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Reactions to warnings in the climate commons☆

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ABSTRACT

People receive daily environmental warnings about the risk of reaching critical climate tipping points leading to irreversible consequences. However, little is known about whether such warnings promote behavioral change, or how emotions underlie such responses. Here, we present two preregistered online experiments, in which group members can harvest financial resources from a common pool while risking collective over-exploitation causing an actual environmental externality. We find that warnings are effective and that the self-conscious emotion guilt consistently correlates with (Study 1) and mediates (Study 2) the effect of warnings on sustainable behavioral change. This suggest that warnings, as a lever of experienced guilt, may qualify as an effective strategy to promote cooperation in the climate commons.

1. Introduction

The immense and detrimental consequences for people and nature arguably make anthropogenic climate change the most pressing environmental challenge of the 21st century. Emphasizing the urgency of this problem, the Intergovernmental Panel on Climate Change (IPCC) expects the mean global temperature to rise by at least 1.5° C above pre-industrial levels between 2030 and 2052, resulting in higher climate-related risks to health, livelihoods, water supply, and human security (Hoegh-Guldberg et al., 2018). Despite this dire outlook, there is high confidence that strengthening the capacities for climate action within the civil societies as well as the private sector can curb emissions to assist limiting global warming to the target of 1.5° C. This, however, requires drastic and rapid emissions reductions, drawing increased attention to demand-side mitigation targeting individuals' lifestyles as a central lever of changing global emission pathways (Creutzig et al., 2018; Dietz et al., 2009; Nielsen et al., 2020; Rosa & Dietz, 2012).

In the hope of increasing individuals' engagement with and responses to climate change, advocates, politicians, as well as scientists routinely rely on public warnings that the remaining carbon budget is being depleted at an unsustainable rate, thereby increasing the risk of exceeding critical climate tipping points (Lenton et al., 2019; Ripple et al., 2019). Despite the ubiquitous use of warning the public, however, how people respond to such warnings on an affective and behavioral level has not received much research attention. In fact, previous research on environmental warnings mainly stems from climate communication research that predominantly relies on self-reported or hypothetical pro-environmental behaviors, which have shown to be only moderately linked to real behavior (e.g., Kormos & Gifford, 2014). A few existing laboratory studies, on the other hand, involve actual decision-making, but do not include real environmental consequences, are largely of correlational nature, and provide only little insights into potential psychological mechanisms underlying behavioral reactions. To address these shortcomings, we investigate how warnings about depleting resources associate with (Study 1) and cause (Study 2) actual pro-environmental behavior change, and examine in how far emotions help to explain behavioral reactions.

1.1. Previous research on environmental warnings

The existing evidence about the role of environmental warnings on behavioral reactions stems from different streams of research. First, environmental warnings are often implicitly included in climate messages that aim at promoting pro-environmental attitudes and behavior, for example by eliciting specific emotions (e.g., Brosch, 2021), or by shaping perception of and knowledge about consequences of unmitigated climate change (e.g., Abrahamse et al., 2005; Zhang et al., 2018). This research, however, does not provide specific information about the

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effectiveness of environmental warnings per se (i.e., the provision of information that without behavioral change, negative environmental consequences will occur). Furthermore, these studies have predominantly relied on self-reported or hypothetical measures (c.f., Jaeger & Schultz, 2017), which are susceptible to biases such as social desirability, consistency bias, or recall inaccuracy (Bleys et al., 2018; Carlson et al., 2020; Lange & Dewitte, 2019, Vesely & Klöckner, 2020). In fact, research has shown that intentions and self-reported willingness to act environmentally friendly are only moderately correlated with actual behavior, leaving 79% of the variance in the association between self-reported and objective pro-environmental behavior unexplained (R. A. Howell, 2014; Kollmuss & Agyeman, 2002; Kormos & Gifford, 2014).

On the other hand, some studies have provided first insights into reactions to environmental warnings in actual decision-making tasks, albeit without real environmental consequences attached to behavior (Parks et al., 2017; Vasi & Macy, 2003) and without control conditions allowing for causal inference (Baumgartner et al., 2021; Joireman et al., 2009). For example, Joireman et al. (2009) studied the impact of warnings in a resource dilemma game with complete resource uncertainty. They find that after a warning, average harvesting rates drop – but rebound to pre-warning levels after a few rounds. More recently, Baumgartner et al. (2021) focused on inter-individual differences in reactions to warnings and identified different behavioral types with respect to their resource extraction behavior. They found that the behavioral type, which increased their extraction rate after receiving a warning, exhibited lower levels of guilt compared to the two other types, which showed a sustainable response to the warning. Furthermore, Vasi and Macy (2003) found that warnings only promote cooperation when they were coupled with empowerment messages. Finally, Parks et al. (2017) found that warnings about resource scarcity are likely to undermine cooperation, but only when no environmental information (i.e., information about the amount available for harvesting) was given.

Thus, evidence regarding the effectiveness of environmental warnings is still scarce, and results are mixed. Moreover, it is unclear whether and to what extent previous findings translate into the context of consequential pro-environmental decision-making (i.e., when actual environmental consequences are at stake). Finally, most of the findings outlined above are mute to potential psychological mechanisms driving behavioral reactions to warnings. One promising candidate potentially underlying warning-related behavior change are emotions, as they have shown to be crucial drivers of responses toward climate change (e.g., Brosch, 2021; Chapman et al., 2017), and strongly influence human behavior in general (Schwartz, 1977; Teper et al., 2015).

