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Combatting climate change misinformation: Evidence for longevity of inoculation and consensus messaging effects

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ABSTRACT

Despite the fact that there is a 97% consensus among climate scientists that humans are causing global warming, the spread of misinformation continues to undermine public support for climate action. Previous studies have found that resistance to misinformation can be induced by cognitively inoculating individuals against doubt-sowing about climate change. However, the long-term effectiveness of this approach is currently unknown. In a preregistered replication and extension experiment we combined a scientific consensus message with an inoculation treatment, and exposed participants to an influential misinformation message one week later. We explored 1) whether we can replicate the finding that inoculation is able to protect against a misinformation attack, and 2) whether or not the consensus and inoculation effects remain stable over the course of one week. Successfully replicating the effects of the original study, we found a strong initial consensus effect that is sensitive to doubt-sowing misinformation. Importantly, we also found that the consensus effect can be inoculated against misinformation. Extending the replication, we found that the consensus effect shows partial decay over time, while the inoculation effect remains stable for at least one week. We discuss the impact of our findings for inoculation theory, climate change psychology, and public policy.

1. Introduction

Climate change is one of the most pressing problems of our time (Allen et al., 2014), requiring large-scale collective action (van der Linden, Leiserowitz, Feinberg, & Maibach, 2015). If no public action is taken, the continued rise in global temperatures could bring fundamental harm to human society and ecosystems. Numerous detrimental effects are already occurring, from extreme temperatures and floods to failed crop harvests and climate refugees (Biermann & Boas, 2010; Stocker et al., 2013). Indeed, many ecological systems are currently being threatened with destruction and biodiversity is falling drastically (Bridgewater, Loyau, & Schmeller, 2019).

Among climate scientists, a strong scientific consensus has been established on the fact that humans are causing global warming (Cook et al., 2016). Consensus research has replicated this finding in at least five high quality studies over the past years, estimating the consensus among scientists from a minimum of 91% to a maximum of 100% (Anderegg, Prall, Harold, & Schneider, 2010; Carlton, Perry-Hill, Huber, & Prokopy, 2015; Cook et al., 2016, 2013; Doran & Zimmerman, 2009; Oreskes, 2004; Stenhouse et al., 2014; Verheggen et al., 2014). These studies further show a strong positive relationship between expertise in climate science and scientific consensus on human-caused climate change (Cook et al., 2016). However, most people are not climate science experts, and need to navigate facts through a cloud of (mis)information.

1.1. Consensus messaging

Research has shown that communicating descriptive norms, such as the fact that 97% of scientists agree that humans are causing climate change, can positively influence belief in climate change and support for action, bridging the ideological divide (Goldberg, van der Linden, Ballew, Rosenthal, & Leiserowitz, 2019; Kerr & Wilson, 2018; Lewandowsky, Gignac, & Vaughan, 2013; van der Linden, Leiserowitz, & Maibach, 2018; van der Linden et al., 2015, 2019). A recent dual-process model of attitudinal change on climate change, the Gateway Belief Model (GBM), shows how debiasing misperceptions about scientific norms can lead to higher perceived scientific consensus, which in turn serves as a gateway belief with cascading effects on personal attitudes and support for collective action (van der Linden et al., 2015, 2019). Although research on the benefits of communicating scientific consensus is now well-established (see van der Linden et al., 2019, for a

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recent review), research has also shown that when it is countered with an opposing (misinformation) message that contradicts the scientific consensus (e.g., a misleading petition claiming "there is no scientific consensus on climate change"), the positive effect of communicating the consensus is reduced or even completely neutralised (van der Linden, Leiserowitz, Rosenthal, & Maibach, 2017).

1.2. Misinformation

Efforts to tackle the climate change problem have suffered from the influence of various forms of misinformation (Farrell, 2019; Farrell, McConnell, & Brulle, 2019; Lewandowsky, Oreskes, Risbey, Newell, & Smithson, 2015; McCright, Charters, Dentzman, & Dietz, 2016; Oreskes & Conway, 2010). Among the many climate change misinformation techniques used, the most prevalent technique is sowing doubt about the scientific consensus (Oreskes & Conway, 2011). Through false-balance media coverage of the topic (e.g., 50%/50% instead of 97%/3%) or by using fake expert accounts (e.g., a professor in an unrelated field proclaiming to be a climate expert), perceptions of scientific consensus can be distorted (Cook, Maibach, van der Linden, & Lewandowsky, 2018, 2017; Koehler, 2016; Kortenkamp & Basten, 2015; Stocking, Holly Stocking, & Holstein, 2009).

At the same time, researchers find that online misinformation can spread faster and deeper than factual information, making it harder for scientific facts to reach the entire population (Lewandowsky, Pilditch, Madsen, Oreskes, & Risbey, 2019; Scheufele & Krause, 2019; Vosoughi, Roy, & Aral, 2018). Even when factual information corrects a myth, the initial belief (based on a falsehood) can still exert a continued influence (Ecker, Lewandowsky, Fenton, & Martin, 2014; Lewandowsky, Ecker, Seifert, Schwarz, & Cook, 2012; Swire, Ecker, & Lewandowsky, 2017). When the correction goes against the prevailing worldview of a polarised group, this correction may even backfire, though it should be noted that the literature on backfire effects is increasingly debated (see Ecker et al., 2014; Ecker & Ang, 2019; Guess & Coppock, 2018; Wood & Porter, 2019). In short, although the 'debunking' approach to misinformation is often ineffective, it is still the most prevalent method used to tackle fake news (Graves & Cherubini, 2016). In contrast, it has been suggested that a more effective way of tackling misinformation is one based on building up resistance *before* any damage is done (Cook, Lewandowsky, & Ecker, 2017; van der Linden, 2019), an approach called "inoculation" or "prebunking".

1.3. Inoculation theory

Over the past 50 years, inoculation theory has emerged "as the most consistent and reliable method for conferring resistance to persuasion" (Miller et al., 2013, p. 127). Initially designed as a vaccine against brainwash by propaganda (McGuire, 1970), inoculation theory is now arguably the most established theory on resistance against persuasion (Eagly & Chaiken, 1993; Miller et al., 2013). Analogous to a biological vaccine, cognitive inoculation works by exposing people to severely weakened doses of misinformation ('the virus') to slowly build up cognitive resistance ('the antibodies') against misinformation (Compton, 2013; McGuire, 1962, 1964; McGuire & Papageorgis, 1961). The inoculation process consists of two related components, namely; a) a forewarning of an attitudinal attack (the *affective* basis) and b) a process of refutational preemption (the *cognitive* basis). The underlying idea is that prior experience with persuasive arguments, combined with a warning of an upcoming threat, provides familiarity and alertness which can be used to disarm a later persuasive attack (Ivanov, 2017). Meta-analyses have demonstrated that this method is generally effective, with effects (compared to no-treatment control groups) averaging on $d = 0.43$ (95% CI = [0.39, 0.48]), which can be regarded as a strong effect size in persuasion research (Banas & Rains, 2010; Weber & Popova, 2012).

