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How people update their beliefs about climate change: An experimental investigation of the optimistic update bias and how to reduce it

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Author Note

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Author Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Tobias Kube, Peter Kramer and Sophia Lieb. The first draft of the manuscript was written by Tobias Kube and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Abstract

People usually update their beliefs selectively in response to good news and disregard bad news. Here, we investigated in two pre-registered experiments (*N*=278 and *N*=306) whether 1) such valence-dependent belief updating also underlies information processing in the context of climate change and 2) whether it can be altered by interventions informing about different aspects of climate change. To this end, we adapted a well-established belief update task to the context of climate change. In multiple trials, participants were asked about their beliefs about adverse consequences of climate change; subsequently, they were asked to update their beliefs in light of new information. Both studies provided evidence against the hypothesis that people integrate good news about climate change more than bad news. After half of the trials, participants were randomized to one of four video-based interventions, each of which aimed at promoting a more accurate risk perception and increasing pro-environmental intentions. After the interventions, participants showed a more accurate risk perception and women rather than men increased their intentions for pro-environmental behavior. The results provide implications for climate change communication as they show that when facing the consequences of climate change, people adjust their risk perception accurately and increase their pro-environmental intentions.

Keywords: belief updating; optimism bias; climate change; pro-environmental behavior; risk perception

Introduction

Although scientific evidence is accumulating to document the devastating consequences of climate change (IPCC, 2021), many people still hope that it may not be as calamitous as science predicts (Ojala, 2015; Wullenkord & Reese, 2021). Previous research has examined a number of psychological factors that contribute to the failure to translate scientific evidence into specific behaviors that help mitigate climate change (Gifford & Nilsson, 2014; Klöckner, 2013; Moser & Kleinhückelkotten, 2018), such as social norms (Biel & Thøgersen, 2007; Schultz et al., 2007), lack of personal experience (Weber, 2006), and ideological worldviews (Antonio & Brulle, 2011; Dunlap & McCright, 2008). Besides these well-studied predictors of behavior, biases in information processing are also relevant for the perception of climate change and pro-environmental behavior (Beattie et al., 2017; Jones et al., 2017; McDonald et al., 2015). In the present research, we sought to examine whether an optimistically biased integration of new information on climate change contributes to individual climate inaction.

Research from the well-established social psychology literature on attitude change and persuasion has shown that people in general respond quite rationally to the presentation of new evidence (Hill, 2017; Tappin & Gadsby, 2019; Wood & Porter, 2019). However, research on motivated reasoning (Kunda, 1990) has demonstrated that people can also be biased in their evaluation of evidence. For instance, people tend to integrate new information on political issues preferably if it is consistent with their general attitudes and partisanship (Swire et al., 2017; Taber et al., 2009; Tappin et al., 2017). In the context of climate change, one study supports the assumption that attitudes influence the extent to which new information is used to update beliefs: When presenting participants with manipulated information on the projected global temperature rise, Sunstein et al. (2017) found that people who deny the existence of – or threat by – anthropogenic climate change updated their

beliefs more if new information suggested that global warming may not be as dramatic as predicted than if it suggested that it may be even more dramatic than predicted. The opposite pattern was found for people who strongly believed in the threat by climate change (Sunstein et al., 2017). On the other hand, another recent study showed that regardless of political ideology, people did correct their beliefs about political statements as a function of the discrepancy between their prior beliefs and new evidence, indicating that the more the evidence deviated from participants' initial predictions, the more they updated their beliefs (Vlasceanu et al., 2021).

Aside from the consistency of new information with people's prior beliefs, the valence of new information also influences belief updating (Kube & Rozenkrantz, 2021; Sharot & Garrett, 2016). To examine valence-dependent belief updating, Sharot et al. (2011) developed a belief update task that has been widely used since its original introduction. In this task, participants are first asked to estimate their likelihood of being personally affected by an adverse life event (e.g., suffering from cancer). Subsequently, participants receive the actual average probability of experiencing the respective event. If participants' predicted likelihood is higher than the actual likelihood, new information is considered "good news", as it reflects that the participants overestimated the likelihood of an unpleasant event. The opposite applies to "bad news", which reflects that an unpleasant event is more likely than participants initially believed. Finally, participants update their personal likelihood of experiencing the event in light of new information. Using this task, the authors demonstrated that people update their beliefs more if new information conveys good news than if it conveys bad news (Garrett & Sharot, 2017; Sharot, Guitart-Masip, et al., 2012; Sharot et al., 2011). The integration of good news over bad news has been referred to as the *good news/bad news effect* (Lefebvre et al., 2017; Sharot et al., 2011) or the *optimistic update bias* (Garrett & Sharot, 2017). Relatedly, the *optimism bias* has been referred to as the tendency

to have optimistically biased beliefs about the future (that is, unrealistic optimism), and the mechanism that generates this bias includes positively biased belief updating (Sharot, 2011). In the present article, we will use the term "optimistic update bias" when referring to the preferential integration of good news over bad news.

