and (self-reported) general willingness to take risks. Our results are not driven by the three subpopulations of at-risk individuals, as findings are robust for individuals with chronic diseases. Additionally, our results do not hint at a non-linear relationship between temperature and general risk attitudes. In contrast to the general willingness to take risks, we did not find any statistically significant association between temperature and health-related risk attitudes. Taken together, our results suggest that risk attitudes for older individuals tend to be rather stable towards changes in ambient temperatures.

Our findings resonate somewhat with evidence provided by Syndicus et al. (2018). In some risk-elicitation tasks, participants in a higher temperature condition indicated higher risk-taking tendencies. However, only temperatures at the higher end of the spectrum were investigated (≤25°C and ≥30°C in the different conditions, respectively). Our result on the missing association of temperature and health-related risk attitudes supports the findings by Stroom et al. (2021), who could not show an effect of high temperature on health risk attitudes either. However, in contrast to our findings, they only detected a significant difference between the high temperature and control condition in the general domain for men. In addition, men were less willing to take risks during high temperatures (Stroom et al., 2021), which seems to contradict our finding of a positive relationship between temperature and risk attitudes. It has to be noted that, similar to Syndicus et al. (2018), only higher temperatures were assessed (22 °C and 28 °C in the different conditions, respectively), rather than the whole temperature spectrum as in our study.

The observed differences between domains supports the claim of domain-specific risk attitudes next to domain-general ones (e.g., Galizzi et al., 2016; Frey et al., 2017). It could be possible that individuals are in general more willing to take risks when temperatures are higher. However, this does not necessarily translate into a change of health-related risk attitudes.

One possible explanation might follow from the cognitive representations and processes behind individuals' risk attitudes. When self-reporting their general risk attitudes, individuals often consider frequent personal experiences, active or voluntary choices, and risks with rather controllable consequences to achieve a judgment about their risk attitudes. They may also think about domain-general risks (e.g., the valence of an outcome), but tap into a variety of different risk domains as well (Arslan et al., 2020; Steiner et al., 2021). Steiner et al. (2021) suggest that, although individuals rely on diverse experiences, they aggregate over those to reach an overall judgment of their general risk attitudes. It seems plausible that individuals refer to a diverse set of risks when asked about their general risk attitudes, since no focus on a particular domain is specified. However, asking about a specific risk domain – in our case the health domain – might provoke stronger associations with previous health experiences and risks; for a similar argument, see Steiner et al. (2021). This might be especially relevant in our sample, since more than half of our participants had at least one chronic disease potentially leading to a higher temperature sensitivity. Their likelihood of having experienced negative health effects, also in connection with temperature, is higher and might be more salient to them. In response, they might not be willing to take more health risks and maintain their level of health risk attitudes even at higher temperatures.

While our findings for the general domain were very robust, the very small magnitude of the regression coefficients needs to be taken into account. It varied between 0.011 and 0.025 points for a change of one degree Celsius across different temperature specifications in our OLS models. Of course, daily temperature fluctuations are usually greater. The standard deviation for our basic temperature variable equaled 8.4 degrees Celsius. As can be expected, associations were larger when temperature was measured in deciles (between 0.378 and 0.488). Nevertheless, even when higher general risk attitudes were associated with higher temperatures, these associations were rather small so that effects might not be considered meaningful from a policy or economic perspective. Additionally, future research needs to address whether and how this manifests in adjusted behavior.

The present research has some limitations. First, our sample stems from one particular region in the south of Germany with a moderate climate. Thus, potential effects at very high or low temperatures could probably not be detected, which might explain our missing findings for non-linear relationships between temperature and risk attitudes.

Also, our data can only illustrate the relationship between temperature and risk attitudes in a cross-sectional manner. This generally makes causal interpretations difficult. Thus, longitudinal analyses might be helpful. They could also provide more insight into the durability of temperature-related changes in general risk attitudes beyond our longest time frame of six days.

