Psychological Booster Shots Targeting Memory Increase Long-Term Resistance Against Misinformation

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Preregistrations for this work are available at https://aspredicted.org/GPR_5FB (Study 1), https://aspredicted.org/8YF_9L4 (Study 2), https://aspredicted.org/WL8_LSK (Study 3), https://osf.io/av7zc?view_only=375c0632fca0444fa07c2bc46a59187b (Study 4), and https://aspredicted.org/42Y_PX1 (Study 5).

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Abstract

An increasing number of real-world interventions aim to preemptively protect or "inoculate" people against misinformation. Inoculation research has demonstrated positive effects on misinformation resilience when measured immediately after treatment via messages, games, or videos. However, very little is currently known about their long-term effectiveness and the mechanisms by which such treatment effects decay over time. We report five pre-registered longitudinal experiments (N_{total} = 11,759) that investigate the effectiveness of psychological inoculation interventions over time. We find that text-based and video-based inoculation interventions can remain effective for one month (whereas game-based interventions appear to decay more rapidly), and that memory-enhancing "booster interventions" can boost the diminishing effects of counter-misinformation interventions to the original effect size. We conclude that misinformation researchers would benefit from integrating knowledge from the cognitive science of memory to design a new generation of psychological interventions that can counter misinformation durably over time and at-scale.

Keywords: inoculation theory, long-term effectiveness, memory, threat, motivation

Psychological Booster Shots Targeting Memory Increase Long-Term Resistance Against Misinformation

Misinformation is a threat to society and the functioning of democracies worldwide [1,2]. It is shown to have impacted a wide variety of critical issues such as vaccine uptake [3–5], support for mitigation of anthropogenic global warming [6–8], and political elections [9,10]. Furthermore, misinformation has also been linked to real-world violence, such as lynch mobs in India and the burning of 5G installations [11,12].

Many current methods to counter misinformation involve debunking [13]. Such post-hoc corrections can be effective, but a growing body of evidence highlights the advantages of preventing the spread of misinformation proactively [14]. One such preemptive approach is psychological inoculation—interventions that warn people about upcoming misinformation threats (the *forewarning*) and, using weakened (micro-)doses of misinformation, teach people the skills required to counter-argue and detect the flawed reasoning that underlies misinformation [15–17]. In the past several years, researchers have successfully tested text-based [7,8,18], gamified [19–21], and video-based inoculation interventions [22,23]. Many inoculation interventions focus on specific issues or misleading narratives [7,8,18]. However, inoculation interventions can also provide a more scalable approach to countering misinformation by targeting the underlying rhetorical "technique" used to manipulate (e.g., using emotional language, polarization) [14,24]. In addition, even if the participant has already been influenced by the misinformation before the inoculation intervention, the intervention can still be effective [25]. Finally, interventions can be either passive or active [17,25], depending on whether participants have to actively engage with the content, or passively consume it.

Classical inoculation theory [17] proposes that an inoculation intervention works by (1) increasing the perceived feelings of "threat" of being influenced by misinformation, which leads to an increased motivation to defend oneself against it, and (2) making people more familiar with the misleading tactics the "manipulator" could use; taken together, these processes increase people's willingness and ability to resist and counter-argue misinformation [15]. In contrast, some scholars have argued that unlike the threat-motivation view, inoculation effects could be better explained in terms of memory processes such as associative learning and forgetting, and that the effectiveness of inoculation interventions is determined by memory strength rather than motivation or threat [26,27].

Despite the recent success of inoculation interventions, three crucial insights are still missing in the literature: how long do the effects of inoculation last, what drives the diminishing effects, and how can we maintain the effectiveness over time? The real-world potential of inoculation interventions has been hampered by these knowledge limitations and the questions regarding the mechanisms by which treatment effects dissipate over time remained unanswered. To date, research has not tested long-term effectiveness systematically across different formats of inoculation or directly explored the underlying cognitive mechanisms [28].

The Present Research

We pursued three research goals: 1) to explore and identify the decay rate of text-based, video-based, and game-based inoculation interventions, 2) to propose a general theory that can account for the underlying mechanisms responsible for effect retention, and 3) to test interventions that can boost the longevity of inoculation effects by targeting these mechanisms.

For each intervention we investigated the long-term effectiveness immediately after the inoculation intervention (**T0**), ~10 days after the intervention (**T10**), and ~30 days after the

intervention (**T30**). Participants in a "booster" group also received an inoculation "booster" intervention (a video of less than 30 seconds based on the original full length-inoculation video) at **T10**. The first intervention (used in **Study 1**) is a passive, issue-focused, text-based intervention that inoculates participants against misinformation about the scientific consensus on anthropogenic global warming [7,8]. The second intervention (used in **Study 2**) is an active, technique-focused, online inoculation game (*Bad News*), in which participants have to create and spread their own misinformation, albeit in severely weakened form, as part of a simulated social media environment [20,26]. The third intervention (**Studies 3–5**) is a short video that inoculates people against misleading emotional language. This intervention was shown to be effective at improving people's ability to detect misleading headlines in a field study on YouTube for up to 24 hours, and has been shown to over 5 million YouTube users as an educational advertisement [23]. Yet, despite its wide-scale implementation on social media, its efficacy beyond 24 hours remains unknown. See Figure 1 for an overview of the different studies and their experimental design.

To disambiguate the underlying mechanisms of the inoculation effects and their longevity, we administered questions to measure each of them separately: (1) motivation and threat, and (2) memory of the refutation, drawing upon the cognitive science literature. See Figure 2 for a graphical comparison of the theoretical models, and **Methods** for more details. We also presented a third, integrated account (the memory-motivation model of inoculation), which states that motivational processes are important to improve memory, but that memory is the main predictor for the longevity of inoculation effects. Finally, we note that when we refer to *decay*, we use a purely functional definition of the term: a decrease in effect over time. We do not refer to decay as a possible explanation of forgetting.