Initially, inoculation theory was developed in a 'germ-free' environment, focusing on protection against attitudinal attacks that were relatively unquestioned (e.g., brushing your teeth). Recent research shows that inoculation is also effective within the context of a broad range of polarised issues, including climate change (Cook et al., 2017; van der Linden et al., 2017; Wood, 2007). Because people have differing prior attitudes on contested issues, conceptually, the inoculation approach is more therapeutic than truly preemptive. Accordingly, to better distinguish between inoculation interventions that try to "treat" an existing attitude and ones that purely protect, scholars have proposed to use the terms prophylactic and therapeutic inoculation (Compton, 2019). As people often have different underlying attitudes toward climate change, inoculation against climate change misinformation can be considered "therapeutic" in the sense that they boost immune response even among the already "afflicted."

In particular, van der Linden et al. (2017) designed an intervention which sought to combine climate change misinformation, consensus messaging, and inoculation. Results supported the effectiveness of inoculation against climate change misinformation. Specifically, the experiment had five conditions, including a) a facts-only condition where people were only exposed to a message about the near-unanimous scientific consensus on climate change (van der Linden, Leiserowitz, Feinberg, & Maibach, 2014), b) a misinformation-only condition where people were exposed to an influential misinformation campaign (the Oregon Global Warming Petition), which formed the basis of a viral story on social media that claimed that thousands of scientists have a signed a petition that global warming is a hoax (Readfearn, 2016), c) a false-balance condition where people were exposed to both the scientific consensus and the misinformation sequentially, and d) two inoculation conditions, both of which started with the scientific consensus message and then preemptively "vaccinated" people against the petition either with just a warning that some political actors try to deceive people on the issue of global warming (the affective basis) or both a warning and a more detailed preemptive refutation of the petition (e.g., people were told beforehand that the petition has bogus signatories such as the *Spice Girls* and *Charles Darwin*). In the control group, people solved a neutral word puzzle. Attitudes toward the scientific consensus were assessed pre-and-post and the inoculation groups were exposed to the "full dose" (a screenshot of the debunked Oregon petition with a short description) at the end of the experiment. The authors found that, although misinformation had a significant negative effect ($d = -0.48$) by itself on perceived scientific consensus (and completely neutralised the positive effect of the scientific consensus in the false-balance condition), the inoculation conditions ($d = 0.33$ and $d = 0.75$) significantly protected attitudes toward the scientific consensus from harmful misinformation.

Cook et al. (2017) published a similar study using the same misinformation treatment with a focus on polarisation based on differences in free-market support. They found that both the consensus message and the inoculation treatment were effective at lowering the negative and polarising effects of misinformation, both for people low and high in free-market support. However, while both the study by van der Linden et al. (2017) and the study by Cook et al. (2017) provide valuable evidence on inoculation and consensus messaging, they do not provide any insights on the longevity of the potential inoculation effects, which is a crucial ingredient for the creation of interventions with long-lasting protection.

1.4. Long-term effectiveness

For its many years of development, there is still a lack of clarity about the long-term effectiveness of inoculation effects. In most studies, the delay between the inoculation and the persuasion attempt is only a matter of minutes or at most a few days (Banas & Rains, 2010). While most longitudinal studies do report decay to some extent, it is unclear what shape the decay function takes, and it has been understudied, in particular pertaining to topics that are regularly debated in the media, such as climate change. Although some longitudinal studies have reported decay starting after two weeks, others have reported effectiveness of up to at least 44 days with booster messages (Banas & Rains, 2010; Ivanov, Parker, & Dillingham, 2018; Pfau et al., 2006).

McGuire (1964) originally argued that a delay of a few days between inoculation and attack is needed for the effect to sink in maximally. While some evidence for the enhancement of resistance by delaying the attack has been found, there is more consistent evidence for the opposite conclusion: the inoculation effect dissipates over time (Banas & Rains, 2010; Ivanov, 2012). Potential explanations for the higher initial effect are the immediate sense of threat and memory salience (Ivanov, 2017; Miller et al., 2013; Pryor & Steinfatt, 1978). The fresh sense of threat is elicited by the affective forewarning element within the inoculation treatment. This sense of threat provides heightened motivation to protect the attitude immediately after intervention. Over time, this warning could become less salient, and participants may be less vigilant to scrutinise incoming counterarguments. A different explanation is the decay of memory. Researchers have found that inoculation interventions strengthen associative memory networks, but this network could be subject to interference (Hardt, Nader, & Nadel, 2013; Lewandowsky & Li, 1995; Pfau et al., 1997, 2005). In their meta-analysis, Banas and Rains (2010) emphasise that "more research about the inoculation decay process is needed" (p. 303).

1.5. Replication study

Most recently, Williams and Bond (2020) conducted a preregistered replication of van der Linden et al. (2017) using the same sampling platform (*MTurk*) and target population (US-only). The authors replicated many of the original findings, including the fact that the scientific consensus message and the inoculation intervention administered prior to the misinformation boosted attitudes toward the scientific consensus. Yet, there was one notable exception: the authors did not find that the inoculation intervention counteracted misinformation to a greater extent than the scientific consensus message alone. As suggested by Williams and Bond (2020), potential explanations for this discrepancy include the presence of ceiling effects (most participants already scored near the maximum end of the scale on perceived consensus), or the fact that misinformation did not appear to lower perceived consensus in the false-balance or inoculation conditions. In fact, although the misinformation was effective by itself, its potency was much weaker ($d = 0.25$) than in the original study. Moreover, contrary to van der Linden et al. (2017) where, in the false-balance condition, misinformation completely neutralised the consensus effect, in Williams and Bond (2020), perceived consensus (0%–100%) actually went up from 83.45 to 92.82 in the false-balance condition ($d = 0.55$, $p < .001$).

1.6. Present study

In our present study, we set out two aims. First, we wanted to shed further light on the debate evoked by the replication study by Williams and Bond (2020). To do this, we decided to conduct our own preregistered replication and extension study of van der Linden et al. (2017). Second, we set out to contribute to the further expansion of inoculation theory by addressing the question of inoculation longevity in the context of a highly polarised and much discussed real-world issue: climate change. We asked the following key question: can we inoculate belief in the scientific consensus on climate change against a persuasive misinformation attack presented at a *later* date?

2. Methods

2.1. Design and procedure

We investigated changes in *Perceived Scientific Consensus* (PSC) on human-caused climate change under different conditions that permit testing the long-term effectiveness of the inoculation effect. In contrast to van der Linden et al.'s (2017) original study where the misinformation message was presented immediately after the intervention, we include a one-week interval between intervention and attack. Our study therefore consists of two phases, the first phase (including pretest T1 and posttest T2), and a second phase one week later (including posttest T3). The independent variables manipulated in our study were *exposure to the consensus message* (0, 1), *exposure to misinformation* (0, 1), *inoculation* (0, 1), and *test* (T1, T2, T3).