Finally, we used a self-reported measure to assess risk attitudes, which does display the disadvantages inherent to all self-reported measurement approaches. However, this measure has been validated with an incentivized lottery task (Dohmen et al., 2011; Falk et al., 2018, 2023) and has been applied in different research contexts (e.g., Decker and Schmitz, 2016; Jaeger et al., 2010; Mamerow et al., 2016).

Future analyses could use a longitudinal data set on risk attitudes and extend the findings on behavioral mechanisms and cognitive processes behind self-reported general risk attitudes (see Arslan et al., 2020; Steiner et al., 2021) to risk attitudes in different domains. Potential deviations in these processes might explain our domain-specific results with respect to temperature. Complementing this, future research should replicate our findings and assess the relationship between temperature and risk attitudes in additional contexts such as the financial or recreational domain.

In sum, this paper contributes to the understanding of self-reported risk attitudes and their relationship with situational factors. We found evidence for a statistically significant, albeit very small, positive relationship between ambient temperature and a general willingness to take risks. The missing significant link with health-related risk attitudes supports the claim of domain-specific risk attitudes. Our unique sample included information on the study participants' chronic diseases. However, controlling for chronic diseases did not influence the links between temperature and risk attitudes. This suggests some evidence for the stability of risk attitudes towards temperature changes and across samples. Further research is needed however.

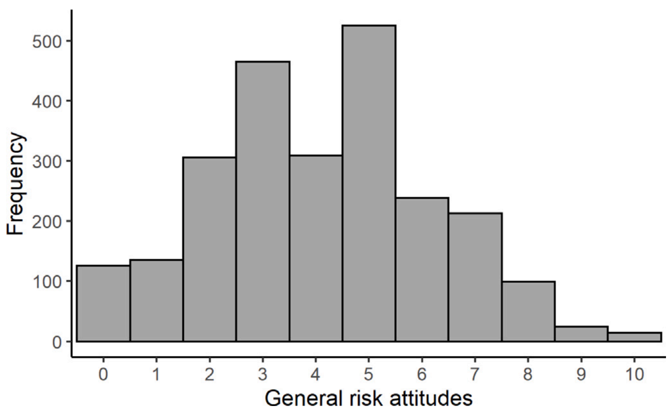

Fig. A.1. Histogram of general risk attitudes ranging from 0 = "not willing to take risks" to 10 = "very willing to take risks".

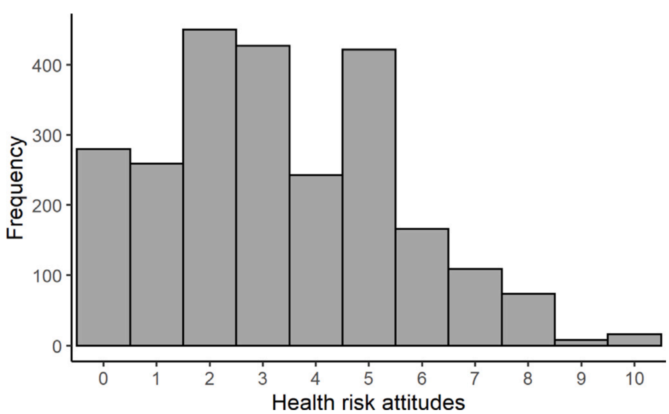

Fig. A.2. Histogram of health risk attitudes ranging from 0 = "not willing to take risks" to 10 = "very willing to take risks".