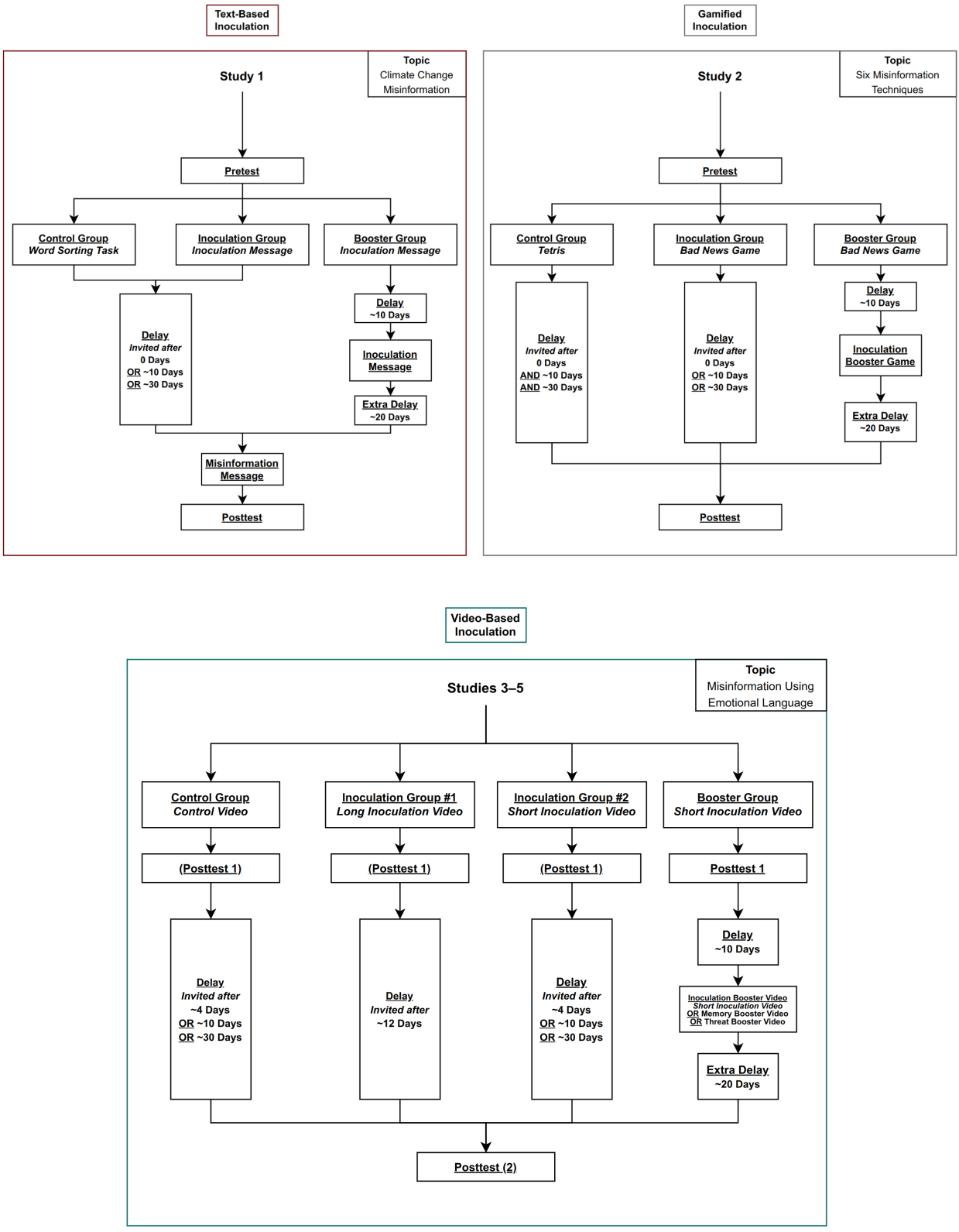

Figure 1. Experimental design flowcharts for Studies 1–5.

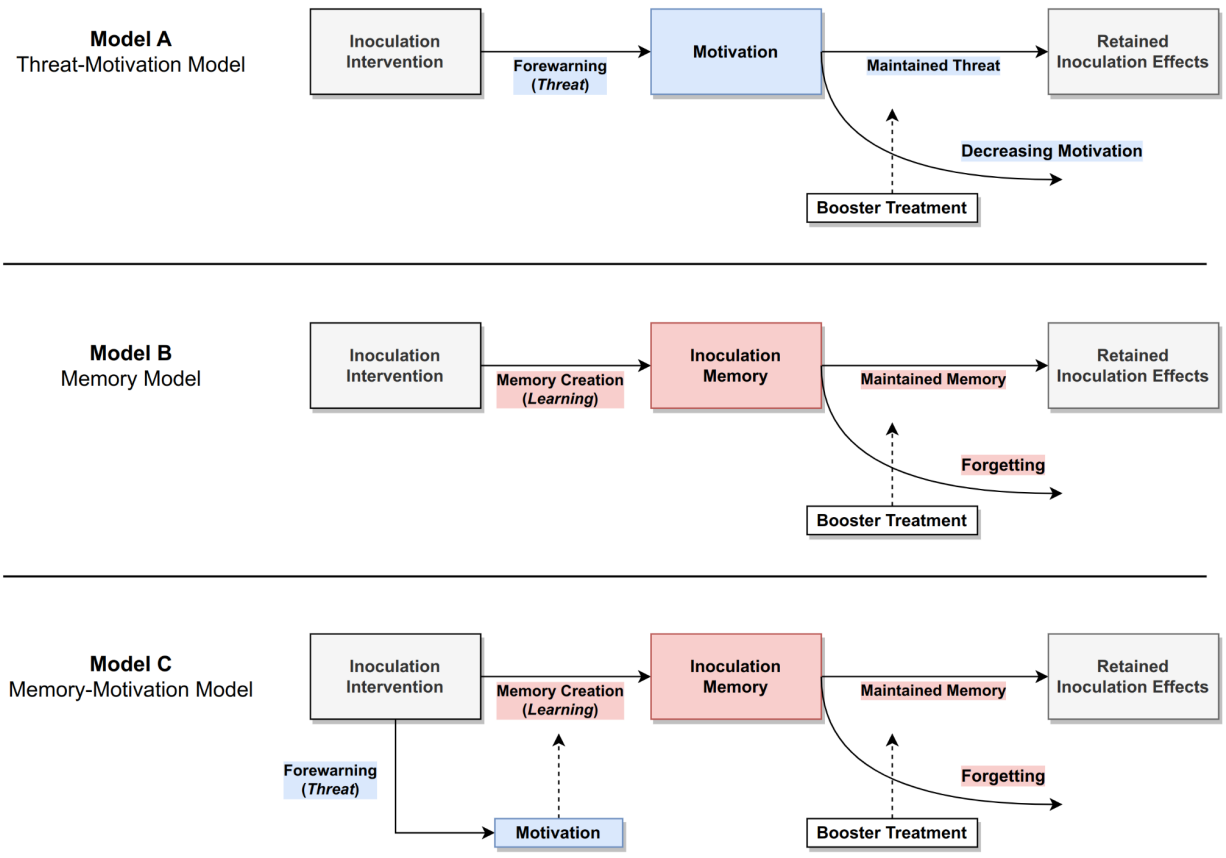

Figure 2. Overview of theoretical models explaining the long-term effectiveness of inoculation.

Results

Study 1: Text-Based Inoculation

In Study 1, participants were exposed to misinformation concerning the scientific consensus on anthropogenic global warming 0, ~10, or ~30 days after reading an inoculation message or completing a control task [8]. We hypothesized that we would replicate the finding that exposure to misinformation reduced the reader's *perceived scientific consensus* (PSC, i.e., perceived agreement amongst scientific experts on a 0–100% scale) of anthropogenic global warming (**H1**) and that an inoculation message can prevent a decrease in PSC (**H2**). The delay intervals of 10 days (**T10**) and 30 days (**T30**) were chosen as we know from Maertens et al.

