Communicating the links between climate change and heat waves with the Climate Shift Index

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ABSTRACT

Extreme weather, including heat waves, poses a significant threat to ecosystems and human health. As global temperatures continue to rise, the frequency and severity of heat waves will increase. Because of this, communicating heat-related risks to the public is increasingly important. One commonly-used communication tool is the Climate Shift Index (CSI), which establishes how much more likely an extreme weather event, such as a heat wave, has been made by climate change. To test the impact of the CSI on people's understanding of the links between climate change and extreme weather, we conducted an experiment informing 3,902 American adults that climate change made the July 2023 heat wave in the U.S. at least 5 times more likely. In addition to this standard CSI wording and 2 control messages, we also explored the effectiveness of reframing magnitude as a percentage, and whether mechanistic and attribution explanations of the relationship between climate change and heat waves further increase understanding. All treatments increased the belief that climate change made the July 2023 heat wave more likely and is making heat waves in general more likely as well. Additionally, we found that expressing the magnitude as a percentage was more effective than the standard CSI framing. We also found that just talking about the heatwave, without mentioning climate change, was enough to change beliefs.

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1. Introduction

Extreme weather poses a significant threat to ecosystems, physical infrastructure, and human societies. As the climate warms, extreme weather events have become more frequent and intense, leading to widespread and increasingly damaging impacts across the globe (IPCC, 2022). One example is heat waves, consecutive days of unusually hot weather, which have many consequences including heat-related illness or death, crop failure, ecological stress, and greater drought or wildfire risk. Anthropogenic climate change will further heighten the threat posed by extreme heat, increasing the intensity, frequency, and duration of heat waves (IPCC, 2023). Already, heat waves are the deadliest natural disaster in the United States, causing 148 fatalities in 2022 (NWS, 2022). Indeed, the five hottest Julys on record all occurred in the last five years (NASA, 2023). Consequently, a direct impact of climate change will be greater human exposure to heat extremes, with detrimental impacts on morbidity and mortality (Mora et al., 2017; Vicedo-Cabrera et al., 2021). Heightened exposure, including across larger and more densely populated areas (Russo et al., 2014) or with compound events such as a heat wave combined with an electricity grid failure (Stone Jr et al., 2023), underscores the need to prepare for intensifying climate extremes.

The combined threats of increased heat and increased exposure to extreme heat indicates that communicating the risk of heat waves will become an increasingly important priority for weather forecasters, journalists, and public health practitioners alike. Perceptions of heat risk play a large role in determining behavioral responses (e.g., when an excessive heat warning is issued, those who do not perceive heat as dangerous are less likely to take action to mitigate the threat; Toloo et al., 2013; Kalkstein and Sheridan, 2007). Low risk perceptions and a lack of awareness about the impacts of exposure to heat waves can lead people to downplay their personal vulnerability to the heat (Sheridan, 2007). Further exacerbating this risk perception gap is that heat is less dramatic and more difficult to visually observe compared to other extreme weather events, therefore individuals often assume that heat is neither a threat to them nor requires heightened precaution (Luber and McGeehin, 2008).

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As heat waves increase in frequency and severity due to climate change, personal experience with hot weather may be a significant driver of public awareness of heat risk. Already, individuals are detecting increases in local temperatures with some accuracy (Howe et al., 2013). Similarly, exposure to record-breaking heat has a significant influence on perceptions that heat waves are increasing and becoming more severe (Hyde and Albarracín, 2023). In addition, a number of studies have found that experiencing hot and dry weather increases belief that climate change is happening and facilitates behavior change (Zaval et al. 2014; Marlon et al. 2021; Hoffman et al. 2022). Nonetheless, evidence establishing a relationship between personal experiences with weather-related events and climate change opinions is mixed (Howe et al., 2019).

Effectively communicating the links between extreme weather and climate change is vital. Intensifying climate extremes will necessitate clear and timely information that allows individuals to better prepare for the increased likelihood of extreme weather in their area. Improving communication of the risk posed by extreme weather in a warming world could enable greater protective and adaptive measures to be taken, thereby avoiding harm to life and property. However, even beyond preparing for extreme weather, it is crucial that people recognize the increased extreme weather risk driven by climate change. It is essential that people understand the risks and consequences of unaddressed climate change in order to spur individual behavior change and policy support (van Valkengoed et al., 2021). Accordingly, further exploration of the effectiveness of different messaging frames is necessary to achieve higher levels of climate change engagement. Strategically tailoring frames, such as alerting coastal communities to the impacts of sea level rise, can contribute to increased belief in climate change, enhanced perceptions of risk, and greater concern about the issue (Bolsen et al., 2018).

a. Extreme event attribution

The field of extreme event attribution (EEA) aims to understand and quantify the influence of anthropogenic climate change in changing the intensity and likelihood of any given extreme weather event (National Academies of Sciences, Engineering, and Medicine, 2016; Clarke et al., 2023). Scientific evidence that the probability or magnitude of a given

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extreme weather event was influenced by climate change is generally strongest for temperature-related events such as heat waves. This is because a long observational record of temperatures is available to ascertain whether changes in the mean conditions of temperatures over long time periods corresponds with changes in temperature extremes (National Academies of Sciences, Engineering, and Medicine, 2016). Although EEA is relatively new, the field is rapidly advancing, and scientists are now able to detect in near-real time the connection between individual extreme weather events and climate change (Gilford, et al. 2022). Furthermore, because of recent methodological advances in attribution science, attribution analyses that may have taken days to months can now be computed as an event is unfolding, providing immediate value for climate change communicators in attributing day-to-day weather events to climate change (Gilford et al., 2022).