Following van der Linden et al. (2017), we designed our study in an additive format, where one new intervention is added per group, resulting in four different groups.[1] In the control group, participants were not exposed to anything, but did an unrelated word sorting task after pretest T1 instead to equalise the length of the task across conditions. In the consensus group, participants received the standard descriptive norm message about the scientific consensus after pretest T1. In the (false-)balance group, participants received the consensus treatment after pretest T1 as in the consensus group, but in addition to this a misinformation message one week later (just before posttest T3). Finally, in the inoculation group, the inoculation message was added immediately after the consensus message, and a misinformation message was presented one week later (just before posttest T3). Misinformation was thus not presented on the same day as the consensus or inoculation messages. This allowed us to eliminate potential short-term memory and demand effects, and helped us to test a decay hypothesis in which the benefit of consensus and inoculation messaging fully evaporates within one week. Further, to avoid demand effects, participants were told that they had randomly received the topic of 'climate change' out of 20 possible topics, and distractor questions were inserted after each intervention. See Fig. 1 for an overview of the interventions in each group, and Fig. 2 for a simplified graphical flowchart of the full experiment procedure. A detailed overview of the exact steps from a participant perspective can be found in Supplementary Information S1.

The experiment was approved by the University of Cambridge Psychology Research Ethics Committee (ref. PRE.2019.027).

2.2. Materials

Our core materials were adopted from van der Linden et al. (2017) and consist of a consensus message, a misinformation message, and an inoculation message. The consensus message simply informed participants that; "97% of climate scientists have concluded that human-caused climate change is happening."

The misinformation message used was a screenshot of the Oregon Global Warming Petition, which is a real but debunked petition summary that claims that "31,487 American scientists have signed a petition stating that human-caused climate change is not happening". This specific misinformation intervention is identical to those used by van der Linden et al. (2017), Cook et al. (2017), and Williams and Bond (2020). van der Linden et al. (2017) initially selected this intervention as it was deemed most persuasive among a range of climate myths in a US nationally representative sample ($N = 1{,}000$).

Similarly, the inoculation method used is the exact same inoculation message used by van der Linden et al. (2017) specifically tailored to prebunk the Oregon Petition that includes both a forewarning (some politically-motivated groups use misleading tactics to try to convince

[1] The original experiment had six groups, including two different inoculation conditions and a misinformation-only condition (van der Linden et al., 2017). Like Williams and Bond (2020), we omitted the partial inoculation group for simplicity. We pre-tested the misinformation-only condition (to make sure it is still effective) and therefore omitted it from the experimental design in the full study to preserve power for a longitudinal study.

CONDITION	INTERVENTION		
	T2		T3
	Consensus Message	Inoculation	Misinformation
Control Group	✗	✗	✗
Consensus Group	✓	✗	✗
Balanced Group	✓	✗	✓
Inoculation Group	✓	✓	✓

Fig. 1. Overview of interventions per group.

the public that there is a lot of disagreement among scientists) and a detailed preemptive refutation (e.g., that the petition is debunked, contains bogus signatories, and that 31,000 may seem like a big number but only constitutes about 0.3% of all US science graduates).

A detailed overview of all materials can be found in Supplementary Information S2.

2.3. Measures

In random order, participants indicated their PSC, belief in climate change, belief in human causation, worry about climate change, and support for action. PSC was measured on a continuum (visual-analogue slider scale) ranging from 0 to 100 (M = 83.60, SD = 18.39), with the question "*To the best of your knowledge, what percentage of climate scientists have concluded that human-caused climate change is happening?*". Political ideology was measured on a 7-point Likert scale (M = 3.13, SD = 1.58), ranging from 1 (*very liberal*) to 7 (*very conservative*). A

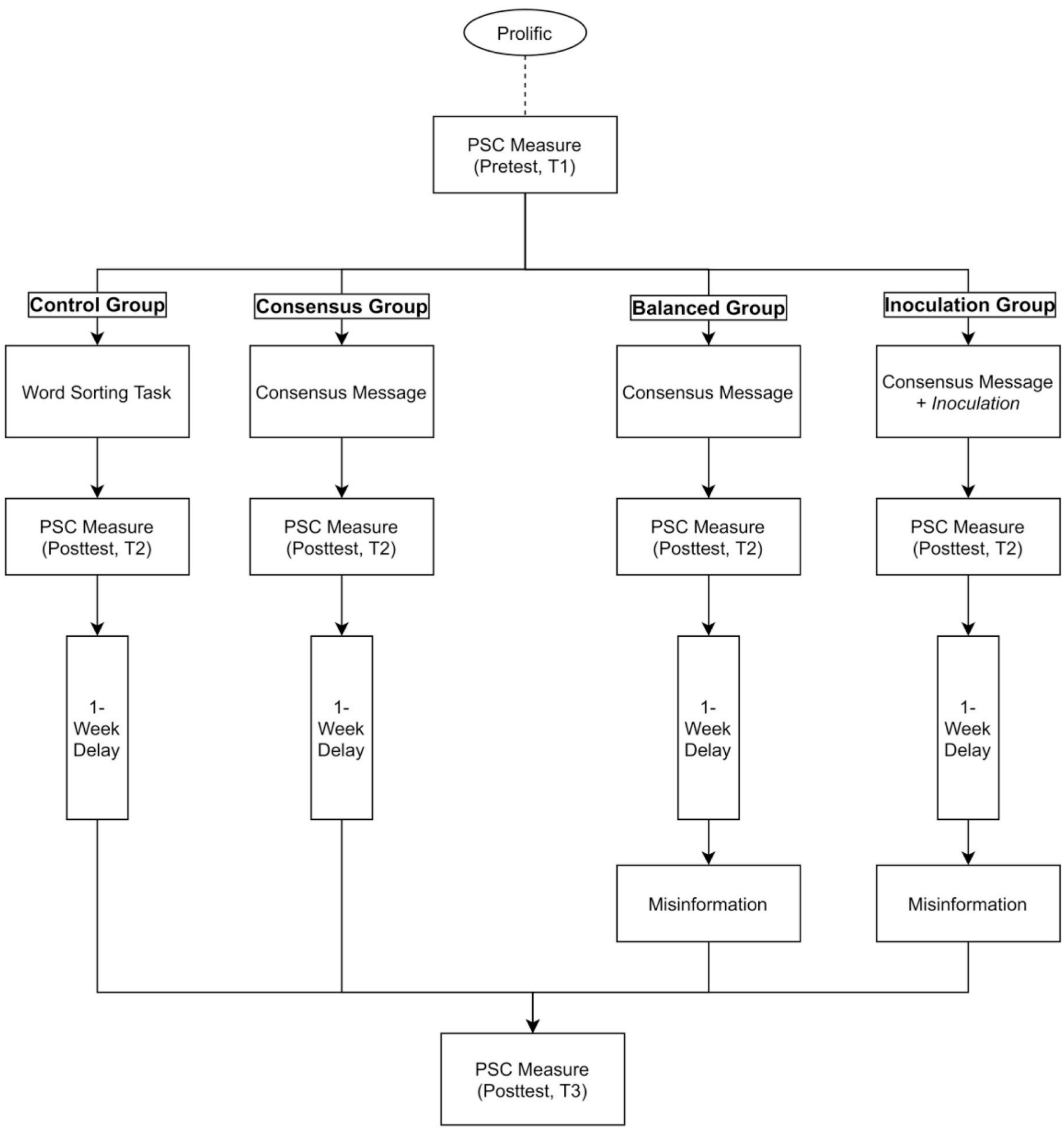

Fig. 2. Simplified flowchart of experiment procedure.
PSC = Perceived Scientific Consensus.

detailed overview of all variables and how they were measured can be found in Supplementary Information S3.