(2020) that there is no significant decay of the inoculation intervention after one week, but some scholars suggests that decay can be detected as soon as two weeks after the intervention [28,29]. This timeframe allowed us to test the limits of the effect with the hypothesis that the effect may still be intact after 10 days (**H3**), but not after 30 days (**T30**; **H4**). Our design also allowed us to test the effectiveness of a booster intervention in the form of a repetition of the original intervention at **T10**, which we expect to top up the effect and reduce its decay at **T30**, which is 30 days after **T0** or 20 days after the booster at **T10** (**H5**). Finally, we tested three hypotheses as to whether both memory and threat-induced motivation are viable predictors of the outcome of inoculation interventions, with inoculation booster interventions expected to improve memory (**H6**) and motivation (**H7**) and the inoculation effect expected to be mediated by memory and motivation (**H8**). See **Methods** for details on how memory is measured. Supplement S24 presents an overview of the preregistered hypotheses and what evidence was found to support them. The study was preregistered on AsPredicted at https://aspredicted.org/GPR_5FB. All materials, survey files, analysis scripts, and raw and clean datasets are available on the OSF repository for this study at https://osf.io/9zxje/?view_only=44a8556694b54d09a2e2a9875071de2f.

We started by testing [**H1**] the main effect of the misinformation message and [**H2**] the main effect of the inoculation message. We found that, in line with our hypotheses, the misinformation message had a negative effect on the perceived scientific consensus (PSC), [**H1**] M_{pre} = 84.33, M_{post} =79.53, M_{diff} = -4.80, 95% CI [-7.10, -2.50], $t(301) = -4.11$, $p < .001$, d = -0.237, 95% CI [-0.351, -0.122], while when an inoculation message was shown before the misinformation message, there was no negative effect, or better, there was a positive effect on the perceived scientific consensus that climate change is human-caused, [**H2**] M_{pre} = 84.72, M_{post} =

92.06, M_{diff} = 7.34, 95% CI [5.59, 9.10], $t(316) = 8.24$, $p < .001$, $d = 0.463$, 95% CI [0.347, 0.579].

After replicating the main effects, we investigated effect retention at **T10** (*Mdn* = 8 days) and **T30** (*Mdn* = 29 days). We first found that the inoculation effect was still significant at 8 days, [**H3**] $F(1, 514) = 18.94$, $p < .001$, $d = 0.384$, 95% CI [0.209, 0.558]. For the analyses at 29 days, we first confirmed a significant omnibus test for the intervention variable, $F(2, 685) = 12.63$, $p < .001$, and then found that the effect at 29 days was still significant with a smaller effect size, [**H4**] $t(685) = 2.96$, $p_{tukey} = .009$, $d = 0.281$, 95% CI [0.094, 0.468]. As we expected the inoculation effect to no longer be significant after 29 days, this result provides evidence against **H4**. See Figure 3 (Panels A–B) for a visual plot of the inoculation effects over time.

Testing **H5**—whether the inoculation effect at T30 (29 days) was still significant for participants who took part in the booster intervention as compared to the control group—we found a significant, medium-sized effect, [**H5**] $t(685) = 5.02$, $p_{tukey} < .001$, $d = 0.475$, 95% CI [0.287, 0.662], in line with the hypothesis (see Figure 3, Panels A–B). Although not preregistered, we also looked at the contrast between the booster group and the inoculation group, and found no significant effect, $t(685) = 2.13$, $p_{tukey} = .085$, $d = 0.194$, 95% CI [0.015, 0.373]. See Figure 3 (Panels C–D, "Booster" group) for a plot showing the memory boost at 29 days provided by a second inoculation after 8 days. Memory in this study is measured as the performance on a multiple-choice objective recall test of what was present in the original inoculation intervention (see **Methods**).

For **H6** and **H7**, we tested the direct effects of the booster condition on the two mediators in the memory-motivation model at **T30** (29 days). For this analysis we only looked at **T30** as participants in the booster condition only received the posttest questions at **T30** (at **T0** and at

T10 they received the inoculation and booster interventions respectively without posttest measurement). We first found that the omnibus test for the intervention was significant for memory, $F(2, 686) = 95.28$, $p < .001$, in line with **H6**, but not for motivation, $F(2, 686) = 0.31$, $p = .731$, leading us to reject **H7**. The contrast between the double inoculation (booster) group and the single inoculation group for objective memory showed a strong significant effect of the booster intervention, [**H6**] $t(686) = 8.15$, $p_{tukey} < .001$, $d = 0.741$, 95% CI [0.558, 0.924]. See Figure 3 (Panels C–F) for a visualization of the effects of the intervention on memory and motivation over time.

We then tested an approximation of the memory-motivation model using an SEM analysis with the *lavaan* package in R. In this model we included inoculation at **T0** (yes/no) as a predictor variable, motivational threat and objective memory as mediator variables, and PSC as an outcome variable. We found that across the different time points, there were significant direct effects of memory and motivation on resistance to misinformation, and indirect effects of the inoculation intervention through memory and motivation. See Figure S1 for a schematic depiction of the **T30** model and Analysis S2 for an overview of the model estimates. See Analysis S3 for an exploratory analysis of the underlying mechanisms using dominance analysis.