As a result, new methods for near-real time extreme event attribution are emerging that can quantify how anthropogenic climate change is changing the likelihood of daily local weather events at a particular time and place (Gilford, et al. 2022). One such commonly-used communication tool is the Climate Shift Index (CSI), a novel method of EEA that quantifies how climate change has altered the frequency of daily surface air temperatures at any location in the world, compared to a climate without anthropogenic climate change (Climate Central, 2023). The CSI uses an 11-point ordinal scale ranging from -5 to +5, where each successive level indicates that temperatures are becoming *x* times more or less likely due to climate change.

The CSI provides the public with heat wave risk alerts, helping meteorologists communicate to the general public how climate change is affecting local conditions, shifting perceptions of climate change impacts as a distant problem to the “here and now,” and assisting journalists in communicating the extent to which climate change is influencing local heat extremes and the corresponding impacts to public health, ecosystems, and physical infrastructure (Climate Central, 2023). Because the CSI is a relatively new tool in EEA, its application for climate change communication has received only limited attention in the literature so far (Bolsen, Palm & Kingsland, 2019). However,

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it has been shown that messages emphasizing increased incidences of drought and heat waves are more effective at persuading people that climate change is happening and is an important issue when coupled with an animated map of the CSI, showing temperature increases in the United States over time (Bolsen, Palm & Kingsland, 2019).

More generally, there is a large body of literature looking at strategic framing and persuasive messaging to influence climate change perceptions and decisions. The way information in climate messages is presented (both textually and visually) affects the extent to which it promotes positive attitudinal and behavior change (e.g., Badullovich et al., 2020; Bergquist et al., 2023; Bolsen & Shapiro, 2017; Li & Su, 2018). Framing involves highlighting certain aspects of an issue in order to influence cognitive processes and shaping the audience's interpretation (Wicks, 2005). For example, people perceive messages about extreme weather and climate change as more credible when they are attributed to the government rather than a nonprofit (Howe & Shpeer, 2022). Effective framing can evoke specific emotional responses, activate certain cognitive structures, and ultimately shape individuals' perceptions of reality (Lakoff, 2014), although the effects may differ across some demographic variables (e.g., party affiliation; Druckman et al., 2019; Bayes & Druckman, 2021).

b. Study context

Our study is a novel opportunity to investigate if the CSI is an effective way of communicating the links between climate change and extreme weather. Additionally, we examine whether alternative messaging frames are more effective in communicating the CSI, adding to a small body of literature on the subject. The way that statistical probability is framed can have a significant influence on the efficacy of messages and how they are perceived by the public. For example, many people experience ratio bias, perceiving ratios of large numbers as more likely than ratios of small numbers despite the information presented being logically equivalent (e.g., $\frac{2}{4}$ as more likely than $\frac{1}{2}$; Pedersen, 2017). This then impacts their opinion formation and policy preferences in political contexts. Similarly, studies on weather forecast uncertainty have found that conditional probability percentages (e.g., 10% chance of rain) and non-numerical text (e.g. rain is not likely) are

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generally preferred to other communication formats such as relative frequency (e.g., 1 in 10) and odds (e.g. odds are 1 to 9) when communicating the probability of precipitation (Joslyn and Nichols, 2009; Morss et al., 2008). A focus-group study exploring how people engaged with different ways of communicating EEA also found that framing EEA findings with terms such as likelihood was easier to understand than magnitude or probability (Ettinger et al., 2021). Likewise, participants perceived larger numbers (e.g., 17 times more likely versus 4 times more likely) and percentages (e.g., 300% more likely versus 4 times more likely) as eliciting greater shock and attention than smaller numbers (Ettinger et al., 2021). To explore whether different numerical framings impacted the efficacy of the EEA message in our study, we developed two alternative treatments that expressed the CSI as a percentage (e.g., 400% more likely) and as a time period (e.g., an event likely to occur only once every five years is now likely to occur at least once each year).

Further, it is possible that including a contextual explanation with the CSI may enhance its credibility, legitimacy, or persuasiveness. For example, previous research has shown that people express higher confidence in the accuracy of EEA and more deeply support the connection that climate change increases the intensity and frequency of extreme weather when context for how these processes occur is provided in EEA results (Ettinger et al., 2021). Similarly, research in health risk communication suggests that providing individuals with contextual information about a health problem is more effective than providing statistical information in changing personal risk perceptions (Rothman and Kiviniemi, 1999). To test whether adding contextual explanations for the CSI impacts its efficacy, we included mechanistic (i.e., how climate change affected a particular extreme weather event) and attribution (i.e., how scientists know that climate change affected a particular extreme weather event) explanations as part of the treatments.

For this study, we focused on the major heat wave that covered much of the United States (US) in July 2023. More than 85% of Americans experienced temperatures above 90 degrees Fahrenheit, with millions of people across the southern US experiencing temperatures over 100 degrees (Elamroussi & Zerkel, 2023). The July 2023 heat wave

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was highly abnormal, with scientists finding that it would have been virtually impossible to occur in the US without anthropogenic climate change (World Weather Attribution, 2023). The CSI has made it possible to quantify how many times more likely the heatwave was due to climate change, finding that these high temperatures were made at least 5 times more likely by climate change (Climate Central, 2023).