2.4. Hypotheses and empirical strategy

All hypotheses and analysis strategies were designed beforehand and preregistered.[2] All deviations from the preregistration are indicated in Supplementary Declaration S1.

As we wanted to look at how the consensus messaging effect decays over time, we first needed to replicate if we could indeed find a significant positive effect (van der Linden, Leiserowitz, et al., 2019). This led to our baseline hypothesis H_1.

[H_1] *In all intervention groups, consensus messaging has an initial positive effect on perceived scientific consensus.*

To measure whether misinformation neutralises the positive influence of the consensus effect and whether inoculation helps to protect this effect, the next question we asked is how the consensus message effect would evolve over the course of one week. Based on longitudinal studies comparing different messaging methods, we expected the consensus effect to retain its significance for at least one week (van der Linden, Leiserowitz, et al., 2019; van der Linden, Maibach, et al., 2019). This led to our second hypothesis (H_2).

[H_2] *The consensus message will retain its positive effect after one week.*

To evaluate whether inoculation protects against misinformation that is presented one week later, the misinformation still needed to be effective at countering the consensus effect after a one-week delay. As the misinformation message was used in two different studies at two different time points, showing a similar negative effect, we also expected a significant negative effect in our study (Cook et al., 2017; van der Linden et al., 2017).

[H_3] *Misinformation presented one week after the consensus messaging treatment reverses the consensus messaging effect back to baseline.*

Finally, we wanted to investigate whether an inoculation message can indeed protect the newly changed belief against misinformation presented at a later point in time. Based on a meta-analysis of inoculation decay, we expected the inoculation effect to remain significant for at least one week (Banas & Rains, 2010).

[H_4] *When an inoculation treatment is added to the consensus message, the consensus effect remains significant, even after a misinformation attack one week later.*

To adhere to open science standards, we preregistered our study and provide full access to the anonymised dataset and all relevant materials (Nosek et al., 2015). Our preregistered analyses and any deviations from them are highlighted in Supplementary Declaration S1. Materials, datasets, and analysis scripts are publicly available on our OSF repository: https://osf.io/6bjsn/ (https://doi.org/10.17605/OSF.IO/6BJSN).

2.5. Sample

On the basis of the original climate change inoculation study where a specific inoculation effect size (compared to a no-treatment control) was found of $d = 0.75$ (van der Linden et al., 2017) and the more general meta-analysis effect size $d = 0.43$ (Banas & Rains, 2010), we hypothesised to find effect sizes of $d = 0.50$ or higher. We performed a power analysis to test our hypotheses with power = .95 and $\alpha = 0.05$, while accounting for a potential 30% attrition in participants between T2 and T3. On the basis of this analysis we recruited a total of 480 participants ($n = 120$ per group) through the online platform *Prolific Academic* (https://prolific.ac/). We limited the sample to participants of age 18 or above and US participants in order to match the design of the original study and Williams and Bond (2020) as closely as possible. Participants were told in the recruitment message that they would receive a total of 0.50 GBP if they participated in both Part 1 and Part 2 of the study. All participants gave informed consent before participation.

In the preregistration we stated that we would remove participants who either failed both attention checks or finished the first part of the study in less than 1 min. All participants passed these checks, except for one who failed both attention checks; this case has been removed from the dataset. In the transition to Part 2 we lost 64 participants, which amounts to 13% attrition. As we had accounted for 30% attrition in our preregistered analyses, and to have comparable results across conditions, we use complete cases only for this study.[3] Neither political ideology nor pretest score could predict the attrition rate (see Supplementary Analysis S1 for a complete attrition analysis).

Within the complete-cases dataset ($N = 415$), 51% of participants were female with a median age of 34 ($M = 36.60$, $SD = 12.80$), they resided in 45 different US states, had a political ideology skewed towards left-wing (59% liberal, 19% conservative, $M = 3.13$, $SD = 1.58$), and a majority had a higher-education-level diploma (54%). As allocation to the different groups was random, the demographics are well balanced between the groups. All demographics data were self-reported through the survey. For a more extensive overview of the demographic variables, see Supplementary Information S4. The sample characteristics of the studies by van der Linden et al. (2017), Williams and Bond (2020), and the current study are largely similar (see Supplementary Information S5).

3. Results

3.1. Pilot study

To verify if the misinformation intervention is still effective two years after the initial study and in a US sample recruited via the *Prolific* platform instead of *Amazon MTurk*, we decided to run a pilot study with 80 participants. The only purpose was to replicate the negative effect of the misinformation intervention. Participants indicated their PSC (T1), were then exposed to the misinformation item (the Oregon Petition), and finally indicated their PSC once more (T2). According to the ori-

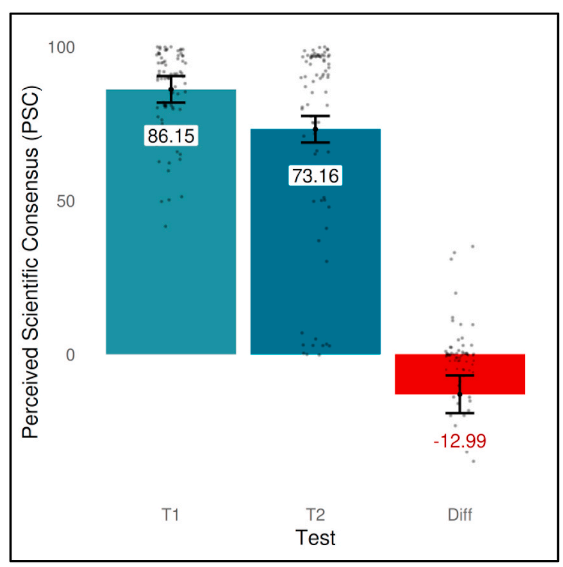

Fig. 3. Means of *Perceived Scientific Consensus*, before (T1) and after (T2) exposure to misinformation. Error bars represent 95% confidence intervals. $N = 80$.

[2] https://aspredicted.org/bm6ny.pdf.

[3] The preregistration does not specify whether to use the full dataset or the complete cases dataset.

ginal study, we expected an effect size d close to -0.48 (van der Linden et al., 2017).

After performing a paired samples t-test, we found the expected effect size ($t(79) = -4.23$, $M_{diff} = -12.99$, 95% CI = $[-19.10, -6.87]$, $p < .001$, $d = -0.47$), which indicated that this treatment is just as effective in decreasing PSC as in the original study. See Fig. 3 for a visualisation of the T2-T1 difference.

H1. The Consensus Effect

Our first hypothesis stated that we should find a significant positive effect of exposure to the consensus message. To test our baseline hypothesis as preregistered, we used an ANCOVA with PSC at first posttest (T2) as the dependent variable, PSC at pretest (T1) as a covariate, and *group* as a between-factor. We found the expected significant effect of group ($F(3, 409) = 21.85$, $p < .001$, $\eta_p^2 = 0.14$).