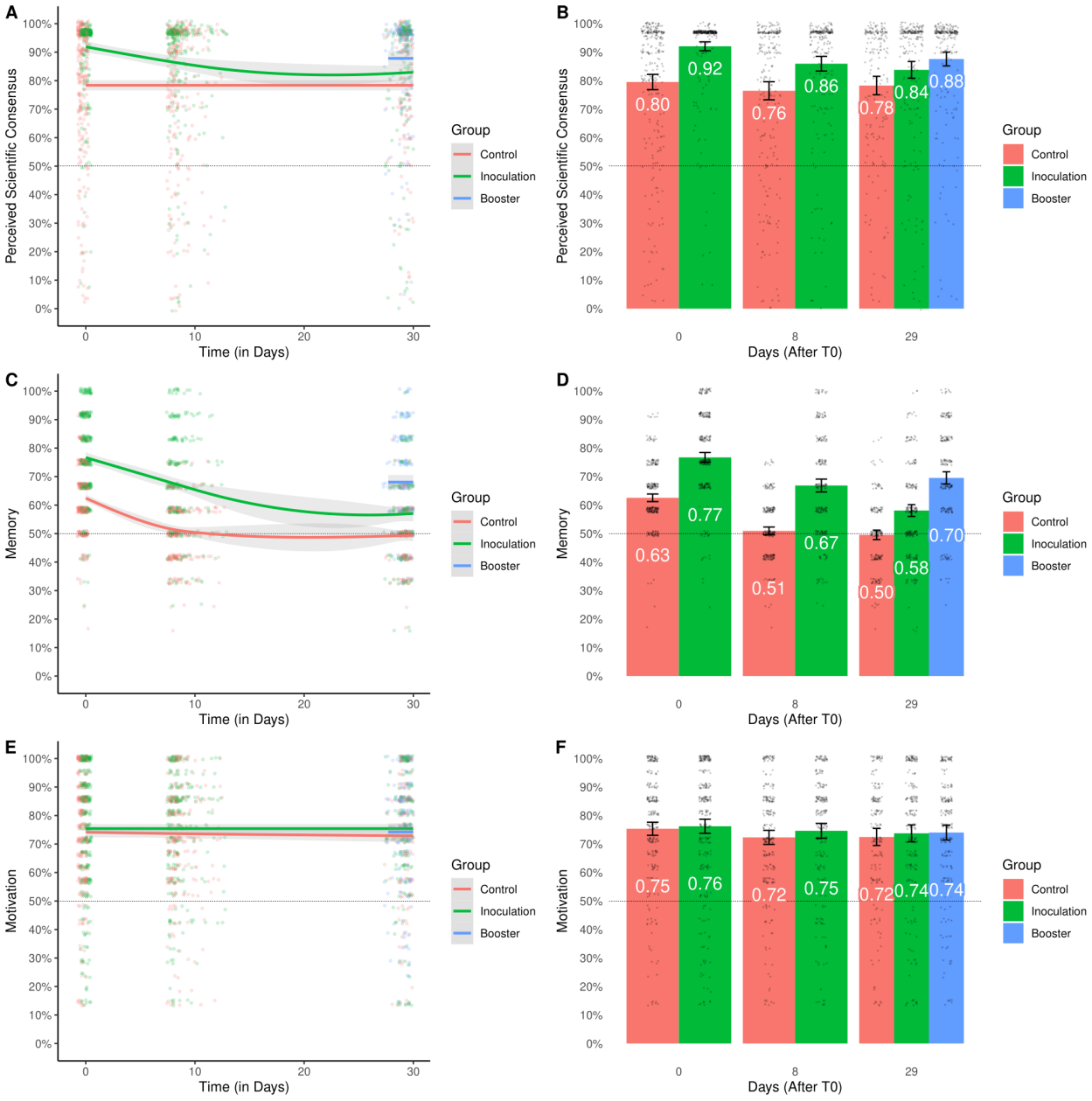

Figure 3. Results of Study 1 comparing the role of memory and motivation in relation to the inoculation effect over time. Error bands and bars represent 95% confidence intervals. $N = 1{,}825$.

Study 2: Gamified Inoculation

For Study 2 ($N = 674$) we implemented the gamified intervention design by Maertens et al. (2021), and tested the *Bad News* game (BN) with the same new approach and questions from

Study 1 for memory and motivation, and a newly developed version of *Bad News* to serve as the booster game. We set out to shed light on the validity of a memory theory of inoculation in the setting of gamified inoculation, and to investigate the potential of booster shots further. We sought to replicate the main effect at **T0** (**H1**) and expected the long-term effectiveness to remain intact for at least 10 days (**H2**). Meanwhile, we expected the effect to no longer be significant after 30 days when no booster was received (**H3**), but still significant after 30 days if participants played a booster game 10 days after **T0** (**H4**). We also expected the booster intervention to improve the objective memory of the intervention at **T30** (**H5**), as well as increase the motivation to defend oneself at **T30** (**H6**). Finally, we aimed to test the importance of memory and threat at mediating the inoculation effect (**H7**). Memory in this study was measured by summing the scores on all objective multiple-choice memory test items for the original intervention. Motivation was measured as the average rating of a series of subjective Likert-scale (1–7) statements asking participants whether they were motivated to defend themselves against misinformation (see **Methods** for an overview). All preregistered hypotheses and their evidence can be found in Supplement S25. A full overview of all items and survey files, R analysis scripts, raw and clean datasets can be found at the OSF repository for this project at https://osf.io/hwmge/?view_only=82bf2bc0f6ec4c5680e728cf5975244a. This study was also preregistered on AsPredicted at https://aspredicted.org/8YF_9L4.

We tested the main effect of the *Bad News* game on participants' reliability rating of misleading content using a one-way ANCOVA with pretest reliability ratings as a covariate, intervention as the independent variable, and misinformation reliability ratings as the dependent variable, at **T0**. We found inoculation to have a significant large effect on the outcome, $F(1, 316) = -43.37$, $p < .001$, $d = -0.779$, 95% CI [-1.020, -0.538], meaning that participants rated

misinformation as less reliable after the inoculation intervention, and providing strong evidence in favor of **H1** and replicating previous findings (Basol et al., 2020; Maertens et al., 2021).

The same ANCOVA design as for **H1** was used to test the decay hypotheses **H2** and **H3**, this time at **T10** (*Mdn* = 9 days after the intervention) and at **T30** (*Mdn* = 29 days after the intervention). The inoculation effect was no longer significant 9 days after the intervention, $F(1, 239) = -3.54$, $p = .061$, $d = -0.244$, 95% CI [-0.500, 0.012], but trending in the expected direction, thereby providing mixed evidence for **H2**. At 29 days after the intervention, the omnibus ANCOVA test for the intervention was also on the border of significance $F(2, 325) = 2.64$, $p = .073$, reflecting the lack of any effect for the standard inoculation group, in line with our expectations for **H3**, and a non-significant effect that is trending in the expected direction for the booster group, thereby providing mixed evidence for **H4**. See Figure 4 for an overview of the unreliability ratings (Panels A–B) over time.

As preregistered, we then continued to test whether the booster inoculation had a positive effect on memory of the **T0** intervention (the total score on an objective test battery) and motivation at **T30** (self-reported motivation to protect oneself against misinformation). For these analyses we used a **T30** ANOVA similar to the one used for the previous hypothesis test but this time with memory and motivation as the dependent variable for **H5** and **H6** respectively, and without the pretest. We first found that the intervention had a significant omnibus effect for memory, $F(2, 326) = 35.56$, $p < .001$, in line with **H5**, but not for motivation, $F(2, 326) = 0.06$, $p = .966$, leading us to reject **H6**. Looking at the specific group contrast for memory, we found a significant and large increase in memory for the booster intervention compared to the control group, $t(326) = 8.43$, $p_{tukey} < .001$, $d = 1.149$, 95% CI [0.867, 1.432], in line with **H5**. Although not preregistered, we also looked at the difference in memory between the boosted inoculation

group and the single inoculation group, also finding a significant difference, $t(326) = 3.99$, $p_{tukey} < .001$, $d = 0.538$, 95% CI [0.270, 0.806]. See Figure 4 for a plot of the effect of the intervention on memory (Panels C–D) and motivation (Panels E–F) for each of the time points.

Our final hypothesis is a test of the memory-motivation model of inoculation, to investigate the interplay between memory and motivation in predicting inoculation effect outcome. To do this, as preregistered, we tested an SEM model that included inoculation as a predictor of the misinformation detection score, and memory and motivation as mediators. We found, in line with **H7**, that across time points, memory had a significant direct effect on misinformation reliability ratings, and the inoculation intervention had a significant indirect effect on misinformation reliability ratings through memory. The effects for motivation were not significant, except for the effect of motivation on memory. See Figure S4 for a schematic presentation of the tested **T0** approximation of the memory-motivation model and Analysis S5 for a presentation and discussion of the relevant SEM model estimates. See Analysis S6 for an exploratory analysis of the underlying mechanisms using a dominance analysis.