The primary goal of the present research

The primary goal of the present study was to apply research on the optimistic update bias to the context of climate change and thereby to connect it with the literature on the role of hope and optimism in the perception of climate change inaction (Wilson, 2021). With regard to the latter, a series of studies by Ojala (2012a, 2012b, 2015) has drawn a differentiated picture of how optimism and hope influence action vs. inaction in the context of climate change: On the one hand, there is "constructive hope" (i.e., hope that motivates people to engage in actions that might help mitigate climate change) that is positively associated with pro-environmental behavior. On the other hand, hope based on denial (i.e., the unrealistic hope the consequences of climate change may not be as devastating as predicted), hinders pro-environmental behavior. Beyond these correlational studies, an experimental study investigated how trait optimism affects the perception of information related to climate change (Beattie et al., 2017): Using eye tracking, the authors found that people with high trait optimism spent particularly little time attending to information conveying bad news about climate change, which the authors interpreted as a form of ignorance.

Research on the optimistic update bias has mostly focused on beliefs about personal life events, while beliefs about public events have only rarely been considered. In terms of climate change, we are aware of only one study examining participants' update of beliefs in response to new information (Sunstein et al., 2017). The task from this study, however, was

not a version of the original belief update task comprising multiple trials (Sharot et al., 2011). The ultra-short version of a belief update task by Sunstein et al. (2017) actually comprises two serious problems in our view: First, it assesses the update of only one single belief and provides people with only piece of information, thereby significantly reducing the robustness of the results as compared to the multiple-trial design of the original task. Second, the investigators provided participants with fake information on the expected global temperature rise, which is problematic in our opinion, as we believe that the information participants are provided with in the belief update task should be accurately reflecting the current state of knowledge, as it was also done in the original task. Therefore, the aim of the present study was to apply an adaption of the original belief update task to the context of climate change by i) using multiple events and ii) carefully selecting those events based on current scientific knowledge. Accordingly, in multiple trials, participants were asked about their beliefs about a specific adverse event related to climate change before being presented with current evidence regarding this event and indicating an update of their beliefs.

Regarding the question of whether the optimistic update bias is pertinent in the context of climate change, two competing hypotheses can be considered. On the one hand, there is strong evidence for the optimistic update bias in relation to personal life events (Garrett & Sharot, 2017; Sharot, Guitart-Masip, et al., 2012; Sharot et al., 2011) and it is probable that climate change will also have consequences for people's personal lives. Therefore, one possible hypothesis is that people update their beliefs about climate change more in response to good news than in response to bad news. On the other hand, it has been argued in theoretical pieces of work that the optimistic update bias might diminish in the context of public events (Sharot, 2011; Sharot & Garrett, 2016), implying that while people are overly optimistic about their own future, they are more pessimistic about global issues. This distinction between "private optimism and public despair" has recently been demonstrated in

the context of the current COVID-19 pandemic (Globig et al., 2022), and there is some indication that it may also apply to the perception of climate change (Dunlap et al., 1993). Acknowledging the plausibility of both hypotheses, we pre-registered the prediction of a greater update of beliefs in response to good news than in response to bad news, since this was the most consistent finding from all previous studies using the original belief update task. In addition to that, the study by Beattie et al. (2017) suggests that optimism also influences information processing in the specific context of climate change.

Building on previous research (Beattie et al., 2017; Kuzmanovic et al., 2015; Sunstein et al., 2017), we will also examine whether the propensity to integrate good news over bad news is associated with low pro-environmental attitudes and high trait optimism. In addition, we will examine the association of belief updating with intentions for pro-environmental behavior.

An additional goal of the present research

Under the assumption that an optimistic update bias contributes to low pro-environmental intentions, an additional goal of the present research was to examine how an unbiased, accurate processing of new information on climate change can be supported. To this end, we applied three different video-based interventions, which were based on the following rationales. Drawing from research on “fear appeals” (Ruiter et al., 2014; Witte & Allen, 2000), we tested in one experimental condition whether informing people about the threatening consequences of climate change would promote an unbiased processing of new information and increase their pro-environmental intentions. However, other research has shown that simply providing people with threatening information often does not change their attitudes and behaviors (Kok et al., 2018). Rather, it is not only important how people perceive a threat, but also how they perceive possibilities to avert and control the threat