In line with our preregistration, we compared the consensus group ($M_{diffT2T1} = 9.06$, $SD = 16.29$), the balanced group ($M_{diffT2T1} = 9.82$, $SD = 13.65$), and the inoculation group ($M_{diffT2T1} = 10.17$, $SD = 13.74$) using between-subjects tests to the control group ($M_{diffT2T1} = 0.68$, $SD = 3.19$), and expected a significant positive result for each comparison.[4] Compared to the control group, we find a significant effect for the consensus group ($t(113) = 5.19$, $M_{diff\text{-}in\text{-}diffs} = 8.38$, 95% CI [5.18, 11.57], $p < .001$, $d = 0.71$), the balanced group ($t(111) = 6.56$, $M_{diff\text{-}in\text{-}diffs} = 9.14$, 95% CI [6.38, 11.91], $p < .001$, $d = 0.92$), and the inoculation group ($t(115) = 6.89$, $M_{diff\text{-}in\text{-}diffs} = 9.49$, 95% CI [6.76, 12.22], $p < .001$, $d = 0.95$). All findings are in line with our hypothesis.

Fig. 4 depicts a bar plot visualising the within-group difference scores of the consensus treatment by group before exposure to misinformation, highlighting the similarity of the effect in each experimental group. A detailed overview of all pre, post, and within-subject difference scores can be found in Supplementary Analysis S2.

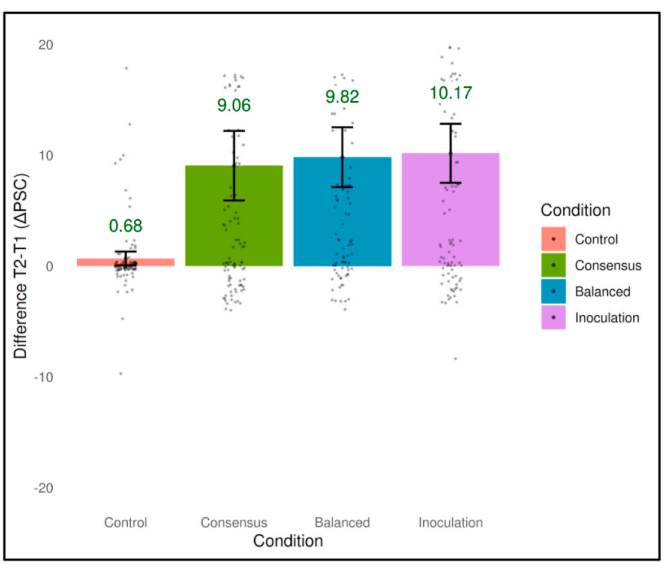

Fig. 4. Comparison of T2-T1 difference scores between *Perceived Scientific Consensus* (in percentage points) for each group. Error bars represent 95% confidence intervals. $N = 415$.

H2. Decay of the Consensus Effect

Our second hypothesis stated that the consensus effect would still be found after a one-week delay. To test the second hypothesis as preregistered, we use an ANCOVA with the final PSC (T3) as dependent variable, *group* as between-factor, and T1 PSC as covariate. The days between T2 and T3 approximately resembled a one-week delay ($M = 7.07$, $Med = 6.94$, $SD = 0.36$). We found a significant effect of group ($F(3, 410) = 3.13$, $p < .026$, $\eta_p^2 = 0.02$).

As preregistered, we compared the consensus group ($M_{diffT3T1} = 4.27$, $SD = 15.82$) to the control group ($M_{diffT3T1} = -0.08$, $SD = 13.61$), and found the T3-T1 difference-in-differences test to indicate a significant effect ($t(204) = 2.13$, $M_{diff\text{-}in\text{-}diffs} = 4.35$, 95% CI = [0.33, 8.37], $p = .034$, $d = 0.29$), which indicates that the positive effect of consensus messaging remains intact.

While not preregistered, after observing a descriptive T3-T2 decrease in the consensus group ($M_{diffT3T2} = -4.78$, $SD = 13.58$), we wanted to evaluate whether this could imply that there is a partial decay of the consensus effect. Compared to the control group ($M_{diffT3T2,control} = -0.76$, $SD = 13.50$), we found a significant decay ($t(207) = -2.15$, $M_{diff\text{-}in\text{-}diffs} = -4.03$, 95% CI = [-7.72, -0.33], $p = .033$, $d = -0.30$). More specifically, comparing the consensus-control difference scores of T3-T1 to T2-T1, we found that the consensus messaging effect decays by 48% over the course of one week.[5] For a complete overview of all raw means per group and within-group difference score analyses, see Supplementary Analysis S2.

H3. The Misinformation Effect

The third hypothesis stated there would be a negative effect of exposure to a doubt-sowing misinformation message one week after being exposed to the consensus message, resulting in a complete neutralisation of the initial positive effect. As preregistered, we compared the (false-)balanced group ($M_{diffT3T1} = -1.78$, $SD = 22.83$) to the control group ($M_{diffT3T1} = -0.08$, $SD = 13.61$), and found no effect ($t(163) = -0.65$, $M_{diff\text{-}in\text{-}diffs} = -1.70$, 95% CI [-6.91, 3.50], $p = .51$, $d = -0.09$). This indicates that the positive benefit has indeed been eliminated by the misinformation, in line with our hypothesis.

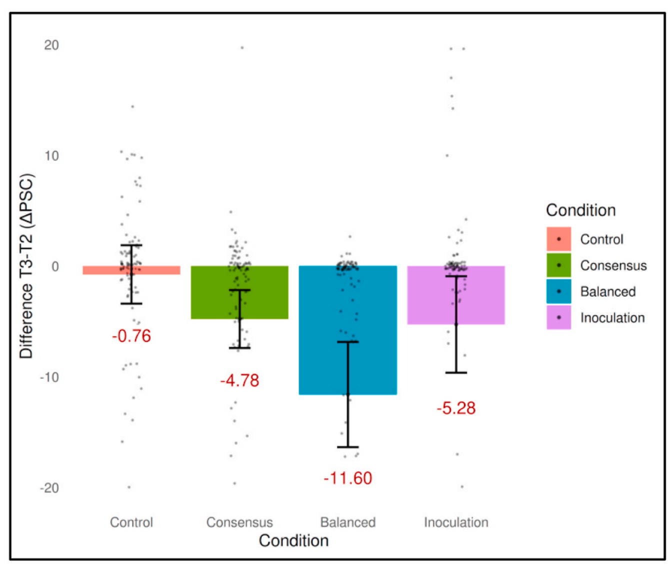

Fig. 5. Comparison of T3-T2 difference scores between *Perceived Scientific Consensus* (in percentage points) for each group. Error bars represent 95% confidence intervals. $N = 415$.

[4] The preregistration does not specify which test to use for the specific group comparisons. We chose to use difference scores in order for the results to be directly comparable to the approach of Williams and Bond (2020).

[5] Decay formula used: 1-(Consensus (T3 - T1) - Control (T3 - T1))/(Consensus (T2 - T1) - Control (T2 - T1)).

See Fig. 5 for a bar chart of within-group differences, which highlights the negative effect of exposure to misinformation in the false-balance group. See Supplementary Analysis S2 for an overview of all pre, post, and within-group difference scores.