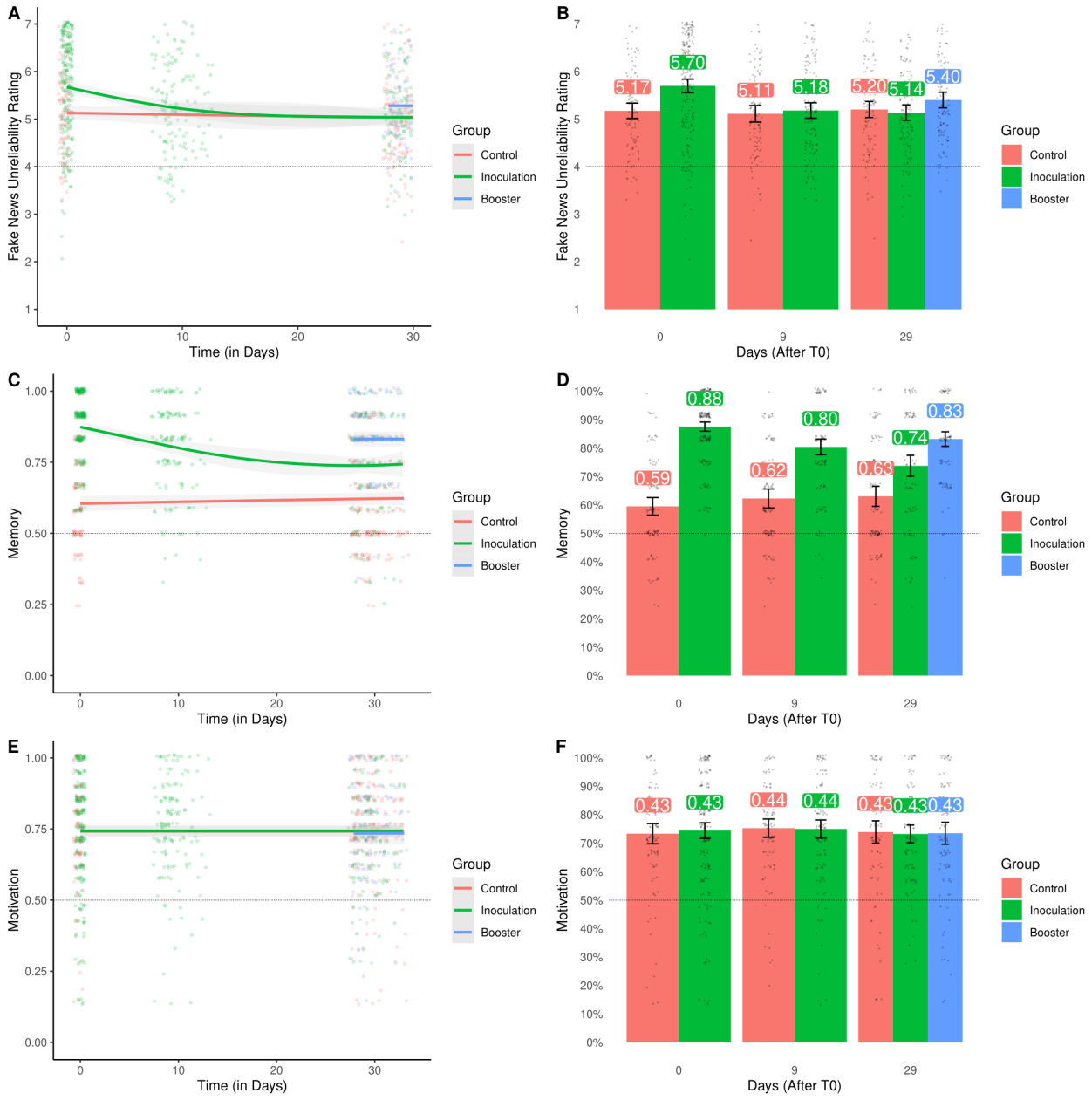

Figure 4. Results of Study 2 comparing the role of memory and motivation in relation to the inoculation effect over time. Error bands and bars represent 95% confidence intervals. $N = 674$.

Studies 3–5: Video-Based Inoculation

In Studies 3–5 we set out to explore the long-term effectiveness of video-based inoculation interventions, as well as the mechanisms driving these effects. In our first

experiment, we explored the effectiveness of a short inoculation video compared to a long inoculation video. In our second experiment, we tentatively explored the role of memory and motivational threat, as well as the longevity of the inoculation effect using multiple time points . In our third experiment, we attempted to replicate the findings from Study 4, test a memory-motivation model with a set-up comparable to Study 1 and Study 2, and explore the potential role of three types of "booster" interventions to determine which intervention most effectively boosts the inoculation effect. The booster videos were either a repetition of the original inoculation video (explaining how to spot manipulative emotional language and warning people of the threat of misinformation), a threat-focused video (that tried to boost threat and motivation by reminding people of the threat of misinformation, but did not reiterate how emotional language works), or a memory-boosting video (that reiterated how to spot manipulative emotional language but did not warn people of the threat). See **Methods** for an overview of how memory and motivation were measured. See Supplement S26 for an overview of the preregistered hypotheses for Studies 3–5 and their evidence. For an overview of the analyses and test results for the hypotheses of Studies 3 and 4, see Supplementary Analyses S7 and S9 respectively.

We tested **H3.1**, which states that the short video improves discernment performance, by exploring the main effect of the short inoculation video at **T0**, with the full sample size (N = 5,703). An omnibus test was significant, $F(1, 5701) = 76.81$, $p < .001$, indicating we can look at our specific main effect analysis. We found that the effect was significant, $M_{diff} = 0.44$, $t(5701) = 8.76$, $p_{tukey} < .001$, $d = 0.295$, 95% CI [0.229, 0.361].

After confirming a significant omnibus test, $F(4, 2215) = 10.14$, $p < .001$, we looked at the contrasts between the groups at **T30**. We found, contrary to our hypothesis **H3.2**, that the

group which had not seen a repeated inoculation video or any of the two booster videos still showed a significant inoculation effect at **T30** (29 days after **T0**), $M_{diff} = 0.34$, $t(2215) = 3.30$, $p_{tukey} = .009$, $d = 0.230$, 95% CI [0.093, 0.367]. In line with **H3.3**, **H3.4**, and **H3.5**, we found that the inoculation effects remained significant for the groups that were boosted at **T10** (9 days after **T0**), whether it was through a repetition of the inoculation, $M_{diff} = 0.36$, $t(2215) = 3.65$, $p_{tukey} = .003$, $d = 0.250$, 95% CI [0.115, 0.384], a "threat booster" video, $M_{diff} = 0.38$, $t(2215) = 3.66$, $p_{tukey} = .002$, $d = 0.258$, 95% CI [0.120, 0.397], or a "memory booster" video, $M_{diff} = 0.64$, $t(2215) = 6.35$, $p_{tukey} < .001$, $d = 0.440$, 95% CI [0.303, 0.576]. Descriptively, the memory booster video performs the best, with 100% retention of the original effect size, while the other two booster conditions retain ~86% of the original effect size, and the control booster condition 78%. See Figure 5 for a visual plot of the manipulativeness discernment (Panels A–B), memory (Panels C–D), and motivation (Panels E–F) in each condition over time in Study 5.