1.2. Emotions and pro-environmental behavior

Climate change messages have often focused on eliciting different emotions. For example, manipulating information about humans' responsibility for global warming (Ferguson & Branscombe, 2010; Rees et al., 2015) or providing negative feedback about one's carbon footprint (Adams et al., 2020) was shown to increase experienced guilt, which in turn was positively linked to people's willingness to engage in mitigation behavior or to sign a petition addressing environmental issues. Similarly, climate communication targeting in-group responsibility about environmental damage has shown to increase anger and guilt on the one side, as well as feelings of responsibility and pride on the other side (Harth et al., 2013). Whereas anger predicted intentions to punish wrongdoers, both guilt and pride resulted in an increased self-reported willingness to engage in pro-environmental behaviors. With regard to anger, a recent study found that feeling angry about climate change predicted greater environmental engagement and pro-climate activism (Stanley et al., 2021).

Furthermore, optimistic messages regarding the likelihood of humanity's success in climate change mitigation were shown to increase people's hope, which, however, undermined their motivation to act environmentally friendly (Hornsey & Fielding, 2016). In contrast, hope-based messages focusing on solutions and efficacy have shown to increase climate-related political participation (Feldman & Hart, 2016, 2018). Similarly, "constructive" hope in the sense of an optimistic feeling that climate change can be successfully mitigated by collective action was positively linked to self-reported pro-environmental behavior (Ojala, 2015) and political engagement (Marlon et al., 2019). In line with these findings, research has shown that individuals with elevated feelings of powerlessness in general are less likely to take action on climate change (e.g., Atiken et al., 2011). Finally, personal feelings of worry (Smith & Leiserowitz, 2014; van der Linden et al., 2017) and fear (Hartmann et al., 2014) were associated with higher levels of support for public action for global warming or pro-environmental intentions. Regarding fear, however, there is an ongoing debate about whether fear-based messages may also lead to a passive state of denial or avoidance (Brosch, 2021; Chapman et al., 2017; Chen, 2016).

With regard to environmental warnings, it is largely unknown what kind of emotions they elicit and in how far these emotions are causally linked to people's actual efforts to avoid environmental harms. Based on the findings on emotions outlined above, it is possible that warnings reduce people's hope and drive them into a state of powerlessness, which can undermine pro-environmental behavior. On the other hand, it is possible that warnings elicit higher levels of worry and thereby increase environmentally friendly behavior. Furthermore, environmental warnings may also serve as a social signal, as they provide information on the behavior of an entire group. Therefore, warnings could increase experienced guilt of having contributed to environmental damage and thereby increase pro-environmental behavior change, or – to the contrary – increase environmentally harmful behavior as a result of experienced anger about others' unsustainable behavior.

1.3. Contributions of the present research

In an effort to provide novel evidence on the affective and behavioral consequences on environmental warnings, the present research examines the effect of warnings on emotions and pro-environmental behavior with real environmental consequences under controlled laboratory settings. To this end, we conduct two controlled online studies addressing emotional and behavioral responses to environmental warnings. Integrating methodological tools from experimental economics into the psychological study of pro-environmental behavior, we rely on a threshold public good game with actual environmental externalities, in which members of a social group can repeatedly and privately harvest resources from a common pool while risking that collective over-exploitation of the resource triggers a real-world pollution (Tavoni et al., 2011). Importantly, however, we implement a warning into the game that occurs depending on participants' harvesting behavior. Thus, similar to the global dilemma of limiting the increase in global mean temperature, individuals need to cooperate with each other in order to prevent negative environmental consequences for all despite individual incentives to free-ride, which is also referred to as the 'the tragedy of the commons' (Hardin, 1968).

2. Study 1

2.1. Threshold public good game with real CO_2 externalities

In an interactive online study, participants were randomized into anonymous groups of four. In each of ten rounds of play, participants had the opportunity to anonymously extract anywhere between one and six points out of a common pool, and each extracted point led to an additional monetary payoff (see Materials and Methods). Participants were informed that collectively exceeding a total extraction of 80 points at the end of the tenth round as a group (i.e., yielding an average sustainable resource extraction of no more than 2 points per individual and round) would lead to an actual environmental externality in the form of 200 lbs of carbon emission. The emission was realized using certificates

purchased from the European Union emission trading system (EU-ETS). In this sense, refraining from individual harvesting marks a consequential pro-environmental behavior as it is an effort to contribute to the collective environmental good at a personal financial sacrifice, because any retired certificate leads to the real abatement of 200 lbs of CO_2. If a group collectively exceeded the threshold, the certificate remained in the market and could therefore be used for emission by another polluter.

2.2. Implementation of environmental warnings

To study the behavioral changes incurred by environmental warnings, we implemented the following procedure: if a group surpassed a total extraction amount of 40 points after round five, all group members received a non-expected warning that the environmentally harmful threshold would be exceeded unless the group's collective extraction rate decreases. After the warning (or the neutral control message, respectively) participants indicated their affective responses in terms of how guilty, hopeful, angry, powerless, and worried they felt (see Materials and Methods for details). Subsequently, they continued with the second five rounds making decisions about how many points to extract. Hence, in our study, every participant faced the same dilemma having to decide about foregoing personal financial gains through the restriction of their harvesting behavior while being uncertain about the decision of the other group members.

2.3. Hypotheses

Based on previous studies stemming mainly from the broader climate communication literature, we expect higher levels of experienced guilt (Adams et al., 2020; Baumgartner et al., 2021; Harth et al., 2013; Tarditi et al., 2020), worry (Smith & Leiserowitz, 2014; van der Linden et al., 2017), and hope (Olaja, 2015) to be associated with a decrease in extraction behavior after receiving a warning. On the other hand, we hypothesize that higher levels of anger (Stanley et al., 2021) and powerlessness (Atiken et al., 2011) are associated with a higher level of resource extraction after a warning.