The primary research question of this study is whether the Climate Shift Index is an effective way of communicating the links between climate change and extreme weather, and whether alternative ways of communicating this information lead to different effects. We tested six treatments, one which includes the CSI only, one which frames magnitude as a percentage, one as a time period, two which include either a mechanistic or attribution explanation, and one which combines both the mechanistic and attribution explanations, in order to explore the ways in which different numerical or verbal framings can influence the impact of the message. We were primarily interested in the extent to which participants thought climate change a) made the July 2023 heatwave more likely, and b) is making heat waves in the United States more likely in general. We had two hypotheses:

H1: Every treatment will outperform the controls for all main dependent measures (see below)

H2: The CSI + mechanistic + attribution treatment will perform best

2. Methods

The materials, data, analysis code, and preregistration needed to reproduce this experiment and corresponding analyses are available on our Open Science Framework (OSF) project page (https://osf.io/6n25h/). All analyses were preregistered unless stated otherwise. Our research protocol was approved by the Yale University institutional review board. Participants were randomly assigned to one of eight conditions (two controls and six treatments (Table 1).

Table 1. List of conditions and their text.

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Condition	Text
Pure control	Cheetahs are one of the world's most-recognizable cats, known for their speed. They can run at up to 71 miles per hour. Cheetahs have many adaptations that enhance their ability to sprint. Their legs are proportionally longer than those of other big cats; an elongated spine increases stride length at high speeds; they have special paw pads for extra traction; and a long tail helps them balance.
Active control	In July 2023, a major heat wave covered much of the US. More than 85% of Americans experienced temperatures above 90 degrees Fahrenheit, with millions of people across the southern US experiencing temperatures over 100 degrees.
Standard Climate Shift Index (CSI)	In July 2023, a major heat wave covered much of the US. More than 85% of Americans experienced temperatures above 90 degrees Fahrenheit, with millions of people across the southern US experiencing temperatures over 100 degrees. Scientists say these high temperatures were made at least 5 times more likely by climate change.
CSI as a %	In July 2023, a major heat wave covered much of the US. More than 85% of Americans experienced temperatures above 90 degrees Fahrenheit, with millions of people across the southern US experiencing temperatures over 100 degrees. Scientists say the high temperatures were made at least 400% more likely by climate change.
CSI as a time period	In July 2023, a major heat wave covered much of the US. More than 85% of Americans experienced temperatures above 90 degrees Fahrenheit, with millions of people across the southern US experiencing temperatures over 100 degrees. Scientists say that before climate change, a heat wave like this might have occurred only once every five years. But because of climate change, a heatwave like this is now likely to occur at least once each year.

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CSI + mechanistic explanation	In July 2023, a major heat wave covered much of the US. More than 85% of Americans experienced temperatures above 90 degrees Fahrenheit, with millions of people across the southern US experiencing temperatures over 100 degrees. Scientists say the high temperatures were made at least 5 times more likely by climate change. This happened because the average global temperature has increased by 2 degrees Fahrenheit, which makes hotter days and extreme heatwaves more likely to occur. July's heat wave was the result of a "heat dome" in the US - an area of high pressure where hot air is pushed down and trapped in place.
CSI + attribution explanation	In July 2023, a major heat wave covered much of the US. More than 85% of Americans experienced temperatures above 90 degrees Fahrenheit, with millions of people across the southern US experiencing temperatures over 100 degrees. Scientists say the high temperatures in July were made at least 5 times more likely by climate change. Using computer models, scientists compared the likelihood that a heatwave would occur in a world without carbon emissions released by humans and today's world with decades of carbon emissions building up in the atmosphere. This is an established scientific method to determine how much climate change has or has not affected individual extreme weather events.
CSI + both explanations	In July 2023, a major heat wave covered much of the US. More than 85% of Americans experienced temperatures above 90 degrees Fahrenheit, with millions of people across the southern US experiencing temperatures over 100 degrees. Scientists say the high temperatures were made at least 5 times more likely by climate change. This happened because the average global temperature has increased by 2 degrees Fahrenheit, which makes hotter days and extreme heatwaves more likely to occur. In this case, July's heat wave was the result of a "heat dome" in the US - an area of high pressure where hot air is pushed down and trapped in place. Using computer models, scientists compared the likelihood that a heatwave would occur in a world without carbon emissions released by humans and today's world with decades of carbon emissions building up in the atmosphere. This is an established

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	scientific method to determine how much climate change has or has not affected individual extreme weather events.

a. Sample

Data were collected from September 25, 2023 to October 5, 2023. Respondents were recruited from the Prolific Academic panel. We restricted participation to adults living in the USA. We used quotas for age, gender, and political affiliation in order to ensure a representative sample, using benchmarks from a recent nationally-representative probability sample (Leiserowitz et al., 2023). When data collection slowed for harder to reach populations on Prolific (e.g., Republicans over the age of 45), we loosened the age or gender restrictions on some of the bins.