(Witte, 1992). In the specific context of climate change and environmental education, there is also evidence suggesting that in order to motivate people to change their behavior, it is not sufficient to inform them about the consequences of their behavior, but people also need to be presented with specific alternative behavioral options (Carlson et al., 2020; Nisa et al., 2019; Spence & Pidgeon, 2010). Therefore, we presented participants from a second condition, with both the video from the *Threat* condition on the threatening consequences of climate change and with a subsequent video highlighting individual actions that people might take to mitigate climate change. We predicted this approach to be more effective than the threat-only condition. Participants from a third condition were informed about common biases in risk perception (including the optimism bias), and we examined whether such information about typical biases would make people more aware of their own biases and thus improve the accuracy of information processing. To our knowledge, no previous study has tested the effects of such an approach in the context of climate change, but there is some evidence from clinical psychology suggesting that informing people about cognitive biases helps them be less prone to these biases (Kube et al., 2019). Beyond their theoretical value, the comparison of these three experimental conditions with a control condition in terms of their effects on changes in belief updating and pro-environmental intentions may provide implications for effective climate change communication.

General Methods

Ethics

Both studies were approved by the local ethics committee of the university where the studies were performed and were conducted in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments.

Transparency and openness

Both studies and the corresponding analyses were pre-registered on AsPredicted.org (Study 1: https://aspredicted.org/ATP_VTM; Study 2: https://aspredicted.org/L7J_44G). All materials are available through the manuscript and the supplement; remaining details regarding the materials as well as the data can be made available upon request.

Study 1

Methods

Participants

Participants who were at least 18 years old were recruited via email lists, public postings, and social media. As pre-registered, the required sample size was determined based on the intention to have enough power to detect small to medium effects (f = .20) of the three video-based interventions on reducing biased belief updating. This effect size was assumed based on the results of previous studies aiming to increase pro-environmental beliefs (Bieniek-Tobasco et al., 2020; Carlson et al., 2020; Nisa et al., 2019; Spence & Pidgeon, 2010). Accordingly, an a-priori power analysis using G*Power for an analysis of covariance (α = .05; 1-β = .80) indicated a minimum sample size of 277 participants. Of note, this sample size would clearly offer us enough power for the primary goal of the present study (i.e., examining whether the optimistic update bias is pertinent in the processing of new information on climate change), since previous research has found medium effects for the optimistic update bias (Garrett & Sharot, 2017; Sharot, Kanai, et al., 2012; Sharot et al., 2011).

The study was conducted online via the survey platform www.soscisurvey.de. Data collection lasted from July to September 2020. A total of 412 people participated in the study. Of these, 307 entered sufficient data to be included in the analyses according to the

pre-registration. Twenty-four participants did not endorse a control item as pre-defined and were therefore excluded. Another five participants had to be excluded because they reported technical problems with the videos. Thus, all analyses are based on data from 278 people (M_{age} = 29.8, *SD* = 11.6 years, 69.1% females). A majority of the sample reported to have a high-school degree (39.6%) or a university degree (48.2%).

Belief update task

We used an adapted version of the belief update task by Sharot et al. (2011), as illustrated in Figure 1. In particular, based on an extensive literature search regarding current scientific prognoses about adverse consequences of climate change, we developed 16 scenarios. Each of these scenarios described probable consequences of climate change, such as flooding, drinking water shortages, and species extinctions. Half of the scenarios referred to global events, the other half related to events located in Germany and Europe (see Table S1 in the supplement).

Insert Figure 1 here.

For each scenario, a general introduction was presented first. Afterwards, participants were asked to indicate how likely they think they will be affected by the event (by indicating a number between 0 and 100%). Next, participants were presented with current scientific prognoses on the probability for the respective event to occur. These probabilities ranged between 5% and 99%, with an average of 52.8% for the pre-intervention trials and 58.9% for the post-intervention trials. We deliberately aimed to have an average probability around 50% to make sure that the "room" for underestimating vs. overestimating the risk of an event is comparable. Based on the difference between participants' first estimation and the probability presented subsequently, an estimation error was computed. Specifically, the estimation error was calculated for each of the 16 scenarios based on the formula:

(1) Estimation error = first risk estimate - presented probability

An estimation error > 0 reflects an overestimation of the risk of the adverse climate event (i.e., conveying good news), an estimation error < 0 reflects an underestimation of the actual risk (i.e., conveying bad news). After receiving new information on the respective climate event, participants were asked to re-assess their personal estimations. Based on this updated risk estimate, a belief update score was calculated based on the following formula:

(2) Update score = first risk estimate - second risk estimate

For each participant, a belief update score was computed for the average belief update in all scenarios where the respective person received good news; the same was done for all bad news scenarios. The update score for good news reflects the extent to which participants adjusted their beliefs in all trials in which they overestimated the risk initially, whereas the update score for bad news refers to the overall update across all trials in which participants underestimated the risk, respectively. To compare the magnitude of the update regardless of the algebraic sign, an unsigned belief update score is computed for the comparison of valence-dependent belief updating. Separate update scores were computed for pre-intervention trials and post-intervention trials, resulting in four update scores per person: good news pre-intervention; good news post-intervention; bad news pre-intervention; bad news post-intervention. Finally, these update scores had to be adjusted based on the magnitude of the estimation error, because large estimation errors naturally result in large updates (Sharot & Garrett, 2022), that is, the update score of each trial for each participant is divided by the estimation error. For a critical discussion of the strengths and limitations of this belief update task, see supplement.