2.4. Materials and Methods

2.4.1. Participants and sample size

626 participants who were fluent in English were recruited on the platform Prolific to take part in a decision-making study (see Supplementary Material for more details about the recruitment). In addition to a flat payment of one British pound (GBP), participant earned a behavior-dependent bonus of one to six GBP. Expected completion time was 20 min. As defined in the preregistration protocol, we only included participants into the analysis who passed the bot checks, correctly answered all three control questions and passed the attention check. To ensure that we only included participants who were attentive toward the task and who had actually seen the warning, we additionally excluded participants who missed more than 20% of the harvesting decisions prior to and after the warning or did not make a decision in round number five. This yielded a final sample of $n = 408$. Participants (37% female, age: $M = 26.5$, $SD = 8.44$) came predominantly from the United States and Europe. Our sample size decision followed budgetary constraints (Lakens, 2021).

2.4.2. Measures and procedure

The study was programmed using oTree (D. L. Chen et al., 2016), an open-source software for implementing interactive experiments. After giving consent and reading the instructions, participants were asked to answer two hand-written questions with the aim of detecting computer-generated responding (i.e., "bot checks"). Thereafter, participants answered three control questions to ensure they understood the behavioral paradigm and knew that its environmental consequence was real (see Supplementary Material for the exact wording). Participants who failed the control questions or who had to wait for more than five min for other participants to form a group with were redirected to the last page and received the participation fee of one GBP. All other participants were quasi-randomly assigned to anonymous groups of four (see Supplementary Material for more details about the assignment).

As soon as a group was formed, participants began with the first round of the threshold public good game. In each of ten rounds of play, they were given the opportunity to anonymously extract anywhere between one and six points out of a common pool, leading to an additional payoff of 0.10 GBP per extracted point (i.e., yielding, in total, an additional payoff of one to six GBP). Participants were instructed that collectively exceeding a total extraction of 80 points at the end of the tenth round as a group would lead to an actual environmental externality in the form of 200 lbs of carbon emission. Decision times were restricted to 20 s per round, ensuring that no single participant prevented the group from moving through the study without delay. If one participant or more dropped out of the game (e.g., due to poor internet connection or early termination of the study), the remaining participants could continue the study without noticing any irregularity. To prevent the total harvesting of the group to be affected by participants dropping out from the study or missing the decision for other reasons (e.g., not paying attention), a missed decision was recorded as a decision of two extracted points. Note that this is the highest number of points that can be extracted per round without risking the threshold to be exceeded making this decision as neutral as possible. To assess participants' expectation about the harvesting behavior of the other group members, we asked them to indicate their beliefs about the mean extraction rate of the other group members following their decisions in round two and ten.

The warning was implemented in the following way: if a group exceeded a total extraction amount of 40 points after round five, all group members received an unannounced warning that the threshold would be exceeded unless the group's collective extraction rate decreases, triggering the actual CO_2 externality of 200 lbs. Groups who collectively stayed below the extraction amount of 40 points after round five received a control message stating that a few questions would follow next. Thereafter, participants were asked to indicate their current emotional state in terms of five distinctive emotions (guilty, hopeful, angry, powerless, worried) on a scale from 1 (not at all) to 7 (very much). This assessment also included an attention check, where participants were explicitly asked to select the option "not at all". After round ten, participants received feedback about their individual total extraction as well as the group's total level of harvesting. They were also informed about how much money they earned and whether or not their group surpassed the critical threshold leading to an actual CO_2 emission.

Following the threshold public good game, several questionnaires were administered. Participants completed the Social Value Scale (SVS; Steg et al., 2012), which includes items reflecting egoistic, hedonic, altruistic, and biospheric values. Biospheric values, being the most relevant dimension for the purpose of this study, were measured with four items: respecting earth, unity with nature, protecting the environment, and preventing pollution. Participants rated the items as "guiding principle in their lives" on a 9-point scale ranging from −1 (opposed to my guiding principles) to 7 (extremely important). The biospheric values subscale showed a very good internal consistency (Cronbach's $\alpha = 0.89$). Finally, participants completed a series of demographic questions, reporting their gender, age, level of highest education, employment, household income, as well as their political orientation on the liberal-conservative spectrum, ranging from 1 (very liberal) to 7 (very conservative). After the study, the total amount of CO_2 that participants prevented from being emitted as a result of keeping the collective extraction amount below the critical threshold (i.e., 3.5 tons of CO_2) was bought out of the carbon emission market. The service provider for Study 1 was CO2 Esto (www.co2esto.com; emission certificate number: 4174/2020/2480815034, see Supplementary Fig. S1).

The study was approved by the local ethics committee and conducted according to the principles expressed in the Declaration of Helsinki. All

participants gave written informed consent and were informed of their right to discontinue participation at any time. Our study did not involve deception.

2.5. Results

2.5.1. Behavioral responses to environmental warnings

As displayed in Fig. 1A, out of the final sample ($n = 408$), 73.78% ($n = 301$) received a warning as their groups had extracted more than a total of 40 points up to round five (also referred to as baseline behavior). Note that although threshold surpassing depended on the total extraction of the group, all analyses were performed on an individual level. This was possible as participants did not receive any feedback from other group members and made anonymous decisions themselves, which also allowed us to include participants into the analyses whose group members (or some of them) had to be excluded based on different exclusion criteria. For comparisons of means, all p-values are two-tailed and paired t-tests or Welch's t-tests (between group comparisons) were used (Delacre et al., 2017; Lumley et al., 2002).