We set the smallest effect size of interest at $d = 0.15$ (Lakens et al., 2018). We conducted a power analysis using the pwr package in R to determine how many respondents would be needed to detect $d = 0.15$ at 80% power and an alpha level of .05. The analysis showed that about 700 respondents per condition would be needed to achieve the desired statistical power. However, this is a substantially conservative estimate of power because we measured the dependent outcomes both pre- and post-treatment, which substantially increases power when used in analyses (Gerber and Green, 2012). For a sample size of 500 per condition (pwr.t.test(n = 500, sig.level = .05, power = .8)) we would be able to detect a $d = .177$ effect size, but that does not account for the additional power gained by controlling for a pre-treatment measure of the outcomes. Thus, we set our goal sample size at 500 respondents per condition (4,000 total), which powered this study to detect effect sizes much smaller than the smallest effect size of interest.

3,971 people completed the survey but 69 were removed for failing an attention check, and thus 3,902 valid cases were used in the main analyses (Table 2). Demographic comparisons between the treatment and control groups can be found in Supplementary Information 1.

Table 2 . Overview of demographic variables for participants in the study

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N = 3,902	**n (%)**	**% population estimate***
Age		
18-29	611 (16%)	20%
30-44	1197 (31%)	26%
45-59	1385 (35%)	24%
60+	690 (18%)	30%
Missing	19 (<1%)	0%
Gender:		
Man	1880 (48%)	48%
Woman	1965 (50%)	51%
Another identity	39 (1%)	1%
Missing	18 (<1%)	0%
Education:		
No High School	29 (1%)	9%
High School	556 (14%)	29%
Some college	1242 (32%)	27%
College degree	1450 (37%)	19%
Graduate degree	606 (16%)	16%
Missing	19 (<1%)	0%
Income:		
Less than $10,000	21 (1%)	4%
$10,000 to less than $25,000	410 (11%)	9%
$25,000 to less than $50,000	916 (24%)	16%
$50,000 to less than $100,000	1385 (36%)	29%
$100,000 to less than $200,000	159 (4%)	33%
$200,000 or more	829 (21%)	10%
Missing	182 (5%)	0%
Race/Ethnicity		
White, non-Hispanic	2908 (75%)	62%
Black, non-Hispanic	330 (9%)	12%
Hispanic	316 (8%)	17%
Asian or Pacific Islander, Non-Hispanic	191 (5%)	6%
Another race, more than one race/ethnicity,	128 (3%)	3%
Native American, or Alaska Native	9 (<1%)	0%
Missing	20 (<1%)	
Political party:		
Republican	1,613 (41%)	44%
Democrat	1,860 (48%)	33%
Independent	207 (5%)	13%
No party	200 (5%)	10%
Missing	22 (1%)	1%

Note: Population estimates are taken from Leiserowitz et al. (2023).

b. Materials and procedure

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The survey began with pre-treatment measures of climate change beliefs and risk perceptions, an attention check, and potential moderators, followed by random assignment to one of the treatment conditions. Next came post-treatment outcomes, and demographic questions. Each section is described in more detail below. See OSF materials for the full survey (https://osf.io/6n25h/).

1. TREATMENT AND CONTROL CONDITIONS

Treatments and control consisted of a short text, plus a map by Climate Central (see full materials at https://osf.io/6n25h/). The pure control discussed cheetahs and their speed. The active control was a short paragraph about the July 2023 heat wave. The treatments all started with this first paragraph, and then added 1-2 paragraphs about how the heat wave was affected by climate change (Figure 1). Both the active control and the treatments were accompanied by a map from Climate Central representing high temperatures made more likely by climate change, but with the figure legend removed.

In July 2023, a major heat wave covered much of the US. More than 85% of Americans experienced temperatures above 90 degrees Fahrenheit, with millions of people across the southern US experiencing temperatures over 100 degrees.

Scientists say these high temperatures were made at least 5 times more likely by climate change.