H4. The Inoculation Effect

Our final hypothesis stated that the inoculation would protect the positive effects of the consensus message from misinformation presented one week later. As preregistered, we tested this by comparing the inoculation group ($M_{\text{diffT3T1}} = 4.90$, $SD = 20.60$) to the control group ($M_{\text{diffT3T1}} = -0.08$, $SD = 13.61$), and found the predicted positive effect ($t(104) = 2.06$, $M_{\text{diff-in-diffs}} = 4.97$, 95% CI = [0.20, 9.74], $p = .041$, $d = 0.28$). While not preregistered, as a final robustness check, we also compared the difference-in-differences for the inoculation group ($M_{\text{diffT3T1}} = 4.90$, $SD = 20.60$) to the (false-)balanced group ($M_{\text{diffT3T1,}} = -1.78$, $SD = 22.83$), and found a significant effect ($t(200) = 2.20$, $M_{\text{diff-in-diffs}} = 6.68$, 95% CI = [0.70, 12.66], $p = .029$) with an effect size of $d = 0.31$.[6] These results are all in line with our hypothesis and indicated that inoculation is indeed able to protect the positive effects of consensus messaging against later presented misinformation.

For a measure of the protection percentage of the inoculation effect, we calculated the consensus effect decay rate for the inoculation group and compared this to the decay rate in the consensus-only group.[7] We found that the consensus effect decays at the same rate (48%) for the inoculation group as for the consensus-only group, without being influenced by the misinformation. At the same time, we found full decay (100%) of the consensus effect in the false-balance group that received misinformation, but no inoculation. This indicates that inoculation was able to eliminate the negative misinformation effect in its entirety. Given that the misinformation was presented one week after the inoculation, this demonstrates 100% protection with a one-week delay between inoculation and attack.[8]

See Fig. 6 for a bar chart visualising the T3-T1 difference scores by group, and Supplementary Fig. S1 for a bar plot of all conditions and test dates combined. A schematic overview of all difference scores can be found in Supplementary Analysis S2.

3.2. Exploratory

In line with the original study by van der Linden et al. (2017), we examined potential differences by ideology. First, to assess whether the inoculation effect stays intact across the ideological spectrum, we performed a linear regression of the T3-T1 PSC difference scores (within the inoculation group) on ideology, and found no significant effect ($F(1, 103) = 2.63$, $\beta = 0.16$, 95% CI [-2.35, 2.67], $p = .11$, $R^2 = 2\%$). This is in line with the original study.

We found similar stability across party affiliation (Democrat, Independent, Republican), but an uneven starting point ($M_{\text{Democrat}} = 87.96$, $M_{\text{Independent}} = 80.91$, $M_{\text{Republican}} = 72.13$; see Fig. 7, panel A, Control). People from all parties benefited from the consensus messaging treatment (see Fig. 7, panel A, Consensus) and were negatively affected by the misinformation message (see Fig. 7, panel A, Balanced), with the largest changes for Republicans. Finally, when inoculated against misinformation, the net result is positive across party affiliation (see Fig. 7, panel B, Inoculation). While most of these interpretations are based on descriptive raw means, they are in line with the original findings by van der Linden et al. (2017).

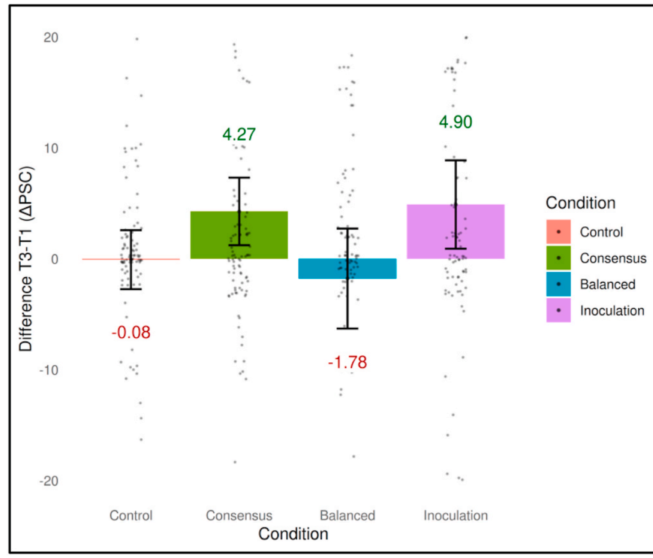

Fig. 6. Comparison of T3-T1 difference scores between *Perceived Scientific Consensus* (in percentage points) for each group.[9] Error bars represent 95% confidence intervals. $N = 415$.

Next, on the basis of the original study by van der Linden et al. (2017) and the hypotheses formulated by Williams and Bond (2020), we expected 1) the consensus treatment to have a greater positive effect on Republicans than Democrats, 2) the misinformation treatment to have a more negative impact on Republicans than Democrats, and 3) Independents to be the least influenced by the misinformation message.

When collapsing all treatment groups we found that the consensus messaging effect for Republicans ($M_{\text{diffT2T1}} = 15.47$, $SD = 18.90$) was indeed more positive compared to Democrats ($M_{\text{diffT2T1}} = 4.97$, $SD = 10.29$): $t(53) = 3.55$, $M_{\text{diff-in-diffs}} = 10.50$, 95% CI [4.57, 16.43], $p < .001$, $d = 0.69$. This finding is in line with van der Linden et al. (2017), but in contrast to the findings by Williams and Bond (2020), who did not find evidence for this hypothesis (possibly due to low power). We also found that the misinformation treatment descriptively has a more negative effect on Republicans ($M_{\text{diffT3T2}} = -21.42$, $SD = 39.59$) than Democrats ($M_{\text{diffT3T2}} = -11.51$, $SD = 24.17$), but the effect was not significant ($t(13) = -0.83$, $M_{\text{diff-in-diffs}} = -9.91$, 95% CI [-35.66, 15.85], $p = .42$, $d = -0.30$). These findings are compatible with both the original study by van der Linden et al. (2017) and the findings by Williams and Bond (2020). Finally, we found that Independents are indeed the least influenced by misinformation ($M_{\text{diffT3T2}} = -8.63$, $SD = 16.41$), which is in line with findings by van der Linden et al. (2017), Cook et al. (2017), and Williams and Bond (2020).[10]

4. Discussion

In an extended replication study of van der Linden et al. (2017), we conducted a longitudinal experiment where we combined consensus

[6] Although not preregistered, consistent with Williams and Bond (2020), we found no significant difference between the consensus-only ($M_{\text{diffT3T1}} = 4.27$, $SD = 15.82$) and the inoculation condition ($M_{\text{diffT3T1}} = 4.90$, $SD = 20.60$): $t(195) = 0.25$, $M_{\text{diff-in-diffs}} = 0.62$, 95% CI = [-4.37, 5.61], $p = .81$.

[7] Retention formula used: [(Inoculation (T3 - T1) - Control (T3 - T1))/(Inoculation (T2 - T1) - Control (T2 - T1)]/[(Consensus (T3 - T1) - Control (T3 - T1))/(Consensus (T2 - T1) - Control (T2 - T1)].

[8] When using the same formula with Cohen's d effect sizes instead, we find 72% protection. However, this was not significantly different from 100%.