Among the groups who were warned, 80.4% of the participants ($n = 242$) received a message at the end of the ten rounds saying that their group had surpassed the critical threshold of 80 points, triggering 200 lbs of CO_2 to be emitted. Out of the 107 participants who were sufficiently sustainable during the first five rounds and therefore did not receive a warning, 12 participants (11.2%) were members of groups that exceeded the threshold of 80 points. As shown in Fig. 1B, participants who were part of a group that was warned displayed a higher mean value and a greater variance in their average extraction rate during the first five periods ($M = 2.79$, $SD = 1.48$) than participants who were not warned ($M = 1.76$, $SD = 0.72$; $t(369.38) = -9.35$, $p < .001$).

To examine the behavioral change that resulted from receiving a warning more closely, we analyzed the differences in extraction behavior prior to and after the warning. Participants' mean extraction rate was significantly lower in round six (i.e., the first decision after the warning) compared to round five (i.e., the last decision before the warning, $t(297) = 6.94$, $p < .001$, $d = 0.40$; see Fig. 1C). Similarly, the average extraction rate across all post-warning rounds was significantly lower than the average extraction rate across all pre-warning rounds ($t(300) = 9.15$, $p < .001$, $d = 0.53$). Importantly, despite a slight positive slope from round six to round ten ($b_{round} = 0.07$, $p < .001$, obtained from mixed-effects regression using post-warning data only), the mean extraction rate in round ten was still significantly lower than in any round that preceded the warning, indicating that the warning had a lasting effect on participants harvesting behavior (see Supplementary Tables S1 and S3).

2.5.2. Affective drivers of behavioral change

To test whether these behavioral reactions relate to different affective responses to the warning, linear regressions were performed using the difference scores between average extraction rates across all rounds prior versus after the warning as our dependent variable. Table 1 (Model 1) demonstrates that higher levels of experienced guilt – but not worry, anger, powerlessness, or hope – are significantly associated with a decrease in harvesting behavior after the warning ($b = 0.07$, $p < .05$). This effect remains qualitatively identical when additionally controlling for biospheric values (Steg et al., 2012) (Model 2), and for education, income, age, and gender (Model 3). Zero-order correlations are presented in Supplementary Table S6.

2.5.3. Discussion

In Study 1, we examined the effect of environmental warnings on self-reported emotions and pro-environmental behavior with real environmental consequences. We found that resource extraction rates significantly dropped among individuals who received a warning, corroborating some (e.g., Baumgartner et al., 2021; Joireman et al., 2009) but not all (Parks et al., 2017; Vasi & Macy, 2003) previous

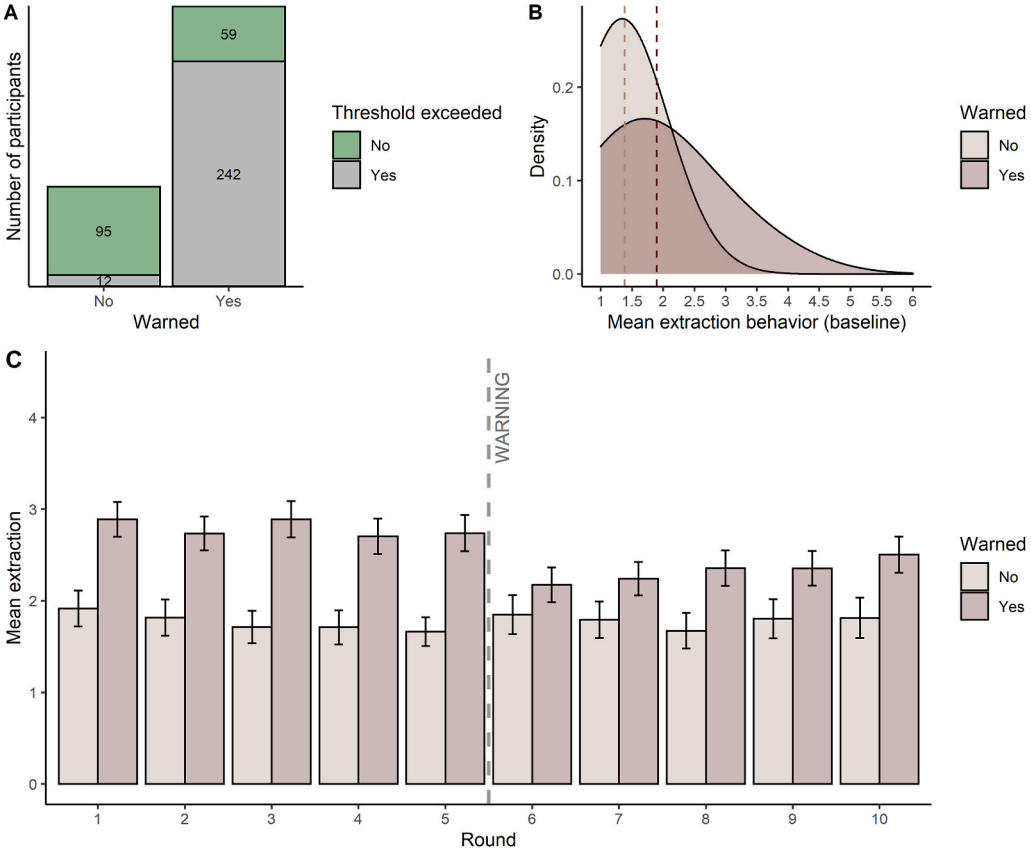

Fig. 1. Frequencies and Distribution of Participants Depending on Whether They Were Warned and the Threshold was Exceeded

Note. Panel A: Number of participants who were members of a group that did vs. did not exceed the critical final threshold depending on whether they had received a warning or not. Panel B: Density plot of mean extraction behavior during the first five rounds (i.e., baseline behavior), vertical lines indicate the mean of the average extraction behavior. Panel C: Mean extraction rate per round for individuals who did or did not receive a warning. The vertical dashed line separates decisions that occurred before versus after the warning. Error bars represent the 95% confidence interval.