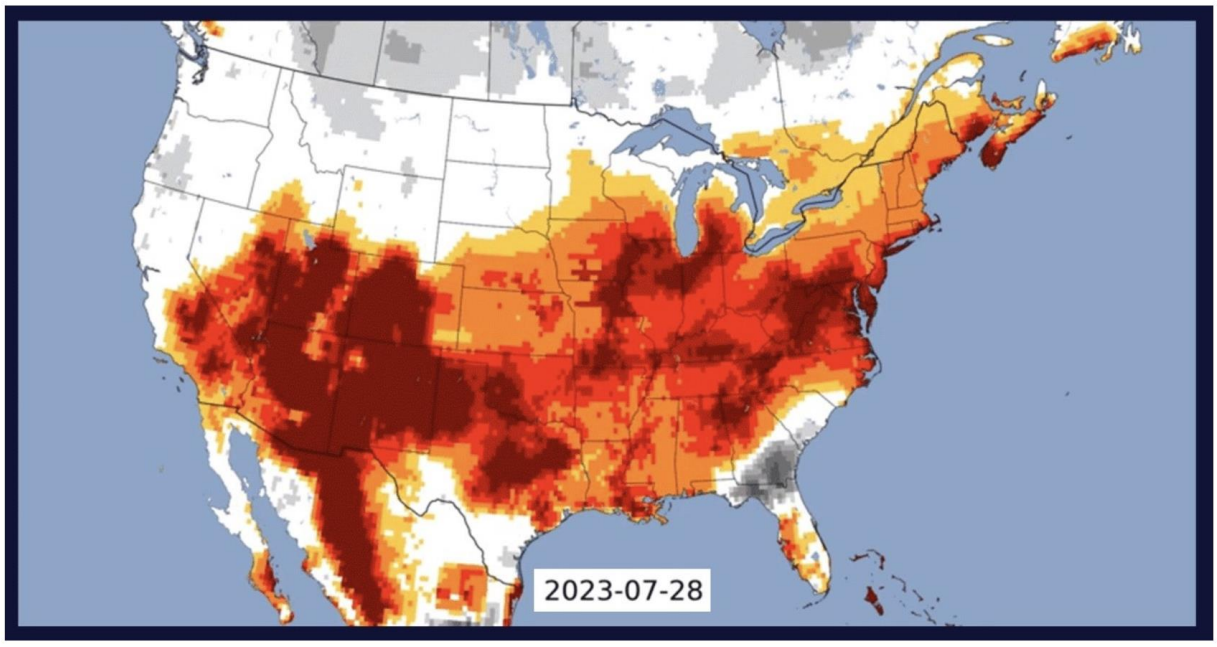

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Figure 1. Message and image shown to participants in the "CSI treatment" condition - see https://osf.io/6n25h/ or Table 1 for other message treatments.

2. OUTCOMES

The main outcomes were to what extent participants think climate change a) made the July 2023 heatwave more likely (1 = *Not at all more likely*, 5 = *Extremely more likely*), and b) is making heat waves in the United States generally more likely, measured on a 5 point likert scale (1 = *Not at all more likely*, 5 = *Extremely more likely*).

As secondary outcomes we measured to what extent participants think climate change a) made the July 2023 heatwave worse, and b) is making heat waves in the United States generally worse, as well as worry about climate change, belief that the US federal government should be doing more to protect people from heat waves caused by climate change, and intentions to discuss the July 2023 heatwave with others. All outcomes were measured both pre- and post-treatment.

3. MODERATORS

We had four measures for sub-group analyses: whether the July heat wave caused harm to the participants personally or to people they know, their level of climate change concern, and their political affiliation (detailed in the demographic section). Specifically, we asked whether participants had experienced a heat wave in their local area during July 2023. If they answered yes, we then measured whether they were harmed by the July heat wave on a 4 point likert scale from "Not at all" to "A great deal." Using the same scale, we also asked how much the people they know were harmed by the July heat wave. Level of climate change concern was determined based on participants' status on the Climate Change's Six Americas segmentation (Leiserowitz, Maibach, & Roser-Renouf, 2009), which categorizes participants into one of six unique target audiences in the US that respond to climate change in different ways, ranging from the "Alarmed" (Americans who are very worried about global warming and support taking action) to the "Dismissive" (those who think global warming is non-existent, not a threat, or an outright

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hoax). Segment membership was determined using the four-item Six Americas Short Survey (Chryst et al, 2018).

4. DEMOGRAPHICS

Finally, we collected socio-demographic data on age, gender, education, income, race, and political affiliation. Political affiliation was determined based on two questions. First, whether participants thought of themselves as Republican, Democrat, Independent, other, or no party/not interested in politics. Then, if a respondent chose Independent or other, they were asked if they thought of themselves as closer to the Republican Party, Democratic Party, or neither. Respondents that chose the Republican or Democratic party were categorized as members of that party, whereas respondents who chose "neither" were categorized as Independents.

c. Data analysis

All analyses and visualization were conducted using R version 4.3.0. We used linear regressions with the full dataset to test the impact of each treatment message on each outcome. We made pairwise comparisons with each level of the factor message treatment to the pure control. These regressions are our primary analyses, controlling for the pre-treatment measure of the corresponding dependent variable to enhance measurement precision and statistical power (Gerber and Green, 2012). We repeated this analysis with an unadjusted regression as a secondary sensitivity analysis (see SI 2).

To assess individual differences in treatment effects, we did the same as described above with the addition of interaction terms and conditional effects. All effect sizes are reported in standard deviation units (by standardizing the DV to have a mean of 0 and a SD of 1).

3. Results

a. Main outcomes

1) EFFECTS ON BELIEFS THAT CLIMATE CHANGE MADE THE JULY 2023 HEAT WAVE MORE LIKELY

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At baseline, the majority of respondents already believed that climate change made the July 2023 heat wave "a lot" or "extremely" more likely (53%). Compared to the pure control, all conditions increased the strength of this agreement (Figure 2). The CSI Percent treatment had the largest impact ($d = 0.17$, 95% CI = [0.11, 0.22], $p < 0.01$), which was statistically significant ($d = 0.08$, 95% CI = [0.01, 0.16], $p = 0.03$) compared to the standard CSI treatment. To give a more intuitive sense of this effect size, we calculated the percentage point difference in the belief that climate change made the July 2023 heat wave "a lot" or "extremely" more likely. The CSI Percent treatment led to a 6 percentage point increase in this belief compared to the pure control, or a 1 percentage point increase compared to the standard CSI treatment.

Figure 2. Effect of messages on the belief that climate change made the July 2023 heat wave more likely, compared to the pure control condition.