We then investigated the effect of booster sessions on the memory and motivation variables (**H3.6**, **H3.7**, **H3.8**, **H3.9**). The first three hypotheses were tested with (a) motivation (average rating on Likert-scale statements regarding motivation to protect oneself against misinformation) or (b) memory (objective performance on a multiple choice test battery) as the outcome variables. Model a, $F(4, 2215) = 8.41$, $p = .003$, and model b, $F(4, 2215) = 132.04$, $p < .001$, both showed a significant omnibus test. Looking at the preregistered contrasts, we found that a threat-focused booster video did not have a significant impact on motivation, $M_{diff} = 0.03$, $t(2215) = 0.28$, $p_{tukey} = .999$, $d = 0.019$, 95% CI [-0.113, 0.151], nor on memory, $M_{diff} = 0.20$, $t(2215) = 1.51$, $p_{tukey} = .556$, $d = 0.102$, 95% CI [-0.030, 0.234]. Neither the re-inoculation procedure, $M_{diff} = 0.09$, $t(2215) = 0.97$, $p_{tukey} = .870$, $d = 0.063$, 95% CI [-0.065, 0.191], nor the memory-focused booster video, $M_{diff} = 0.17$, $t(2215) = 1.81$, $p_{tukey} = .366$, $d = 0.120$, 95% CI

[-0.010, 0.249], had a significant effect on motivation. Meanwhile both the re-inoculation procedure, $M_{diff} = 0.66$, $t(2215) = 5.09$, $p_{tukey} < .001$, $d = 0.331$, 95% CI [0.203, 0.460], and the memory-focused booster video, $M_{diff} = 0.54$, $t(2215) = 4.14$, $p_{tukey} < .001$, $d = 0.273$, 95% CI [0.143, 0.403], had a significant effect on memory.

Finally, to test **H9**, we implemented a SEM model similar to Studies 1 and 2, to test whether the effects of the intervention on the outcome variable are mediated by motivation and memory. We found evidence for full mediation of the inoculation effect through memory and motivation. See Figure 6 for an overview of the memory-motivation model applied to Study 5 and Analysis S13 for an overview and discussion of the model estimates. See Analysis S14 for a dominance analysis of the underlying mechanisms, Figure S15 for a plot of the inoculation effect across political leanings in the combined sample of Studies 3–5, Figure S16 for a plot of the inoculation effect across different memory groups at each time point across Studies 3–5, and Analysis S17 for a word cloud analysis of the open memory questions.

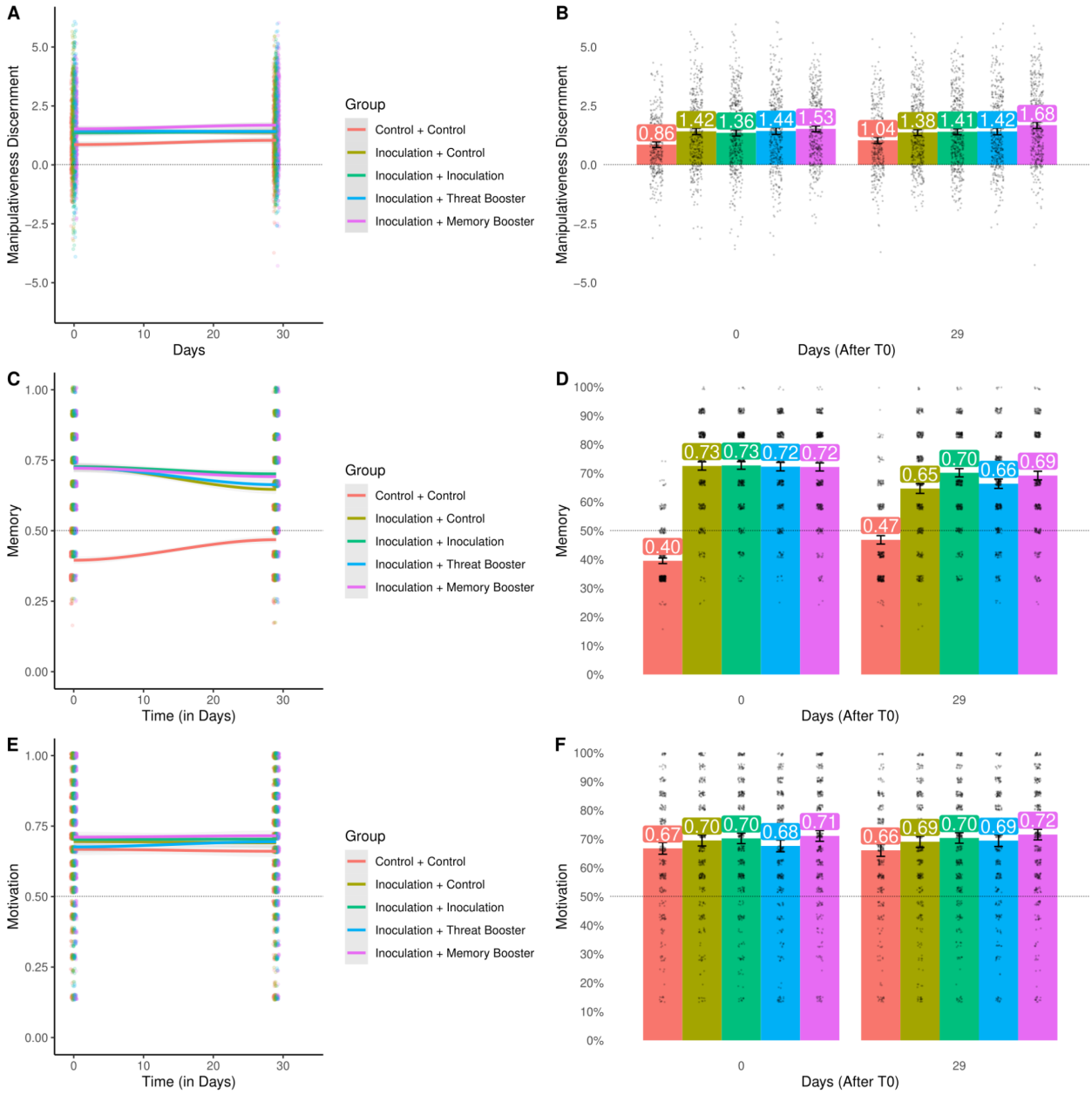

Figure 5. Results of Study 5 comparing the role of memory and motivation in relation to the inoculation effect over time. Error bands and bars represent 95% confidence intervals. $N = 2{,}220$.