Table 1
Multiple linear regression predicting difference in average extraction behavior prior and after the warning.

	Model 1			Model 2			Model 3		
Variable	*b*	CI	*p*	*b*	CI	*p*	*b*	CI	*p*
(Intercept)	0.01	[-0.41, 0.42]	.973	−0.34	[-0.88, 0.19]	.208	−0.09	[-0.81, 0.63]	.799
Guilt	0.07	[0.01, 0.13]	**.033**	0.07	[0.01, 0.13]	**.023**	0.07	[0.01, 0.13]	**.033**
Worry	0.04	[-0.04, 0.11]	.306	0.03	[-0.05, 0.10]	.489	0.02	[-0.06, 0.09]	.694
Anger	0.02	[-0.05, 0.09]	.531	0.01	[-0.05, 0.08]	.686	0.02	[-0.05, 0.09]	.636
Powerlessness	−0.05	[-0.11, 0.01]	.112	−0.05	[-0.11, 0.01]	.107	−0.05	[-0.11, 0.01]	.101
Hope	0.05	[-0.01, 0.11]	.120	0.04	[-0.03, 0.10]	.243	0.03	[-0.03, 0.10]	.297
Biospheric values				0.09	[0.00, 0.17]	**.045**	0.08	[-0.00, 0.17]	.059
Education							0.03	[-0.09, 0.14]	.666
Income							−0.02	[-0.06, 0.02]	.332
Age							−0.00	[-0.02, 0.01]	.608
Gender (dummies) [a]							YES		
Observations	301			301			300		
R^2/R^2adjusted	.045/.029			.058/.039			.066/.027		

Note. Estimates represent unstandardized beta coefficients. The more positive the value of the dependent variable, the higher the reduction of average extraction rate after the warning (i.e., sustainable reaction). Models include only participants who were warned after round five. Number of observations differ across models due to missing values. CI = 95% confidence interval.

[a] Gender was measured categorically (female, male, diverse, and "prefer not to specify") and did not have a significant effect on the dependent variable.

research findings. However, our study differs from previous studies in the sense that a clear extraction threshold was included, and perhaps more importantly, that the extraction decisions had an actual environmental consequences (i.e., CO_2 emissions). With respect to self-reported emotions, we found that higher levels of guilt – but not worry, anger, powerlessness, or hope – were significantly associated with sustainable responses to the warning. Although Study 1 links warnings to environmental behavior change, it is essentially mute with respect to a causal relationship (i.e., whether warnings causally induce guilt, which is associated with behavior change). To overcome this limitation, we complement Study 1 with an experimental study that exogenously varies whether or not over-extracting groups (i.e., extracting more than 40 points up to round five) are warned or not.

3. Study 2

3.1. Experimental design

Study 2 was an interactive online experiment that included the same threshold public good game as Study 1, with identical parameters regarding extraction rates, pay-offs, and thresholds. The only difference was that, in Study 2, we experimentally varied the occurrence of a warning among groups that had extracted more than a total of 40 points up to round five. Thus, approximately half of the participants that were part of over-extracting groups received a warning, whereas the other half received a control message (the same message that was presented to groups that did not exceed a total extraction amount of 40 points up to round five).

3.2. Hypotheses

Based on our findings from Study 1, we expect that warnings are effective in a sense that – on average – they cause pro-environmental behavior change. Among over-extractors, we furthermore expect the relationship between the occurrence of a warning and behavior change to be mediated buy guilt. In other words, we expect that receiving a warning increases self-reported guilt, and that higher levels of guilt are linked to a more sustainable behavioral reaction.

3.3. Methods

3.3.1. Participants and sample size

To define an adequate sample size for detecting a significant indirect effect of warnings on behavior change via guilt, we conducted a Monte Carlo Power analysis (Schoemann et al., 2017; https://schoemanna.shinyapps.io/mc_power_med/). We entered the effect size of guilt on behavior change obtained in Study 1 ($r = 0.18$). As we expected all other correlations (i.e., between warning and guilt, as well as warning and behavior change) to be in a similar range, they were also set to 0.18. We ran 1,000 replications with 20,000 Monte Carlo draws each, and the results indicated that 545 participants are sufficient to achieve 95% power. As it was impossible to accurately predict how many groups would be over-extractors (i.e., participants that would be included in the mediation analysis), we increased the sample size up to 816, following our budgetary constraints (Lakens, 2021).

Thus, 816 participants who were fluent in English were recruited on the platform Prolific to take part in a decision-making study (see Supplementary Material for more details). In addition to a flat payment of one GBP, participant earned an additional behavior-dependent bonus of one to six GBP. Expected completion time was 20 min. As defined in the preregistration protocol, we only included participants into the analysis who passed the bot checks, correctly answered all of the three control questions, and passed the attention check. Furthermore, we excluded participants who missed more than 20% of the harvesting decisions prior to and after the warning or did not make a decision in round number five. This yielded a final sample of $n = 613$. Participants (39% female, age: $M = 30.22$, $SD = 10.59$) came predominantly from the United States and Europe.

3.3.2. Measures and procedure

Except from the implementation of the warning, the procedure of Study 2 was identical to Study 1. After giving consent and reading the instructions, participants were asked to answer the "bot checks" and control questions. Participants who failed the control questions or who had to wait for more than five min for other participants to form a group with were redirected to the last page and received the participation fee of one GBP. All other participants were quasi-randomly assigned to anonymous groups of four (see Supplementary Material for more details). As soon as a group was formed, participants made their extraction decisions in the threshold public good game. After round two and round ten, we asked participants to indicate their beliefs about the mean extraction rate of the other group members.