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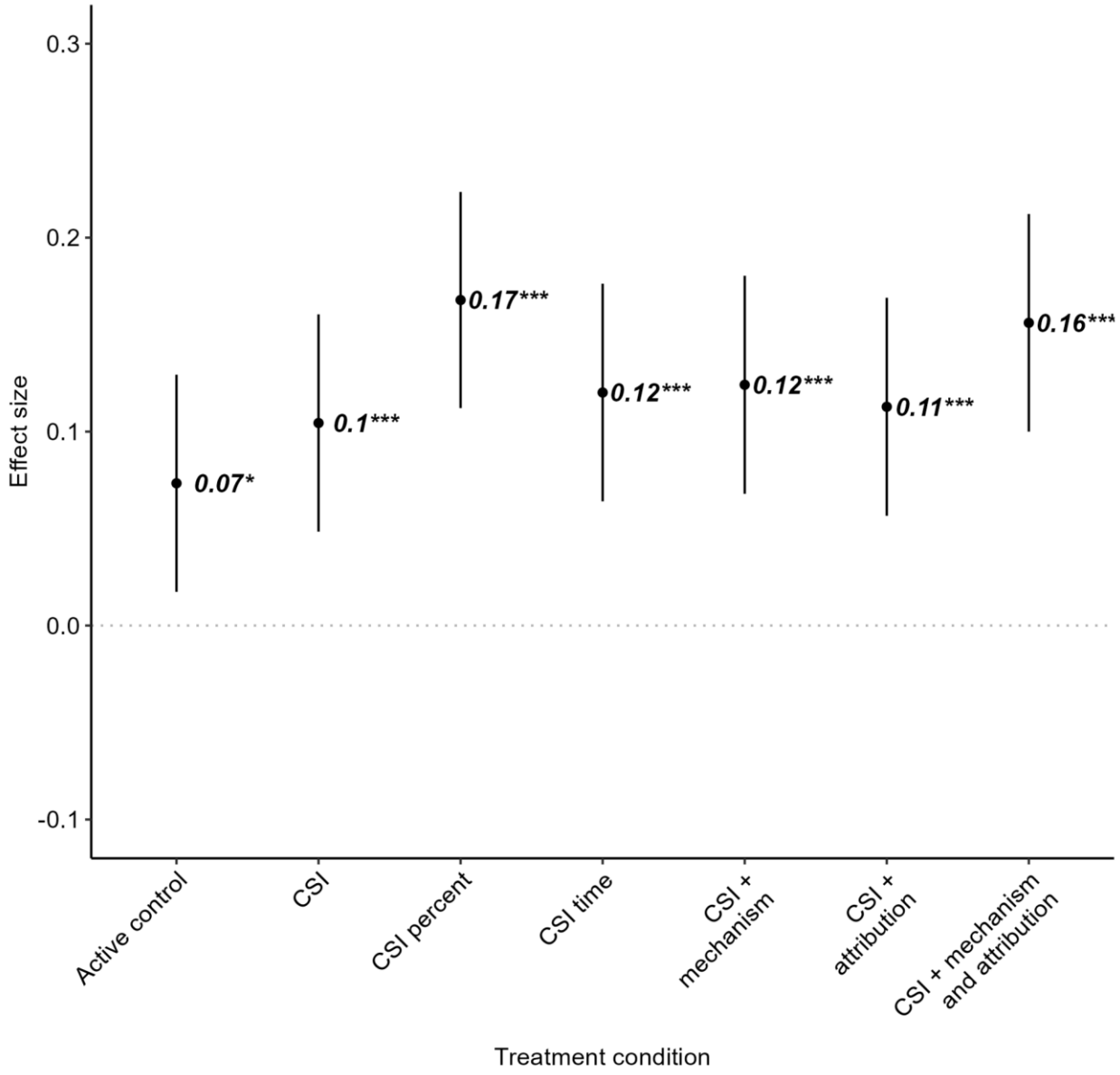

Note. $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$. CSI = Climate Shift Index. Vertical bars represent the 95% confidence intervals (CI). Effect size estimates are standardized mean differences, controlling for pre-treatment measurement of the dependent variable.

2) EFFECTS ON BELIEFS THAT CLIMATE CHANGE IS MAKING HEAT WAVES IN THE US MORE LIKELY

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At baseline, the majority of respondents already believed that climate change is making heat waves in the US "a lot" or "extremely" more likely (58%). Compared to the pure control, all conditions increased the strength of agreement (Figure 3). The CSI + Mechanism & Attribution had the largest impact ($d = 0.19$, 95% CI = [0.13, 0.25], $p < 0.01$), although this was not statistically different ($p = 0.09$) from the standard CSI treatment. To give a more intuitive sense of this effect size, we calculated the percentage point difference in the belief that climate change is making heat waves in the US "a lot" or "extremely" more likely. The CSI + Mechanism & Attribution treatment led to a 9 percentage point increase in this belief compared to the pure control, or a 0.5 percentage point increase compared to the standard CSI treatment.

Figure 3. Effect of messages on the belief that climate change is making heat waves in the US more likely, compared to the pure control condition.