Video-based interventions

After the first half of the climate change scenarios (i.e., after scenario 8), participants were randomized to one of four conditions, all of which included the presentation of one or several video sequences. To make sure that the videos were comparable in terms of style and quality, the video-clips were taken from the German science TV broadcast "Quarks & Co.", produced by the WDR. Participants assigned to the condition called *Threat* were shown a video that emphasizes the calamitous consequences of climate change if actions to mitigate it were not undertaken (https://www.youtube.com/watch?v=FoMzyF_B7Bg; from min 0:02 to 2:48). In the condition referred to as *Threat + Options for Action*, participants first watched the same video as the previous group, before they were presented with another video highlighting individual options to reduce greenhouse gas emissions (https://www.youtube.com/-watch?v=eOnXVjWFIk4; from min 0:00 to 3:09). In the group *Psychoeducation*, participants were shown a video explaining that most people are prone to certain biases in their personal risk perception (https://www1.wdr.de/mediathek/video/sendungen-/quarksund-co/video-risiko-leben--sind-wir-gut- versichert-100.html; from min 20:20 to 24:33), including the underestimation of risks whose consequences are expected to occur in the more distal future (as opposed to the proximal future). In addition, participants were informed about the optimism bias in particular (https://www.youtube.com/-watch?v=B8rmi95pYL0; from min 0:15 to 2:38). Participants from the control group watched a video from the same TV broadcast showing the history of the German pension insurance system (https://www1.wdr.de/mediathek/video/send-ungen/quarks-und-co/video-risiko-leben--sind-wir-gut-versichert-100.html; from min 38:09 to 42:40). This video was chosen as it was similar to the previous videos in terms of length and style, yet with no direct link to climate change or cognitive biases.

Assessment of pro-environmental intentions

Pro-environmental intentions were assessed with an 8-item self-report questionnaire based on a scale by Broomell et al. (2015). Four of the items reflect general intentions to mitigate climate change (e.g., "I will strive to do something about the negative consequences of climate change"), while the other four items express the intention to exhibit specific behaviors to do something against global warming (e.g., "I plan to fly less to protect the climate"). Pro-environmental intentions were assessed twice: before and after completing the belief update task. Cronbach's alpha of the scale was $\alpha = .88$, both at the first and the second assessment.

Additional assessments

To examine potential associations with biased belief updating, we additionally assessed participants' attitudes towards the environment using the New Environmental Paradigm Scale (NEP) (Dunlap et al., 2000), dispositional optimism using the Life Orientation Test Revised (LOT-R) (Glaesmer et al., 2008), basic psychological needs and frustration using the Balanced Measure of Psychological Needs Scale (Sheldon & Hilpert, 2012), and depressive symptoms using the respective module of the Patient Health Questionnaire (PHQ-9) (Kroenke et al., 2001).

Since we could not assess participants' actual, but only their intended, pro-environmental behavior, we included a brief behavioral test as a proxy for people's actual behavior, as presented in the supplement (Table S2).

Statistical analyses

After data screening according to Tabachnick and Fidell (2019) and the examination of possible baseline differences, we performed a paired *t*-test to compare participants' belief update scores for good news trials and bad news trials. In doing so, only the pre-intervention

trials were considered (i.e., trials 1-8), as pre-registered. To assess a potential bias in belief updating, the difference between participants' update towards good news and their update towards bad news was computed, referred to as *asymmetry in belief updating* (with values > 0 reflecting greater update towards good news and thereby indicating a positivity bias). This variable reflecting the asymmetry in belief updating in the pre-intervention trials was correlated with participants' pro-environmental attitudes, trait optimism, and pro-environmental intentions at baseline. The associations with basic psychological needs and depressive symptoms are presented in the supplement. Furthermore, to examine whether the experimental interventions reduced the presumed asymmetry in belief updating, we performed an ANCOVA with the post-intervention asymmetry as the dependent variable, the experimental group as the independent variable, and the pre-intervention asymmetry as the covariate. All aforementioned analyses on belief updating were also rerun using linear mixed models to obtain more robust effect size estimates by considering participant and item variability, as presented in the supplement. Furthermore, we performed two repeated measures ANOVAs to examine whether changes in the estimation error from pre-intervention to post-intervention as well as changes in pro-environmental intentions differed between the experimental groups. Type-I error levels were set at 5%. For the effect sizes of interest (i.e., Cohen's d and η_p^2), we provide 95% confidence intervals. All analyses were performed using IBM SPSS version 27.