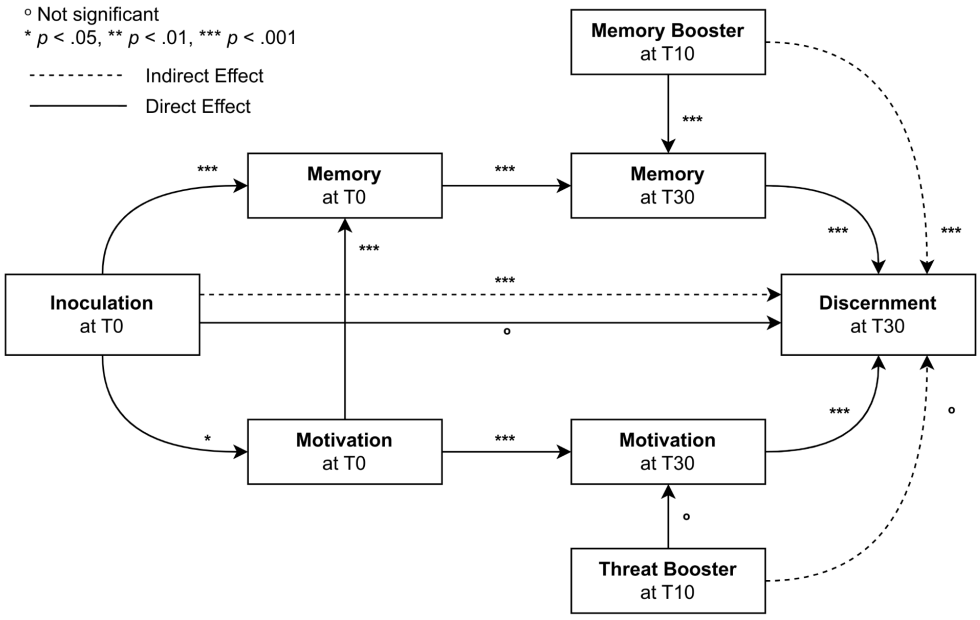

Figure 6. The memory-motivation model of inoculation in Study 5 (N = 2,220). Note that the models for text-based inoculation and gamified inoculation can be found in Supplements S1 and S4 respectively, but that the model presented here is the most complete as it separates memory and threat boosters.

Discussion

Inspired by early research on the potential role of memory in inoculation interventions [27], we explored whether memory is an important mechanism in inoculation interventions, and whether in general interventions to counter misinformation could be extended by using "booster interventions". Memory has long been studied in other areas of misinformation research, such as in the debunking literature [30]. Surveying the literature of preemptive counter-misinformation interventions made clear that knowledge about memory processes could help shed a new light on the underlying mechanisms of the longevity of interventions and how to extend their effects [31,32]. However, inoculation intervention designers have not yet tapped into the wealth of insights

cognitive science and memory research can provide, such as predicting longevity based on a forgetting function, and making interventions more durable by making them more memorable or by using memory-boosting interventions. We integrated insights from the cognitive science of memory with counter-misinformation literature, and proposed a memory-motivation model of inoculation (see Figures 2 and 6).

Through a series of five studies (Studies 1–5), using three different interventions, we can now assess the validity and generalisability of a memory-based theory of the long-term effectiveness of inoculation. To measure the inoculation effects, participants reported their attitudes after a misinformation attack (Study 1) or were asked to rate the reliability (Study 2) or manipulativeness (Studies 3–5) of social media posts. We found that memory is one of the most dominant factors in intervention success and longevity. Moreover, we found that booster interventions have the potential to further increase the longevity of intervention effects via memory strengthening. For text-based, gamified, and video-based interventions, we found that the effect shows a decay rate that is comparable to an exponential forgetting curve [33,34], and that the effect of specific text-based interventions can stay intact for about a month without a booster intervention, while the effects for the video-based and gamified interventions lost significance within the first two weeks without a booster intervention. This difference is likely due to the properties of issue-focused inoculation, that is targeted to a limited amount of content and therefore easier to remember, while technique-focused inoculation is broader and taps into multiple skills. Basol et al. [35] for example found that text-based interventions decayed more quickly than gamified interventions when both are technique-focused. Across the three inoculation formats, however, memory was consistently the most dominant outcome predictor, and booster shots consistently helped to restore intervention effects. Moreover, multiple forms of

booster shots were shown to be effective: repeated interventions (see Study 1), new interventions targeting the same techniques (see Study 2), memory boosters (see Study 5), and quizzing participants in the form of posttesting (see results Study 3 vs Study 5). A threat-only booster intervention (see Study 5) did not seem to be effective, further strengthening the evidence for the dominant role of memory. A structural equation model analysis shows that across all five studies, using a model that integrates both memory and motivation provides a feasible and practical theory to map intervention effects, with motivation influencing the intervention memory and boosters strengthening it. In other words, the studies show consistently that the memory-motivation model proposed in Figures 2 and 6 provides a valuable new way to map and boost the longevity of counter-misinformation interventions (for detailed results, see S18; for detailed integration with memory theory of inoculation see S19; for conceptual and methodological issues in longitudinal inoculation, see S20).

The finding of the dominant role of memory and an inoculation effect decay curve that is compatible with a memory forgetting curve could mean that multiple "booster" interventions may be needed to counteract misinformation in real world scenarios, but also that forgetting may flatten out when enough "booster" interventions are provided. In other words, in line with what would be expected from the memory literature, long-term retention could be achieved through repeated inoculation. This also fits within the biomedical "inoculation" metaphor, just like people may need multiple booster shots to foster immunity for COVID-19, which works in part by training memory B and T cells [36,37]. Future research should therefore explore repeated psychological booster shots.

Some misinformation scholars have argued that in the days after an inoculation intervention, the inoculation effect might increase rather than decrease, as the inoculation effect

might have to "sink in" [38,39]. However, our findings point in the opposite direction: decay is more likely to be exponential (i.e., more decay takes place closer to the intervention date). It is possible that the traditional theory—which posited the benefits of an initial period of delay, but has limited empirical evidence [28]—came into existence due to a lack of high-powered studies systematically looking at the decay curve and the mechanisms of decay. We propose an alternative theory to fill this gap: the memory-motivation model may complement the traditional inoculation model that was based on threat, motivation, and counterarguing, by adding a memory dimension to explain the long-term effectiveness of inoculation.