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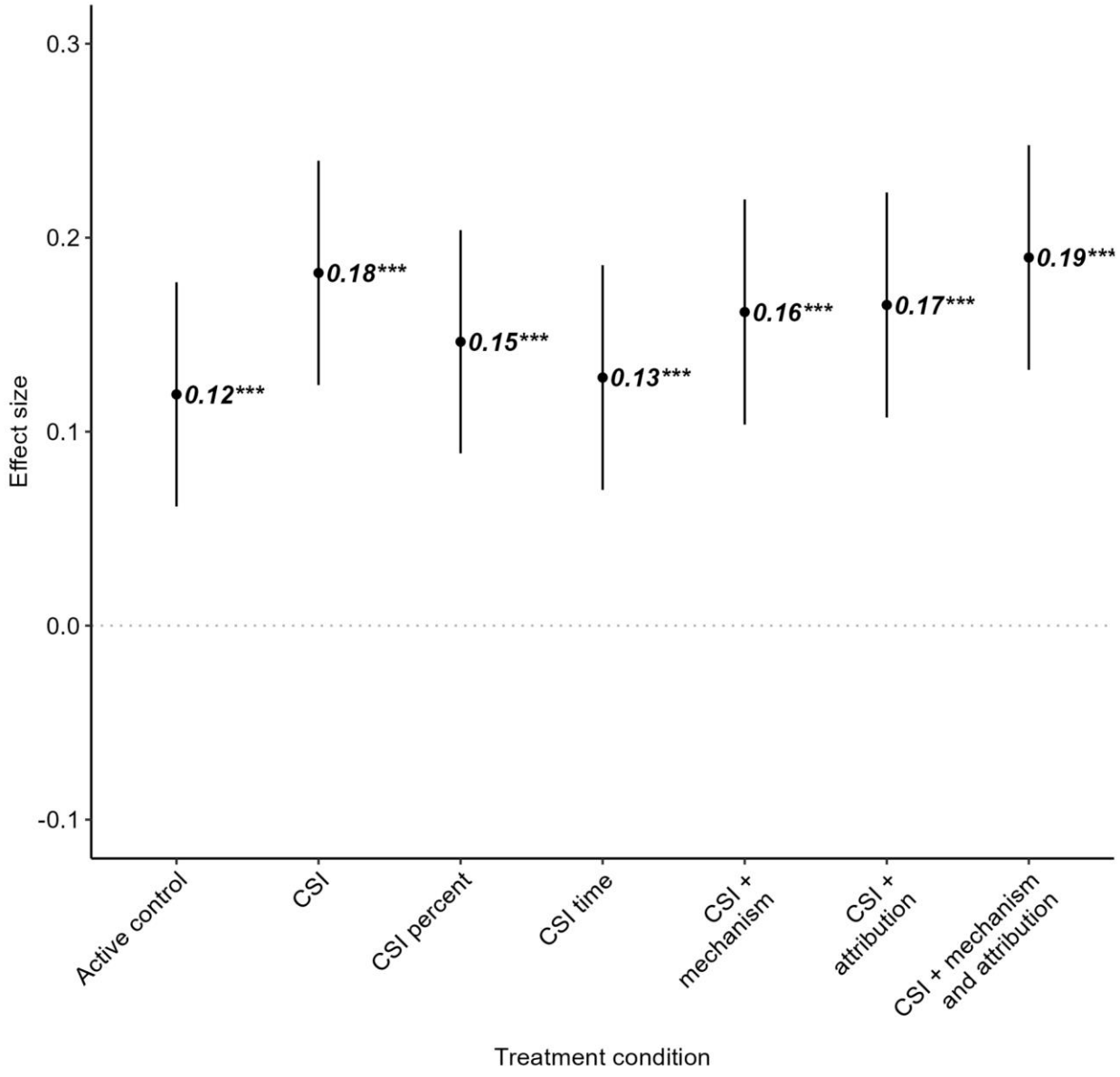

Note. $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$. CSI = Climate Shift Index. Vertical bars represent the 95% confidence intervals (CI). Effect size estimates are standardized mean differences, controlling for pre-treatment measurement of the dependent variable.

b. Secondary outcomes

Next, although all treatment messages emphasized that climate change made the July 2023 heat wave more likely, in exploratory analyses we also tested if the messages

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affected beliefs about whether climate change made the July 2023 heat wave *worse*, and outcomes such as policy support and communication intentions.

1) EFFECTS ON BELIEFS THAT CLIMATE CHANGE MADE THE JULY 2023 HEAT WAVE WORSE

Compared to the pure control, all conditions except for the CSI Time increased the strength of agreement (SI 3). The CSI + Mechanism & Attribution treatment had the largest impact (d = 0.13, 95% CI = [0.07, 0.19], p <0.01), but this was not statistically significant compared to the standard CSI treatment.

2) EFFECTS ON BELIEFS THAT CLIMATE CHANGE IS MAKING HEAT WAVES IN THE US WORSE

Compared to the pure control, all conditions increased the strength of agreement (SI 4). The CSI Percent and CSI + Attribution treatments had the largest impacts (d = 0.17, 95% CI = [0.11, 0.23], p <0.01 for both conditions), but these were not statistically significant compared to the standard CSI treatment.

3) EFFECTS ON BELIEFS THAT CLIMATE CHANGE WILL CAUSE MORE HEAT WAVES OVER THE NEXT 20 YEARS

Compared to the pure control, all conditions except for the standard CSI increased the strength of agreement (SI 5). The CSI + Attribution treatment had the largest impact (d = 0.1, 95% CI = [0.03, 0.16], p <0.01), but this was not statistically significant compared to the standard CSI treatment.