Groups that exceeded a total extraction amount of 40 points after round five were quasi-randomly assigned to a warning or control condition: every second group that reached round five was assigned to the warning condition. Importantly, the timing of a group reaching round five was not due to any systematic reasons. In the warning condition, all group members received an unannounced warning that the threshold

would be exceeded unless the group's collective extraction rate decreases, triggering the actual CO_2 externality of 200 lbs. Groups that were assigned to the control condition (or that did not over-extract the resource), received a message stating that a few questions would follow next. Thereafter, participants were asked to indicate their current emotional state in terms of five distinctive emotions (guilty, hopeful, angry, powerless, worried) on a scale from 1 (not at all) to 7 (very much). This assessment also included an attention check, where participants were explicitly asked to select the option "not at all". After round ten, participants received feedback about their individual total extraction as well as the group's total level of harvesting. They were also informed about how much money they earned and whether or not their group surpassed the critical threshold leading to an actual CO_2 emission. Finally, participants completed the SVS (Steg et al., 2012) and answered several demographic questions (gender, age, level of highest education, employment, household income, political orientation).

After the study, the total amount of CO_2 that participants prevented from being emitted as a result of keeping the collective extraction amount below the critical threshold (i.e., 1.8 tons of CO_2) was bought out of the carbon emission market. The service provider for Study 2 was CO2 Esto (www.co2esto.com; emission certificate number: 4319/2021/3098621167, see Supplementary Fig. S2).

The study was approved by the local ethics committee and conducted according to the principles expressed in the Declaration of Helsinki. All participants gave written informed consent and were informed of their right to discontinue participation at any time. Our study did not involve deception.

3.4. Results

3.4.1. Behavioral responses to environmental warnings

Out of the final sample ($n = 613$), 92.66% ($n = 568$) were part of a group that extracted more than a total of 40 points up to round five. As in Study 1, all analyses were performed on an individual level. Among them, 271 participants received a warning and 297 received a control message. Mean extraction rates did not significantly differ between both conditions (warning: $M = 3.34$, $SD = 1.80$; control message: $M = 3.20$, $SD = 1.75$, $t(448.13) = 0.94$, $p = .35$). The frequencies and distribution of participants for both experimental conditions and depending on whether they were over-extractors or not are displayed in Fig. 2.

In line with the findings from Study 1, participants' mean extraction rate significantly dropped after the warning, both with respect to an immediate reaction (extraction $round_5$ – extraction $round_6$: $= 0.45$, $t(270) = 6.24$, $p < .001$, $d = 0.38$), and averaged across all rounds (mean $extraction_{pre\text{-}warning}$ – mean $extraction_{post\text{-}warning} = 0.32$, $t(270) = 7.18$, $p < .001$, $d = 0.43$). Again, we find that despite a slightly positive slope from round six to round ten ($b_{round} = 0.05$, $p < .001$), the mean extraction rate in round ten was still significantly lower than in any round that preceded the warning, indicating that the warning had a lasting effect on participants harvesting behavior (see Supplementary Tables S2 and S4). Importantly, extraction rates among participants that were assigned to the control condition did not significantly differ between any of the extraction rounds (see Supplementary Table S5).

3.4.2. Affective drivers of behavioral change

To test whether guilt predicts behavioral responses to the warning, linear regressions were performed using the difference scores between average extraction rates across all rounds prior versus after the warning as our dependent variable. Table 2 demonstrates that, in line with Study 1, higher levels of self-reported guilt are significantly and consistently associated with a decrease in harvesting behavior after the warning throughout all models. Note that the zero-order correlations also show a significant relationship between behavior change and anger as well as worry (see Supplementary Table S8), which, however, did not occur in Study 1 (Supplementary Table S6).

3.4.3. Mediation analysis

To test if the effect of the warning on extraction reduction is mediated by experienced guilt, we conducted a mediation analysis using Hayes (2018) PROCESS macro for SPSS with 5,000 bootstrap samples for the confidence intervals and standard errors of indirect effects. Our results revealed that among over-extractors, receiving a warning induced experienced guilt ($b = 0.47$, $SE = 0.15$, $p = < .001$), which in turn predicted a sustainable response ($b = 0.04$, $SE = 0.02$, $p < .05$).