[9] A bar plot with all conditions on all different test times can be found in Supplementary Fig. S1.

[10] Surprisingly, we also found that the misinformation message exerted a descriptively larger negative influence on moderates ($M_{\text{diffT3T2}} = -19.61$, $SD = 27.81$) than on both conservatives ($M_{\text{diffT3T2}} = -17.69$, $SD = 34.60$) and liberals ($M_{\text{diffT3T2}} = -7.06$, $SD = 17.92$). This seems at odds with the consistent finding that Independents are the least influenced by the misinformation and Republicans the most. However, this finding may simply be due to sampling error or differences between *moderates* and *independents*.

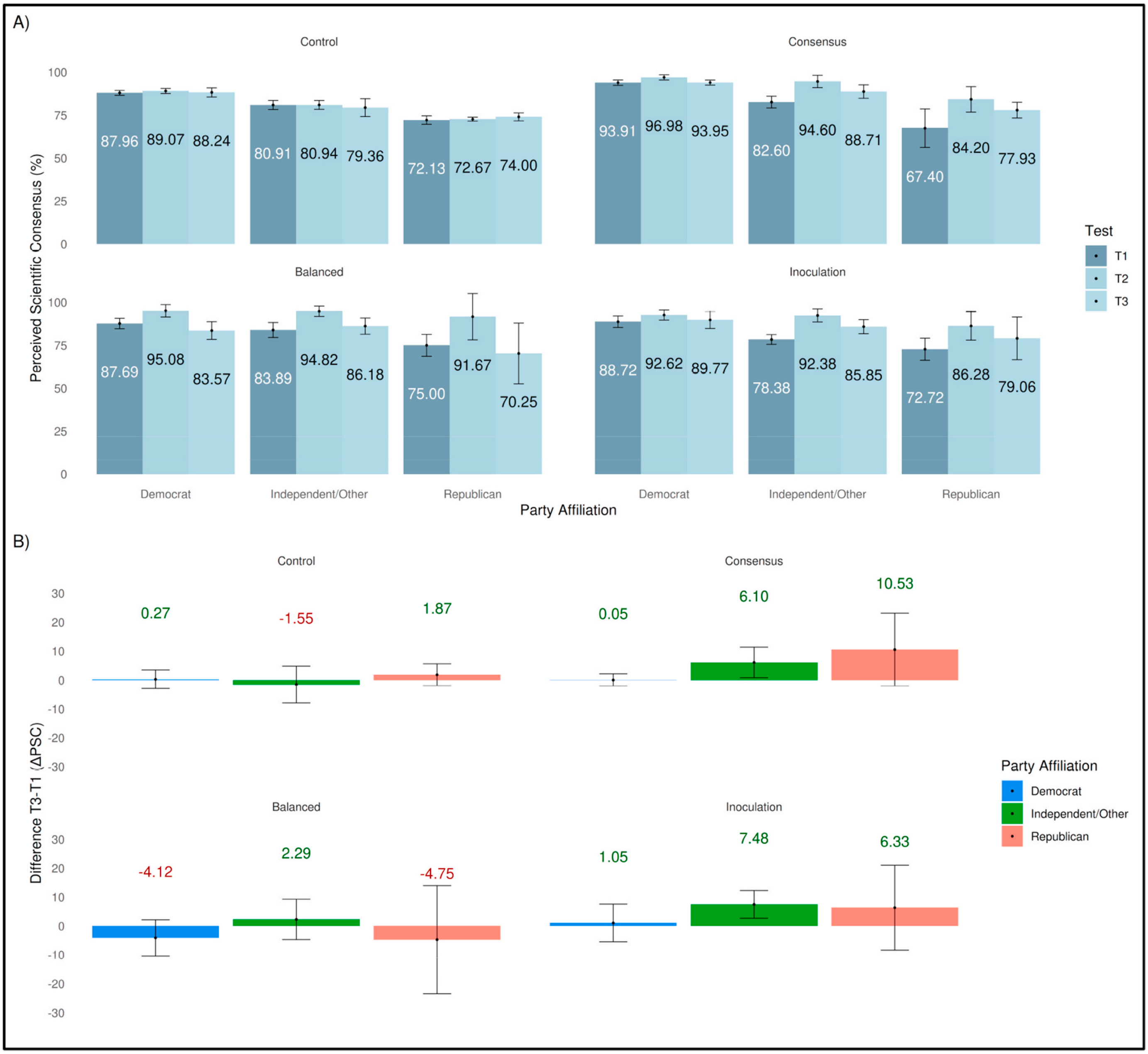

Fig. 7. Means for each test (panel A) and T3-T1 difference scores (panel B) of *Perceived Scientific Consensus*, separated by party affiliation ($N = 415$). Error bars represent 95% confidence intervals.

messaging with inoculation and assessed their effects over time. We replicated the initial positive effect of the scientific consensus message by itself and across ideology and party affiliation (Lewandowsky et al., 2013; van der Linden et al., 2015, 2019), but also found that this consensus effect shows partial decay over the course of one week. We also replicated the finding that the misinformation message counteracts the consensus message and brings perceived scientific consensus back to baseline. Finally, we found that an inoculation message is able to protect the positive effects of the consensus message against doubt-sowing misinformation presented with a one-week delay, without any decay in the inoculation effect over time.

It is important to highlight that a crucial difference between the original study of van der Linden et al. (2017) and the current study is that we introduced a 1-week delay between inoculation and the misinformation attack, assuming that the inoculation would stay intact without reinforcement. Although the initial consensus messaging effect was not as high as in the original study ($d = 0.71$, $d_{\text{vanderLinden}} = 1.23$), and this effect further decayed to an effect of $d = 0.29$ at T3, we still found significant effects for both a consensus effect and an inoculation effect at T3.

Compatible with our findings, an independent replication study of van der Linden et al. (2017) by Williams and Bond (2020) found evidence for both the positive and the protective effects of the consensus message. However, while they found the positive effects of the consensus message to stay significant even after the exposure to the misinformation message, we found a full reversion back to baseline. These findings may indicate that participants in our study gave equal weight to the misinformation as to the facts, which resulted in a net change of zero, consistent with van der Linden et al. (2017). Although Williams and Bond (2020) found a significant inoculation effect compared to a no-treatment control, they found no additional benefit compared to the false-balance condition. These results suggests that the consensus message may have been strong enough to remain significant on its own, and did not need an inoculation as extra protection. We also found a protective benefit of the consensus message on its own, but this effect was less strong, or, alternatively, our misinformation message was more potent. Because in our study no misinformation-only group was present, this cannot directly be tested in the same way. Nevertheless, our pilot study indicated that the misinformation message caused a significant negative effect (with PSC dropping below baseline level) while in the false balance group we found no change in PSC compared to baseline. This indicates, consistent with Williams and Bond (2020) and Cook et al. (2017), that communicating the consensus on its own may have a positive protective effect against misinformation, even without inoculation (see Supplementary Fig. S2). It could be argued that, as the consensus message is presented *before* the misinformation message, the consensus message in itself may have an inoculating feature. Yet, compared to the false-balance group, we found a significant positive effect for the inoculation group ($d_{\text{balanced}} = -0.09$, $d_{\text{inoculation}} = 0.28$), indicating an additional inoculation benefit that is not found in the study by Williams and Bond (2020). However, although the effect of the inoculation group compared to the control group in our study was significant, it was not of the same size as the original study ($d = 0.28$, $d_{\text{vanderLinden}} = 0.75$), which could partly be explained by the decay in the consensus effect. These results may be consistent with the findings from Niederdeppe, Heley, and Barry (2015), who found that narratives decay faster than inoculation messages.