4) EFFECTS ON SUPPORT FOR GOVERNMENT ACTION ON HEAT WAVES

Compared to the pure control, only CSI Time and CSI + Mechanism increased the strength of agreement (SI 6). The CSI Time treatment had the largest impact (d = 0.07, 95% CI = [0.02, 0.13], p = 0.01), and this was statistically significant (d = 0.05, 95% CI = [0.004, 0.1], p = 0.04) compared to the standard CSI treatment.

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5) EFFECTS ON COMMUNICATION INTENTIONS ABOUT THE JULY 2023 HEAT WAVE

Compared to the pure control, all treatment conditions except for the CSI + Mechanism and CSI + Attribution increased the strength of agreement (SI 7). The standard CSI and CSI + Mechanism & Attribution treatments had the largest impacts (d = 0.11, 95% CI = [0.05, 0.16], p <0.01 and d = 0.11, 95% CI = [0.06, 0.17], p <0.01 respectively).

c. Subgroup Effects

Next, we examined whether treatment effects differed depending on a range of factors, including perceived harm caused by the July 2023 heat wave, Six America Segment (i.e., climate concern), and political affiliation. The CSI time and CSI + Attribution messages were *less* effective for people who reported having been harmed by the July 2023 heat wave when it came to the belief that climate change made the July 2023 heat wave more likely (effect size [95% CI] = -0.09 [-0.14, -0.04] and -0.06 [-0.11, -0.004] respectively). The CSI time message was also less effective for participants who reported that people they knew were harmed by the July 2023 heat wave (effect size [95% CI] = -0.06 [-0.12, -0.01]). However the treatments and harm perceptions had no significant interaction effects on the belief that climate change is making heat waves in the U.S. more likely (SI 8).

When participants were segmented by their level of climate concern (measured by their Six Americas Segment; Chryst et al, 2018), the largest treatment effects are seen for the Cautious and Concerned segments, likely because of a ceiling effect at baseline for the Alarmed (SI 10). Participants were also segmented by their political party, but no consistent conditional treatment effects were observed (SI 10).

4. Discussion

Informing people about the impact of climate change on a specific heat wave increases beliefs that climate change made that heat wave, as well as heat waves generally in the US, "a lot" or "extremely" more likely. This is the case regardless of how the information

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is framed or what explanations are used. Certain message framings can also increase policy support for action on climate change and communication intentions about extreme weather events. The findings of this study contribute to the scarce literature on which messages are effective at communicating extreme weather event attribution.

We also found that using percentages, rather than the standard CSI format which uses magnitude, was the more effective way to communicate the links between climate change and a specific heatwave. This finding corroborates previous qualitative research which suggested that conditional probability (i.e., 400%) is easier to understand than natural frequency (e.g., one in two) or magnitude (e.g., five times; Stephens et al. 2012, Ettinger et al. 2021). However the difference between the two treatments is small in practical terms (d = 0.08), and both framings work well.

Although it was not among the main dependent variables in this study, arguably the most important outcome measure to influence is support for government action on climate change to address heat waves. Notably, the standard CSI treatment had no effect on this variable. However, framing the CSI as a time period ("Scientists say that before climate change, a heat wave like this might have occurred only once every five years. But because of climate change, a heatwave like this is now likely to occur at least once each year.") does increase support for government action. Yet this framing was less effective compared to the "times" and "percentage" framings at influencing beliefs about the links between climate change and the likelihood and severity of heat waves. More research is needed to investigate if this difference replicates in future research, and what might be causing the discrepancy. In the meantime, the choice of framing will depend on the primary aim of communicators – improving basic knowledge or building support for government action.

Unexpectedly, we also found that just talking about the July 2023 heat wave, without mentioning climate change, was enough to positively impact beliefs that climate change is making heat waves more likely *and* worse, both for the July 2023 heat wave and heat waves in the US in general. One possible explanation for this finding is previous exposure

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to news media which linked the heat wave to climate change (e.g., Borenstein, 2023; Cappucci & Moriarty, 2023; Vogt et al, 2023). Potentially our active control condition then acted as a prompt to recall this existing knowledge. Note that although talking about the heat wave was better than not mentioning it, directly explaining the impact of climate change was even more effective (SI 11). Future research could explore the relevance of the media environment to the efficacy of messaging treatments on climate change.

Contrary to some previous research, we did not find a backfire effect from our message treatments for climate skeptics (the "dismissive" in our subgroup analysis – SI 10; Dixon et al. 2019). Even where treatment effects were not significant, they always moved in a positive rather than negative direction.

Future work in the area of EEA should continue to explore the impact of communicating different extreme weather events and their link to climate change, such as hurricanes vs flooding vs heat waves (Dixon et al. 2019). More generalized communication (e.g., climate change is making heat waves generally more likely, rather than climate change made the July 2023 heat wave specifically more likely) also needs to be tested. Finally we suggest comparing likelihood versus the severity of extreme weather events due to climate change on people's beliefs and attitudes.

a. Conclusion

Increasing numbers of extreme weather events, while devastating in impact, at least provide more "teachable moments" to communicate the serious risks of climate change impacts that are already happening (Hart & Leiserowitz, 2009). Communicating these links is effective, no matter which of our message treatments is used, but using percentages to quantify the increase in likelihood of extreme weather effects might be most beneficial.

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