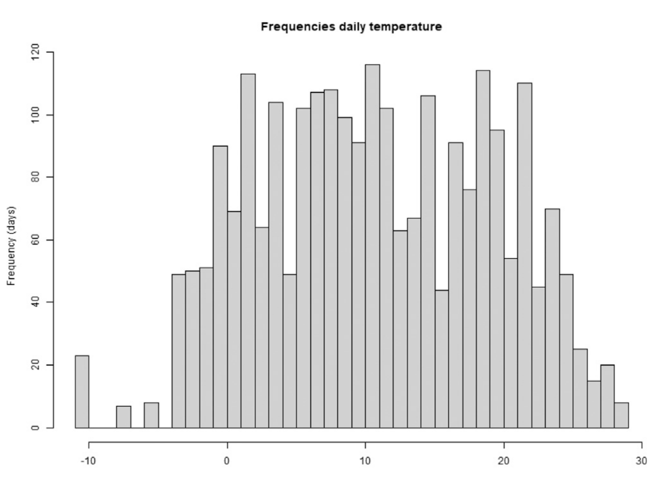

Fig. A.3. Histogram of temperature levels in days. Indicated as 24-h average temperature in °C on the day a study participant visited the study center; $N = 2454$; time frame: January 2018–June 2019.

CRediT authorship contribution statement

Adriana N. König: Conceptualization, Methodology, Formal analysis, Visualization, Writing – original draft. **Michael Laxy:** Investigation, Data curation, Writing – review & editing. **Annette Peters:** Investigation, Data curation, Writing – review & editing. **Alexandra Schneider:** Investigation, Data curation, Writing – review & editing. **Kathrin Wolf:** Investigation, Data curation, Writing – review & editing. **Lars Schwettmann:** Conceptualization, Writing – review & editing, Supervision. **Daniel Wiesen:** Conceptualization, Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

KORA-Fit data used in this study can be applied for via the digital application tool KORA.PASST as part of a project agreement under https://www.helmholtz-munich.de/epi/research/cohorts/kora-cohort/data-use-and-access-via-korapasst/index.html. Temperature data are available via the German Weather Service (Deutscher Wetterdienst) at https://cdc.dwd.de/portal/. R codes of the statistical analyses are available from the corresponding author upon request.

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Appendix

A.1. Additional tables and figures

See Figs. A.1–A.3 and Tables A.1 and A.2

A.2. Robustness checks

See Tables A.3–A.7

Table A.1
Frequencies for health conditions.

	Number	(in %)
Hypertension	1217	(49.6)
Diabetes	202	(8.2)
Asthma	204	(8.3)
One or more chronic diseases	1338	(54.5)
Observations	2454	

Table A.2
Frequencies for risk attitudes in partial proportional odds models.

	Frequency (%)
Self-reported general risk attitudes	
Low	1032 (42.1)
Medium	1072 (43.7)
High	350 (14.3)
Self-reported health risk attitudes	
Low	1416 (57.7)
Medium	831 (33.9)
High	207 (8.4)
Observations	2454

Notes: Low risk attitudes include response levels 0 to 3; medium risk attitudes include response levels 4 to 6; high risk attitudes include response levels 7 to 10.

Table A.3
Robustness checks on general risk attitudes.

Model:	(1) Temp6DayAvg	(2) Squared temperature	(3) Cubic temperature	(4) ΔTemp	(5) Season	(6) Barometric pressure & relative humidity	(7) Optimism
Temperature	0.013**	0.018	0.025*	0.020*	0.019**	0.011*	0.014***
	(0.005)	(0.013)	(0.014)	(0.012)	(0.008)	(0.006)	(0.005)
Squared temperature		−0.0002	−0.002				
		(0.001)	(0.002)				
Cubic temperature			0.00005				
			(0.00005)				
Age	−0.001	−0.001	−0.001	−0.002	−0.001	−0.001	−0.002
	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
Female	−1.028***	−1.031***	−1.029***	−1.030***	−1.030***	−1.035***	−1.033***
	(0.083)	(0.083)	(0.083)	(0.084)	(0.083)	(0.084)	(0.083)
Education	0.029*	0.029*	0.029*	0.030*	0.029*	0.029*	0.017
	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)
Income	0.159***	0.159***	0.159***	0.160***	0.160***	0.156***	0.112**
	(0.046)	(0.046)	(0.046)	(0.046)	(0.046)	(0.046)	(0.046)
Region	−0.027	−0.024	−0.030	−0.064	−0.032	−0.032	−0.027
	(0.087)	(0.088)	(0.088)	(0.086)	(0.088)	(0.087)	(0.087)
Season					−0.120		
					(0.139)		
Barometric pressure						−0.006	
						(0.005)	
Relative humidity						−0.005	
						(0.004)	
Optimism							0.071***
							(0.012)
Constant	3.816***	3.789***	3.831***	3.952***	3.817***	9.908*	2.933***
	(0.549)	(0.550)	(0.552)	(0.545)	(0.549)	(5.664)	(0.564)
Adjusted R^2	0.073	0.073	0.073	0.072	0.074	0.074	0.087
N	2454	2454	2454	2454	2454	2454	2454