The different findings and conclusions between our study and the replication by Williams and Bond (2020) pose important questions. One potential explanation is that in their study they found a weaker misinformation effect ($d = -0.47$, vs $d_{\text{WilliamsBond}} = -0.25$), while we found the same effect as in the original study ($d_{\text{vanderLinden}} = -0.48$). The consensus effect was the same between our studies ($d = 0.71$, $d_{\text{WilliamsBond}} = 0.70$), in both studies lower than in the original study ($d_{\text{vanderLinden}} = 1.23$). Finally, the biggest differences were found in the false-balance group compared to the consensus group ($d = -0.31$, $d_{\text{WilliamsBond}} = 0.09$) and the balanced group compared to the inoculation group ($d = -0.31$, $d_{\text{WilliamsBond}} = 0.07$). We could ask whether a *Prolific* sample is fundamentally different from an *MTurk* sample, but looking at the sample composition this does not seem likely (see Supplementary Information S5). Another explanation is that the specific participants in Williams and Bond (2020) may have been exposed to the treatment and/or misinformation message before. Ceiling effects and timing of the experiments are unlikely to explain the differences as dates and pretest means are similar between our studies. An alternative explanation is a ceiling effect combined with a difference in design. For example, in both studies, a higher pretest score was found for all conditions compared to the original, which had a much larger and more diverse sample (van der Linden et al., 2017). In addition, in our study we present the misinformation message in isolation one week after the consensus message, giving the opportunity for the consensus messaging effect to decay over time and thereby allowing for higher saliency of the misinformation message. We therefore conclude that the most likely explanation is the difference in the misinformation message, which may not have been strong enough in the study by Williams and Bond (2020). As Williams and Bond (2020) note, they also used a slightly different misinformation message, one without a description of the Oregon Petition. For example, in the study by van der Linden et al. (2017), the current study, and Experiment 2 by Cook et al. (2017), a descriptive text was presented together with the misinformation message (see Supplementary Information S2). In all three of these studies, similar misinformation and inoculation effects were found. In contrast, in Cook et al. (2017), Experiment 1, a lower misinformation effect was reported, and no additional inoculation benefit was found in comparison to the consensus-only condition, which aligns more closely with the results by Williams and Bond (2020). We therefore recommend future inoculation studies to carefully pre-test and evaluate the efficacy of the misinformation stimuli.

In both our study and the replication by Williams and Bond (2020) the consensus and inoculation effects were not affected by political ideology. As our experiments focus on the heavily polarised topic of climate change, our studies are in line with growing evidence that inoculation theory is applicable in the context of contested issues and not highly vulnerable to reactance or backfire effects (Williams & Bond, 2020; Cook et al., 2017; van der Linden et al., 2017). Indeed, jointly, these findings are consistent with other recent work which does not find a backfire effect (Guess & Coppock, 2018; Wood & Porter, 2019), in contrast to identity protection theories where backfire effects would be expected in the form of attitude polarisation (Hart & Nisbet, 2012; Kahan, Jenkins-Smith, & Braman, 2011; Nyhan & Reifler, 2010).

Our study does not come without limitations. For instance, we limited our study to a US-only convenience sample from Prolific. Future studies need to investigate whether these results replicate in representative samples and in non-WEIRD countries and regions with different cultural worldviews (Henrich, Heine, & Norenzayan, 2010; Tam & Milfont, in press). In our power calculations we did not take into account the high level of decay (48%) found in the consensus messaging effect. Future longitudinal studies will need to account for the smaller longitudinal effects of $d = 0.28$ found in this study.

Future research is needed to map the decay process of the consensus and inoculation effects more meticulously using longitudinal studies with a higher sample size and more timepoints. One could argue that a one-week retention effect is not sufficient to talk about *long-term* effectiveness in practical terms. It would be useful to know whether the effects last for more than one month, as this would both provide evidence for long-term memory consolidation (Frankland & Bontempi, 2005) and has practical consequences for policy implementations (i.e., minimal resources needed for long-lasting effects). If decay is found, it would be valuable to investigate the decay function and gain insight into how decay could be prevented. One potential avenue to explore is to combine the consensus message with inoculation “booster” sessions (Compton & Pfau, 2005; McGuire, 1961). Just as in the biomedical metaphor of a vaccine, it may be necessary to give the cognitive immune system a regular top-up to remind it what to protect against (Ivanov, 2017). Potential “booster shots” can be either a repetition of the inoculation message, the consensus message, or the misinformation message, or a combination of these (Ivanov, Pfau, & Parker, 2009; Pfau et al., 2005; Pryor & Steinfatt, 1978). Overall, these results provide support for the implementation of inoculation-inspired interventions. For example, one approach to counter climate misinformation in the real-world is to create game-based inoculation interventions that can be used directly by climate change communicators in educational, professional, and policy settings. Examples include the popular fake news game, *Bad News* (Basol, Roozenbeek, & van der Linden, 2020; Roozenbeek & van der Linden, 2019) and the smartphone application *Climate Change vs. Cranky Uncle* (Goering, 2019).

5. Conclusion

Although not all conclusions in our study are straightforward, we have evidence to conclude that both consensus messaging and inoculation theory are effective methods to combat climate change misinformation, and that the longevity of inoculation spans for at least one week. Protecting newly changed beliefs on polarised topics without decay extends the initial predictions of inoculation theory, while building upon the same foundations. This allows for the development of new strategies to combat climate change misinformation, with at least some resistance over time. As this intervention has shown promise in three independent studies at different time-points and across different ideological groups, we invite policy makers and communicators to start evaluating inoculation interventions in the field. The most prevalent forms of misinformation could be identified and severely weakened doses could be tested and distilled into inoculation messages disseminated via social media platforms, news articles, and press conferences. As for most large scientific theories, more investigation and field studies are needed to establish the boundary conditions of long-term resistance, and its practical utility for public policy will have to be evaluated through evidence-based policy applications.

6. Data availability statement

The data that support the findings of this study are openly available in OSF at https://osf.io/6bjsn/ (DOI: https://doi.org/10.17605/OSF.IO/6BJSN).

CRediT authorship contribution statement

Rakoen Maertens: Conceptualization, Methodology, Investigation, Software, Data curation, Formal analysis, Visualization, Writing - original draft. **Frederik Anseel:** Validation, Writing - review & editing. **Sander van der Linden:** Conceptualization, Methodology, Resources, Validation, Visualization, Writing - review & editing, Supervision.

Declaration of competing interest

We have no conflict of interest to disclose.

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Appendix A. Supplementary materials

Supplementary materials to this article can be found online at https://doi.org/10.1016/j.jenvp.2020.101455.

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