Results

Belief update at baseline (pre-intervention)

Participants updated their beliefs more in response to bad news about climate change than in response to good news, $t(263) = -4.036$, $p < .001$, $d = .248$, 95% CI [.126, .371], reflecting a small effect (see Figure 2a). Putting it differently, 59.6% of the participants integrated bad news over good news (as reflected by a difference score $\text{update}_{\text{good news}} -$

$update_{bad\ news} < 0$), 34.7% of the participants integrated good news over bad news ($update_{good\ news} - update_{bad\ news} > 0$), and 5.8% showed a perfectly balanced update pattern ($update_{good\ news} - update_{bad\ news} = 0$).

Insert Figure 2 here.

Relationship of belief updating with pro-environmental attitudes, trait optimism, and pro-environmental intentions

Participants who showed an optimistic update bias (that is, the subgroup of people who integrated good news over bad news) had lower pro-environmental attitudes (r = -.125, p = .043) and higher trait optimism (r = .127, p = .038), but an optimistic update bias was not related to pro-environmental intentions (r = .036, p = .564).

Effects of the video-based interventions

The video-based interventions were designed to reduce a presumed optimistic update bias in the context of climate change. This bias was not found, however, in the majority of the sample, as noted above. Therefore, the interventions could not address their intended target. Although this issue compromises the chance to find meaningful effects of the interventions on belief updating, the interventions had some interesting effects on additional variables, which were examined exploratorily post-hoc. These results are presented below.

Effects on belief updating. The ANCOVA indicated that the four experimental groups did not differ in their belief updating asymmetry, $F(3, 236) = 0.923$, p = .430, η_p^2 = .012, 95% CI [0, .040]. That is, the video-based interventions had no influence on the degree to which participants integrated good news relative to bad news in the post-intervention trials[1].

[1] Including only those participants who integrated good news over bad news did not yield significantly different results, but the resulting sub-sample (n = 91) was substantially under-powered for this analysis.

Effects on the accuracy of risk perception. We explored whether the interventions led to a more accurate and realistic initial risk assessment; that is, whether they reduced the difference between the first risk estimate and the actual risk (i.e., the estimation error). The repeated-measures ANOVA indicated a significant main effect of time, $F(1, 274) = 9.441$, $p = .002$, $\eta_p^2 = .033$, 95% CI [.004, .085], with a more accurate risk perception in the post-intervention trials than in the pre-intervention trials. There was also a significant time by condition interaction, $F(3, 274) = 3.869$, $p = .010$, $\eta_p^2 = .041$, 95% CI [.003, .087], reflecting a lower estimation error for the post-intervention trials than for the pre-intervention trials in the *Psychoeducation* condition and the control group, whereas no such reduction of the estimation error was found in the two conditions emphasizing the threats of climate change (*Threat* and *Threat + Options for Action*). The main effect of condition was not significant, $F(3, 274) = 1.590$, $p = .192$, $\eta_p^2 = .017$, 95% CI [0, .049].

Effects on pro-environmental intentions. The repeated measures ANOVA indicated a significant main effect of time, $F(1, 274) = 28.019$, $p < .001$, $\eta_p^2 = .093$, 95% CI [.038, .162], indicating that, across groups, participants reported higher pro-environmental intentions after the intervention than before. The main effect of condition was not significant, $F(3, 274) = 1.308$, $p = .272$, $\eta_p^2 = .014$, 95% CI [0, .044], nor was the time by condition interaction, $F(3, 274) = 0.571$, $p = .634$, $\eta_p^2 = .006$, 95% CI [0, .026].

Interestingly, post-hoc exploratory analyses revealed that the effects of the intervention on changes in pro-environmental intentions were modulated by gender: Changes in pro-environmental intentions from pre to post occurred only in female participants, whereas there was no such change in men on average, $F(1, 270) = 12.801$, $p < .001$, $\eta_p^2 = .045$, 95% CI [.009, .102], as displayed in Figure 3a.

Insert Figure 3 here.

Interim Discussion

The above results portray that, contrary to the processing of new information about personal life events, the majority of participants updated their beliefs about climate change more in response to bad news than in response to good news. However, participants with low pro-environmental attitudes and high trait optimism did show a propensity to integrate good news over bad news. To examine the robustness of these effects – as well as the exploratory results obtained from Study 1 – we performed a replication study.

Study 2

Methods

Study 2 followed the same general procedure, used the same measures, and applied the same statistical analyses as Study 1. Data were collected between May and September 2021.