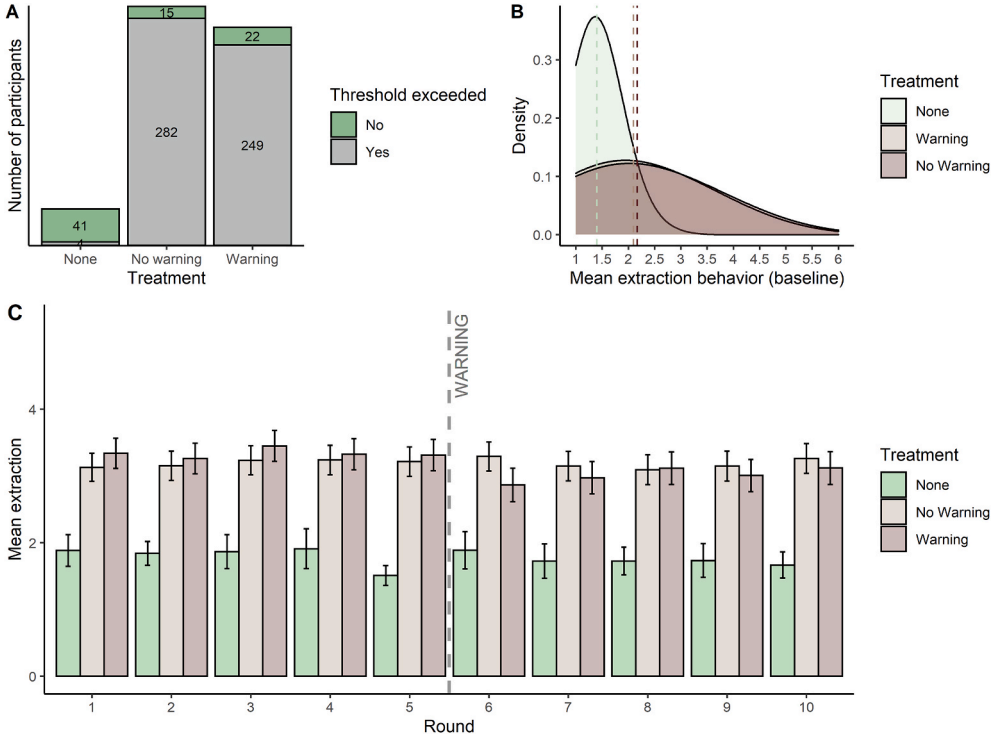

Fig. 2. Frequencies and Distribution of Participants Depending on Whether They Were Warned and the Threshold was Exceeded (Study 2)

Note. Mean extraction rate per round for individuals who were warned ("Warning") or did not receive a warning, either because their groups did not extract more than 40 points up to round five ("None") or because they were part of the experimental treatment that did not present a warning to over-extractors ("No warning"). The vertical dashed line separates decisions that occurred before versus after the warning. Error bars represent the 95% confidence interval.

Table 2
Multiple linear regression predicting difference in average extraction behavior prior and after the warning.

	Model 1			Model 2			Model 3		
Predictors	*b*	CI	*p*	*b*	CI	*p*	*b*	CI	*p*
(Intercept)	-.32	-.65–−.00	**.050**	-.58	−1.00–−.17	**.006**	-.65	−1.20–−.10	**.021**
Guilt	.08	.03–.13	**.001**	.08	.03–.14	**.001**	.09	.04–.14	**.001**
Worry	-.01	-.07 – .05	.676	-.02	-.08 – .04	.472	-.02	-.09 – .04	.490
Anger	.06	-.00 – .12	.061	.06	-.00 – .12	.058	.06	.00–.12	**.047**
Powerlessness	.02	-.04 – .07	.553	.01	-.04 – .06	.676	.01	-.04 – .06	.656
Hope	.06	.01–.11	**.028**	.05	-.01 – .10	.082	.05	-.00 – .11	.074
Biospheric values				.07	-.00 – .13	.053	.06	-.01 – .13	.077
Education							.00	-.10 – .10	.982
Income							-.01	-.04 – .03	.635
Age							.00	-.01 – .01	.595
Gender							YES		
Observations	271			271			271		
R^2/R^2adjusted	.071/.054			.085/.064			.094/.052		

Note. Estimates represent unstandardized beta coefficients. The more positive the value of the dependent variable, the higher the reduction of average extraction rate after the warning (i.e., sustainable reaction). Models include participants from over-extracting groups only. Number of observations differ across models due to missing values. CI = 95% confidence interval.
[a] Gender was measured categorically (female, male, diverse, and "prefer not to specify") and did not have a significant effect on the dependent variable.

Importantly, the indirect effect of the warning on the sustainable response through guilt was also significant, *ab* = 0.02, 95%-Boot CI: [0.001, 0.038] (see Fig. 3). This effect is robust when using the immediate reaction (extraction $round_6$ – extraction $round_5$) as dependent variable (see Fig. S3). Thus, behavioral reactions to warnings were, at least partly, mediated by higher levels of experienced guilt.

3.4.4. Further exploratory analyses

As guilt is an emotion that results from negative self-evaluations as a response to both social or moral norm violations (Teroni & Deonna, 2008), the reason for why people experience guilt may depend on their belief about how others behave (i.e., social norm violations) as well on their biospheric values (i.e., moral norm violation). To address this, we examined a potential relationship between guilt, beliefs about others' behavior, biospheric values and pro-environmental behavior change by testing whether the link between guilt and reduction in resource extraction after the warning jointly depends on participants' level of guilt and biospheric values (i.e., three-way interaction). Using a Bayesian approach, we found weak evidence for a three-way interaction effect in Study 1 (see Supplementary Table S9 and Fig. S5), but not in Study 2. The results from Study 1 show that when biospheric values were low, people responded to the warning in line with their belief about how others behaved – regardless of how guilty they felt. However, when biospheric values and self-reported feelings of guilt were high, people responded sustainably to the warning – independent of their belief of others' cooperation (i.e., showing unconditional cooperation, see Fig. S4).

With respect to the overall pattern of our observed results, we conducted several additional robustness checks. Supplementary Table S10 shows that the effect of guilt on behavioral change is robust when applying more conservative or liberal participant exclusion criteria, or when looking at immediate reactions (i.e., the change from round five to round six).

3.4.5. Discussion

In Study 2, we examined whether environmental warnings induce sustainable behavior change, and whether this relationship is mediated by experienced guilt. In line with our hypothesis, we find that warnings lead to higher levels of self-reported guilt, and that guilt is linked to a reduction of resource extraction. While these findings support our results from Study 1, they also provide first causal evidence of environmental warnings on behavioral change – partially mediated via experienced guilt. This further points to the importance of affect and emotions as drivers of climate change perception and actions (Brosch, 2021; Chapman et al., 2017).