Notes: This table reports estimates from OLS regressions, standard errors in parentheses. Temperature measure in Model (1) is Temp6DayAvg, in Model (2) and (3), it is the main Temperature variable, and in Model (4), we use ΔTemp. Model (5) considers the main temperature measure and contains controls for season, while Models (6) and (7) control for barometric pressure as well as humidity and optimism, respectively; $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

Table A.4
Robustness checks on health risk attitudes.

Model:	(1) TEMP6DAYAVG	(2) Squared temperature	(3) Cubic temperature	(4) ΔTEMP	(5) Season	(6) Barometric pressure & relative humidity	(7) Optimism
Temperature	0.002	0.017	0.023	−0.002	−0.001	0.002	0.0002
	(0.006)	(0.013)	(0.015)	(0.013)	(0.009)	(0.006)	(0.005)
Squared temperature		−0.001	−0.002				
		(0.001)	(0.002)				
Cubic temperature			0.00004				
			(0.00005)				
Age	−0.013*	−0.013	−0.013*	−0.014*	−0.013*	−0.014*	−0.013
	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
Female	−0.703***	−0.707***	−0.706***	−0.703***	−0.703***	−0.710***	−0.701***
	(0.089)	(0.089)	(0.089)	(0.089)	(0.089)	(0.089)	(0.089)
Education	0.015	0.016	0.016	0.015	0.015	0.016	0.024
	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)
Income	0.013	0.011	0.012	0.013	0.013	0.009	0.049
	(0.049)	(0.049)	(0.049)	(0.049)	(0.049)	(0.049)	(0.050)
Region	−0.101	−0.095	−0.099	−0.107	−0.102	−0.110	−0.103
	(0.093)	(0.093)	(0.093)	(0.092)	(0.093)	(0.093)	(0.093)
Season					0.044		
					(0.148)		
Barometric pressure						−0.012**	
						(0.006)	
Relative humidity						−0.001	
						(0.004)	
Optimism							−0.054***
							(0.013)
Constant	4.340***	4.301***	4.334***	4.372***	4.349***	16.594***	5.013***
	(0.585)	(0.587)	(0.588)	(0.581)	(0.586)	(6.037)	(0.603)
Adjusted R^2	0.026	0.027	0.026	0.026	0.026	0.027	0.033
N	2454	2454	2454	2454	2454	2454	2454

Notes: This table reports estimates from OLS regressions, standard errors in parentheses. Temperature measure in Model (1) is TEMP6DAYAVG, in Model (2) and (3), it is the main Temperature variable, and in Model (4), we use ΔTEMP. Model (5) considers the main temperature measure and contains controls for season, while Models (6) and (7) control for barometric pressure as well as humidity and optimism, respectively; $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

Table A.5
Self-reported risk attitudes with temperature in deciles.