Participants

A total of 438 people participated in the study. Of these, 315 entered a sufficient amount of data according to the pre-registration. Nine participants were excluded because they did not endorse a control item correctly and/or their data entry raised concerns about whether they completed the survey conscientiously, as pre-registered. Thus, all subsequent analyses were based on data from 306 participants (M_{age} = 31.12 years, SD = 13.61, 69.9% female). A majority of the sample had a high-school degree ("Abitur" in German; 44.8%) or a university degree (47.1%). The experimental conditions did not differ in any baseline variable, as presented in the supplement.

Belief update task

The belief update task from Study 1 was slightly modified for Study 2 in order to address a potential limitation of Study 1. In particular, we changed the wording of the question about participants' risk estimate, for the following reason. In Study 1, participants

had been asked about how likely they think they will be affected by certain consequences of climate change. For some of the scenarios, this may have been somewhat inconsistent with the way in which the actual likelihoods were presented subsequently, as they did not provide personalized risk estimates, but general probabilities of the respective events. To increase consistency, we therefore changed the questions about participants' risk estimates such that they were asked how likely they think a certain adverse event would occur (e.g., "*What is your personal estimate of the percentage by which drought duration in Germany will increase with a 3°C temperature rise due to global warming?"*). Furthermore, when providing participants with the actual probabilities of the respective climate event, we presented additional information on how this event might affect humans (see supplement). This addition was supposed to increase the individual relevance of the information presented, as we reasoned that the addition of the possible consequences of the climate change events for humans should make it more difficult for participants to disregard the information received by thinking that they will not be affected by it.

Moreover, we created a number of new scenarios and removed some of the previous ones (see supplementary Table S3). Specifically, we removed scenarios in which very high or very low probabilities were presented to participants, because very high vs. low numbers make it difficult for participants to underestimate vs. overestimate the probabilities (Sharot & Garrett, 2022; Sharot et al., 2011). For instance, if the probability of a certain event to occur is 99%, the majority of the sample will underestimate that risk for mathematical reasons; the same logic applies to very low probabilities. Therefore, we decided to use only scenarios in Study 2 in which the probabilities range between 20% and 80%. The average probability of the pre-intervention trials was 52.3% and the average probability of post-intervention trials was 53.9%, thus leaving almost the same "room" for underestimations vs. overestimations. Furthermore, we added some additional scenarios to increase the robustness

of the results across scenarios. Accordingly, we used a set of 22 scenarios (with 11 scenarios before vs. after the intervention). Yet one pre-intervention scenario and one post-intervention had to be excluded because of an extremely unequal distribution of the estimation error (i.e., 97% of the sample - 93%, respectively - overestimated the actual risk). Thus, all analyses in Study 2 are based on data from 20 scenarios.

Video-based interventions

The three interventions used in Study 2 were the same as in Study 1. For the control group, we decided to use a different video because we wanted to rule out the possibility that the video from Study 1 about the history of the German pension insurance system may have triggered thoughts about a threatening future and people's future prospects, and may thus not have been neutral enough. Instead, we used a sequence from the movie "Kick it like Beckham" (min 67:28 to 71:34) that was completely unrelated to topics such as climate change, sustainability, risk assessment, and future prospects. To examine whether the contents of the videos were perceived as intended, we performed a manipulation check, which is presented in the supplement.

Results

Belief update at baseline (pre-intervention)

Although there was again a descriptive trend indicating that participants updated their beliefs slightly more in response to bad news than in response to good news, this effects was not statistically significant in Study 2, $t(291) = -0.764$, $p = .445$, $d = .045$, 95% CI [-.070, .159], as displayed in Figure 2b. In Study 2, 47.9% of the sample updated their beliefs more in response to bad news than in response to good news, 45.5% integrated good news over bad news, and 6.6% showed a symmetric update pattern.

Relationship of belief updating with pro-environmental attitudes, trait optimism, and pro-environmental intentions

As in Study 1, the propensity to integrate good news more than bad news was associated with lower pro-environmental attitudes (r = -.179, p = .002) and higher trait optimism (r = .131, p = .026). It was also related to lower pro-environmental intentions (r = -.148, p = .011), indicating that the more participants integrated good news over bad news, the less they expressed the intention to change their behavior to mitigate climate change.

Effects of the video-based interventions

Effects on belief updating. As in Study 1, the four experimental groups in Study 2 did not significantly differ in their post-intervention update of good news relative to bad news, $F(1, 284) = 0.024$, p = .995, $\eta_p^2 < .001$, 95% CI [0, .005][2].

Effects on the accuracy of risk perception. As in Study 1, the main effect of time showed that the estimation error was reduced from pre-intervention to post-intervention, $F(1, 291) = 54.714$, $p < .001$, $\eta_p^2 = .158$, 95% CI [.089, .233]. A significant time by condition interaction ($F(3, 291) = 2.818$, p = .039, η_p^2 = .028, 95% CI [.001, .067]) indicated that this reduction of the estimation error was most pronounced in the condition *Threat,* whereas it was lowest in the control group, $t(147) = 2.438$, p = .016, d = .400, 95% CI [.075, .724]. The difference between the *Threat* condition and the *Psychoeducation* condition was also significant, $t(144) = 2.326$; p = .021; d = .386; 95% CI [.057, .714]. The other group comparisons were non-significant.