4. General discussion

Sustaining cooperation in the effort of successful climate change mitigation represents one of the major challenges of our society, and

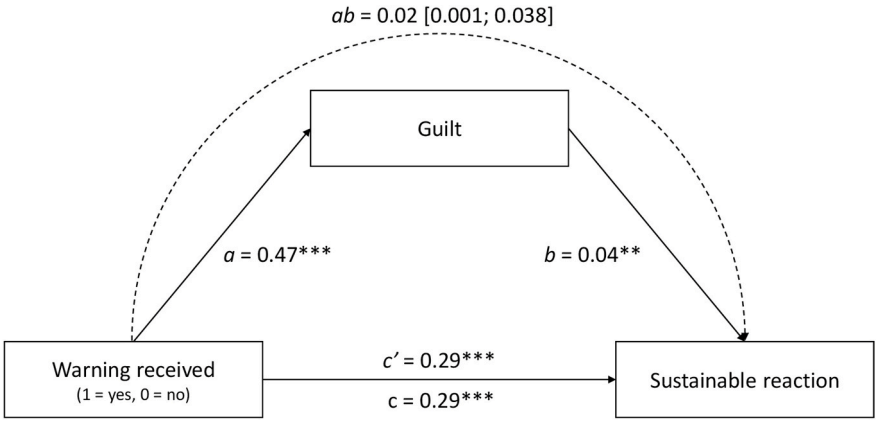

Fig. 3. Mediation Results
Note. Illustration of the mediation effect of receiving a warning on sustainable reaction (i.e., reduction in average extraction behavior prior vs. average to the warning). Results are based on 5,000 bootstrap samples. The dashed arrow represents the indirect effect. *c* = total effect, *c'* = direct effect. $^{**}p < .05$ $^{***}p < .001$.

people are insistently being warned about the threat of reaching critical climate tipping points. Across two studies, we investigated people's affective and behavioral reactions in response to environmental warnings in a threshold public goods game where unsustainable decisions are associated with actual CO_2 externalities. We demonstrate that participants show a lasting, yet diminishing decrease in resource extraction after receiving a warning that their group would surpass a critical threshold causing a CO_2 emission, should their level of extracting points remain unsustainable. Importantly, our results show that experienced guilt is consistently associated with behavioral change. More specifically, guilt mediates the effect of warnings on pro-environmental behavioral change, meaning that higher levels of guilt are predictive of a stronger reduction of resource extraction after receiving an environmental warning.

Our results emphasize the role of guilt as an affective path to actual pro-environmental behavior change after warnings. The feeling of guilt – among shame, embarrassment, and pride – belongs to the group of so-called self-conscious emotions (Tangney, 1995), which typically arise when we violate, meet, or surpass our moral and social standards (Tangney, 2005). However, these emotions, and guilt in particular, are not only about one's self, but also have a strong interpersonal focus. For example, research has shown that guilt leads to reparative actions, such as confessing, apologizing, and undoing, and thus orientates people toward a more constructive and future-oriented direction (A. J. Howell et al., 2012). Moreover, previous literature points to the close link between guilt and empathy: when individuals describe personal experiences of guilt, they show greater empathy for others involved (Sandage et al., 2000; Tangney, 1995). Translating these findings into the context of the present research, warning-induced guilt may thus help people to feel more empathetic toward people and nature, which brings about their need for pro-environmental behavioral adjustment.

Thus, our results show that environmental warnings that increase self-reported guilt may qualify as an effective strategy to promote cooperation in the climate commons. Future research could examine to what extent our findings translate to different types of pro-environmental behavior in the field and further explore the conditions under which environmental warnings are most effective. For example, previous research studying the effect of warning messages on resource extraction behavior (albeit without actual environmental consequences) has shown that warnings are more likely to promote cooperative behavior when coupled with empowerment messages (Vasi & Macy, 2003), and may be detrimental when paired with information about others' behavior (Parks et al., 2017). Moreover, future research could address if and to what extent people react to repeated warnings, especially in the light of the many actual warnings that are displayed on a routine basis (e.g. via social media, news channels, or other media). Longitudinal studies – for example repeated behavioral assessments through experience sampling technology (e.g., Langenbach et al., 2019) – could critically augment our evidence base about the continued efficacy of warnings. Finally, it should be noted that this study only included self-report measures of emotions, which are vulnerable to social desirability bias and only capture conscious appraisals. Future work could therefore use other types of emotional measures and include a wider range of emotional reactions.

To conclude, we find evidence suggesting that warning the public about irreversible climate tipping points may evoke feelings of guilt and thereby encourage behavior change. Furthermore, we provide continued evidence that behavioral games may be a suitable approach to study the psychological mechanisms underlying the willingness to engage in pro-environmental behavior, thereby increasing the methodological toolbox for environmental psychological and related research.

Data availability

Both studies' central hypotheses that guilt, hopefulness, anger, powerlessness, and worry are correlated with behavioral change after the warning was preregistered on the Open Science Framework https://osf.io/c7ukv/?view_only=889d212072984385b6a3799a6e0f85ed). All study materials, raw data and codes are available on the associated project page. All data has been analyzed using the open-source software R as well as SPSS.

Credit statement

Annika M. Wyss: Conceptualization, Methodology, Analysis, Writing - Original Draft, Writing - Review & Editing, Funding acquisition. **Sebastian Berger:** Conceptualization, Methodology, Analysis, Writing - Original Draft, Writing - Review & Editing. **Thomas Baumgartner:** Conceptualization, Methodology, Writing - Review & Editing. **Daria Knoch:** Conceptualization, Methodology, Writing - Review & Editing, Funding acquisition, Supervision.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvp.2021.101689.

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