Domain: Model:	General (1)	Health (2)
Temperature 2nd decile	0.059	0.118
	(0.184)	(0.196)
Temperature 3rd decile	0.201	0.124
	(0.183)	(0.195)
Temperature 4th decile	0.294	0.215
	(0.183)	(0.195)
Temperature 5th decile	0.229	0.219
	(0.184)	(0.196)
Temperature 6th decile	0.488***	0.113
	(0.184)	(0.196)
Temperature 7th decile	0.164	−0.020
	(0.184)	(0.196)
Temperature 8th decile	0.378**	0.164
	(0.188)	(0.200)
Temperature 9th decile	0.252	0.124
	(0.183)	(0.195)
Temperature 10th decile	0.446**	0.097
	(0.185)	(0.197)
Age	−0.001	−0.014*
	(0.008)	(0.008)
Female	−1.031***	−0.704***
	(0.084)	(0.089)
Education	0.028*	0.015
	(0.017)	(0.018)
Income	0.158***	0.013
	(0.046)	(0.049)
Region	−0.033	−0.107
	(0.088)	(0.094)
Constant	3.733***	4.267***
	(0.562)	(0.599)
Adjusted R^2	0.073	0.024
N	2454	2454

Notes: This table reports estimates from OLS regressions, standard errors in brackets. Main temperature measure in deciles; deciles: 1st (comparison): $(-10.3, -0.306]$; 2nd: $(-0.306, 2.41]$; 3rd: $(2.41, 5.54]$; 4th: $(5.54, 7.8]$; 5th: $(7.8, 10.6]$; 6th: $(10.6, 13.2]$; 7th: $(13.2, 16.4]$; 8th: $(16.4, 19]$; 9th: $(19, 21.8]$; 10th: $(21.8, 28.2]$. $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

Table A.6
Self-reported risk attitudes partial proportional odds model: log odds.

Model:	(1)	(2)
Temperature	0.009*	−0.001
	(0.005)	(0.005)
0|1 Temperature		
1|2 Temperature		
Age	0.005	−0.016**
	(0.007)	(0.007)
0|1 Age		
1|2 Age		
Female		−0.524***
		(0.082)
0|1 Female	0.626***	
	(0.084)	
1|2 Female	1.136***	
	(0.127)	
Education	0.018	0.004
	(0.016)	(0.017)
0|1 Education		
1|2 Education		
Income		0.014
		(0.045)
0|1 Income	−0.075	
	(0.046)	
1|2 Income	−0.208***	
	(0.060)	
Region		−0.132
		(0.085)
0|1 Region	−0.050	
	(0.088)	
1|2 Region	0.205*	
	(0.121)	
Constant		
0|1 Constant	0.182	−0.984*
	(0.515)	(0.533)
1|2 Constant	2.383***	1.118**
	(0.532)	(0.534)
N	2454	2454

Notes: This table reports estimates from partial proportional odds models as log odds, standard errors in brackets. Main temperature measure. $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

Table A.7
Self-reported risk attitudes partial proportional odds model: odds.

Domain: Model:	General risk (1)	Health risk (2)
Temperature	1.009* (0.005)	0.999 (0.005)
0|1 Temperature		
1|2 Temperature		
Age	1.005 (0.007)	0.984** (0.007)
0|1 Age		
1|2 Age		
Female		0.592*** (0.082)
0|1 Female	1.870*** (0.084)	
1|2 Female	3.115*** (0.127)	
Education	1.018 (0.016)	1.004 (0.017)
0|1 Education		
1|2 Education		
Income		1.015 (0.045)
0|1 Income	0.928 (0.046)	
1|2 Income	0.813*** (0.060)	
Region		0.876 (0.085)
0|1 Region	0.951 (0.088)	
1|2 Region	1.228* (0.121)	
Constant		
0|1 Constant	1.199 (0.515)	0.374* (0.533)
1|2 Constant	10.838*** (0.532)	3.060** (0.534)
N	2454	2454

Notes: This table reports estimates from partial proportional odds models as odds, standard errors in brackets. Main temperature measure. $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

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