Effects on pro-environmental intentions. Replicating Study 1, the main effect of time was significant, $F(1, 300) = 77.575$, $p < .001$, $\eta_p^2 = .205$, 95% CI [.130, .282], indicating that across groups, participants reported higher pro-environmental intentions after

[2] Again, this was not different when including only those participants who integrated good news over bad news.

the interventions than before. As in Study 1, the time by condition interaction was not significant, $F(3, 300) = 0.027$, $p = .994$, $\eta_p^2 < .001$, 95% CI [0, .001].

Replicating Study 1, the changes in pro-environmental intentions were again modulated by gender, as indicated by a significant time by gender interaction, $F(1, 300) = 4.495$, $p = .035$, $\eta_p^2 = .015$, 95% CI [.001, .052], showing that women increased their intentions to protect the environment from pre-intervention to post-intervention more than men, as displayed in Figure 3b.

Discussion

The primary goal of the present research was to examine how people update their beliefs about climate change in light of new information. Unlike beliefs about personal life events (Sharot et al., 2011), both studies provided evidence against the hypothesis that people update their beliefs about climate change more in response to good news than in response to bad news. In Study 1, participants updated their beliefs even more in response to bad news, but this effect was small and did not replicate in Study 2. Thus, both studies disconfirmed the hypothesis of an optimistic update bias in the context of climate change. Some interpretations may account for this.

First, the results are consistent with recent results from the context of the COVID-19 pandemic (Globig et al., 2022) as well as theoretical arguments (Sharot, 2011; Sharot & Garrett, 2016), suggesting that while people tend to be overly optimistic about their own future, they may not be in relation to more global issues. This distinction has been referred to as “private optimism vs. public despair” and the current findings are consistent with it. Second, it is conceivable that our participants perceived the information on climate change as threatening, resulting in a more thorough consideration of bad news as compared to usual belief updating. This interpretation draws on a study by Garrett et al. (2018) which showed

that the optimistic update bias diminishes when people are under perceived threat, which they interpreted from an evolutionary perspective in terms of the necessity to pay sufficient attention to warning signals when threatened. Accordingly, the engagement with climate change in the context of the present study might have increased the perceived threat by climate change; hence participants might have been more open to integrating bad news. Third, the discrepancy might be related to our modified belief update task (Sharot & Garrett, 2022). In particular, in the original task (Sharot et al., 2011), participants were presented with the average likelihood of being affected by an adverse event (such as suffering from cancer). In the context of climate change, however, it is difficult to determine average risks for individual participants given the global nature and the complexity of the climate crisis. Hence, participants might have had difficulty assessing their personal risk resulting from the more global and – in part – more distal adverse events.

Although the majority of participants was not prone to an optimistic update bias, 35-45% of the participants (across studies) did have this bias as they integrated good news over bad news. Consistent with the findings by Sunstein et al. (2017), this propensity was related to low pro-environmental attitudes. Furthermore, in line with previous research (Kuzmanovic et al., 2015; Sharot et al., 2011), the optimistic update bias was associated with high trait optimism. However, the magnitude of these associations was only small to moderate and should therefore not be overestimated. Nevertheless, these associations may be important to consider as they point to a subgroup of people who are hesitant to take actions against climate change. Indeed, our finding that a subgroup of participants, who are less supportive of pro-environmental actions, integrate good news over bad news, aligns well with what Ojala (2012a, 2015) has referred to as “hope based on denial”. Specifically, according to Ojala (2012a, 2015), this concept means that some people hope that climate change may not be as devastating as predicted by ignoring scientific evidence, and this

corresponds well with our finding that about 35-45% of participants take information less into account when it suggests more dramatic consequences of climate change than they expected.

The additional goal of the present research, that is, the effects of different interventions to reduce an optimistic update bias could not be investigated meaningfully because most participants did not show that bias. However, exploratory analyses revealed some interesting additional effects of these interventions. In particular, the results show that an intense consideration of the probable consequences of climate change promoted a more accurate risk assessment. When interpreting these results, though, it should be noted that only Study 2 found the increase in accuracy in the intervention groups to be different from the control group. Hence, it may be that the increase in accuracy in Study 1 was related to learning (in terms of getting familiar with the task and/or assessing climate risks more realistically over time), rather than to the specific contents of the intervention. Moreover, the results of both Study 1 and Study 2 consistently showed that people's intentions to take personal actions to mitigate climate change increased from pre-intervention to post-intervention. This is encouraging from a pro-environmental perspective, because according to the theory of planned behavior, intentions for a specific behavior are the basis for actually showing that behavior (Ajzen, 1991). However, the specificity of the contents of the interventions is again questionable, because the increase in pro-environmental intentions was found in the control group as well in both studies. This suggests that the intense engagement with the likely consequences of climate change – as all participants did by completing the belief update task – led to the increase in pro-environmental intentions, rather than the specific video-based interventions.

Interestingly, both studies pointed to striking gender differences in changes in pro-environmental intentions, with men being more resistant to changing their intentions than women. This finding might be interpreted in terms of gender differences in response to threat, since research has shown that women are more sensitive and responsive to threat (McClure et al., 2004; Ohrmann et al., 2010), and stress in general (Verma et al., 2011). Other research has shown that these gender differences may also manifest in different behaviors in response to threat, with women more often engaging in behaviors aimed to promote safety and reduce distress (Taylor et al., 2000). Relatedly, a recent study found that in response to acute stress, women rather than men made pro-social everyday moral decisions (Singer et al., 2021). Thus, it might be that female participants in the present studies were more sensitive to the threats related to the climate change scenarios and thereby had a greater desire to reduce distress by expressing higher intentions to engage in pro-environmental behaviors. Viewing it the other way around, it is conceivable that male participants showed psychological reactance (Brehm & Brehm, 2013) in the face of threat: Specifically, men might have felt threatened by the information that climate change would endanger their livelihoods and thus limit their freedom, so that they paradoxically reduced their intentions for pro-environmental behavior in order to preserve their assumed freedom in the short term, consistent with other research showing an increased use of defensive self-protection strategies (such as rationalization and de-emphasizing the seriousness of climate change) in men (Jylhä et al., 2016; Wullenkord & Reese, 2021).

Implications for climate change communication

With all due caution because of the experimental design and the assessment of pro-environmental intentions, rather than actual behavior, the present findings may allow some implications for effective climate change communication (O'Neill & Nicholson-Cole, 2009; Stern, 2012). First and foremost, the current findings show that most people were not prone

to an optimistic update bias when processing new information on climate change; rather, most people took bad news about climate change seriously and updated their beliefs accordingly. Furthermore, our results show that the intense consideration of the probable consequences of climate change increased people's ability to assess the risks of climate change realistically. These findings are encouraging from a pro-environmental perspective as they show that receiving information on the full extent of the climate crisis improves the accuracy of people's risk perception. Moreover, with respect to pro-environmental behavior, our results suggest that women might be more approachable by interventions aimed at increasing pro-environmental intentions. Thus, future research may aim to develop interventions that increase pro-environmental intentions specifically in men and investigate tangible consequences on long-term pro-environmental behavior.

Limitations

The use of young, largely female, little diverse German samples limits conclusions about the generalizability of our results. Furthermore, it is debatable whether a belief update task can be reasonably applied to the context of climate change, where prognoses about adverse events are related to various sources of uncertainty. In addition, the relatively low number of trials as compared to the original task might have increased the effects of artifacts on the update of beliefs (Sharot & Garrett, 2022). Further, we did not control for potential deficits in recalling the probabilities presented correctly. Moreover, although there is consistency between Study 1 and Study 2 with respect to the main findings (i.e., evidence against the hypothesized optimistic update bias; increases in the accuracy of risk perception; increases in pro-environmental intentions; gender differences in changes in pro-environmental intentions), there is also some inconsistency as discussed above. These inconsistencies are most likely related to the slight changes we made to the belief update task

and/or the new scenarios we used in Study 2, in order to address some limitations of Study 1, as discussed above.

Conclusions

Contrary to beliefs about one's personal future, most people are not prone to an optimistic update bias when processing new information on climate change. Rather, the engagement with the likely consequences of climate change increases people's accuracy in assessing the risks of adverse climate change events and increases their intentions to mitigate climate change through personal actions. This may encourage scientists, politicians, journalists, and other people from public discourse to inform people adequately about the full extent of the climate crisis.

Statements and Declarations

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Competing interests

The authors have no relevant financial or non-financial interests to disclose.

Data availability

The datasets generated during and/or analyzed during the current study are not publicly available because participants did not provide consent on this, but the data sets are available from the corresponding author on reasonable request.

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Figure Legends

Figure 1. Illustration of an exemplary trial of the adapted belief update task.

Figure 2. Differences between belief updating in response to good news (better-than-expected information) and in response to bad news (worse-than-expected information) in a) Study 1 and b) Study 2. *** $p < .001$, n.s. = non-significant, error bars reflect the standard error of the mean.

Figure 3. Gender differences in changing pro-environmental intentions from pre-intervention to post-intervention in a) Study 1 and b) Study 2. * $p < .05$, *** $p < .001$, n.s. = non-significant, error bars reflect the standard error of the mean.