Conclusion

The series of studies presented in this work provide a response to three important theoretical, empirical, and methodological questions: 1) what are the mechanisms behind the effectiveness of counter-misinformation interventions based on inoculation, 2) what does the effect decay curve look like, and 3) how can we boost the long-term effectiveness of these interventions? By integrating insights from cognitive science with those from social psychology, we proposed a new memory-motivation theory of resistance to persuasion by misinformation. In a series of five experiments using text-based, gamified, and video-based interventions, we unveiled the intervention effect decay function and established the importance of memory of the treatment in detecting misinformation, and provided evidence for the role of "booster shots" as a means to remedy forgetting. Additional evidence pointed towards motivation as a memory enhancer. We illuminated the underlying theoretical mechanisms of memory strengthening, finding that a regular booster treatment may be needed to enhance the inoculation effect by strengthening memory of the intervention. A comparison across three different media (text-based, gamified, and video-based), each utilizing different inoculation parameters, allowed

us to determine the validity and generalisability of a memory-motivation theory of inoculation. The finding that short interventions can be as effective as longer interventions (see Study 3), indicates that it might be better for practitioners to focus resources on memory-boosting top-ups. This new evidence for the dominant role of memory and the potential for booster shots in the longevity of inoculation effects transforms our understanding of misinformation mechanisms and provides novel tools to those designing counter-misinformation policy and interventions, opening up new opportunities to more effectively tackle misinformation.

Methods

Study 1

Intervention

The first paradigm explores inoculation in the context of text-based climate change misinformation, for an overview see Supplement S21 and Maertens et al. [8]. This paradigm was chosen as 1) it is a well-established inoculation paradigm [7,18], 2) the topic is relevant for both theory (i.e., inoculation using a debated and polarized issue) and society, and 3) it can provide novel insights into the validity of the memory theory of inoculation when using a passive, specific, and therapeutic inoculation intervention.

Design, Sample, and Procedure

The study presents participants with a control task or an inoculation message (some participants see a repetition of this message after 10 days as a booster treatment), followed by—after a delay of 0 days (T0), 10 days (T10), or 30 days (T30)—a misinformation message about the scientific consensus on climate change (see Supplement S21 for a detailed explanation of the intervention materials). The intervention is based on Maertens et al. [8], meaning that it includes the same misinformation, consensus, and inoculation messages, but for this study we

added more and longer time periods, new motivation and memory measures, and a condition that includes a booster treatment. In addition, for this study, the consensus and inoculation messages were not but combined on a single page, and represent the "inoculation" group.

We recruited a high-powered sample (power = .95, $\alpha = .05$, potential effect decay = 40%, attrition = 30%) of US participants aged 18 or older through Prolific ($N = 2{,}657$). As preregistered, participants were excluded when they 1) failed the manipulation check, 2) failed both attention checks, 3) participated in the survey multiple times, or 4) did not complete the entire survey. We also excluded participants who did not participate within a window of 3 days from the intended participation date (i.e., 3 days before or after). This led to a final sample size of $N = 1{,}825$, with an average of 260 participants per group, slightly below the intended $n = 328$ due to a higher-than-expected attrition rate ($T10_{Attrition} = 31\%$, $T30_{Attrition} = 52\%$). Of the final sample, 49.21% identified as male (48.22% as female; 2.03% as non-binary; 0.33% as transgender, 0.22% as "other"), the average age was 35.79 ($SD = 13.07$, $Mdn = 33$), 58.69% had a higher education degree, 62.58% identified as left-wing (22.47% as centrist; 14.96% as right-wing), 48.99% identified most as Democrat (29.48% as Independent; 10.47% as Republican), 65.59% used social media multiple times a day (19.29% once a day, 7.29% weekly, 4.99% less often than weekly, 2.85% never), and 22.19% used Twitter multiple times a day (13.86% once a day, 12.06% weekly, 19.07% less often than weekly, 32.82% never). The participants were randomly allocated to one of three interventions: a word sorting task, the inoculation message, or the inoculation with a booster inoculation at 10 days. We also separated each time point by recruiting a separate sample for each condition, to avoid effects of repeated testing (i.e., each participant only ever received one post-test, at one time point depending on the group they were allocated), leading to a total of 7 groups. The booster treatment employed in this

study was an exact repetition of the original intervention. All participants received the misinformation message just before the posttest. When we refer to "T0", if not otherwise specified, we refer to the posttest at T0. For a complete overview of the study design, see Figure 7. Study 1 was approved by the Cambridge Psychology Research Ethics Committee (ref. PRE.2021.087).

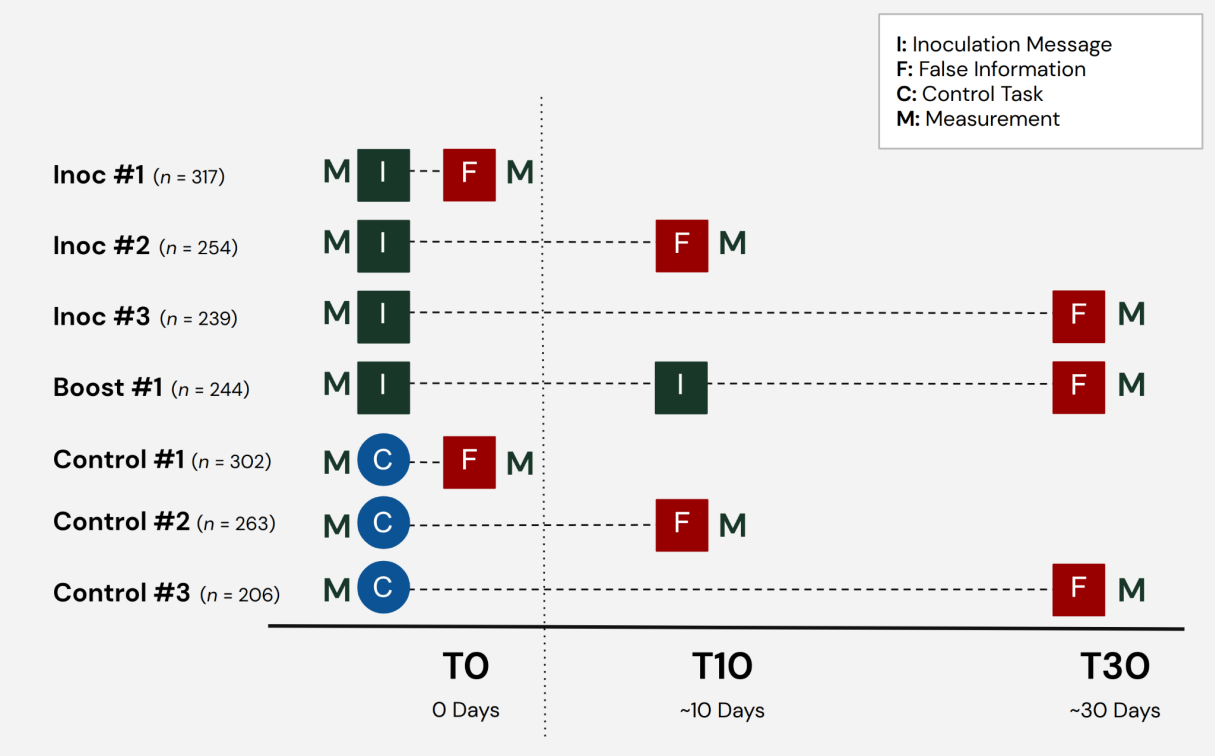

Figure 7. Experimental setup of climate change inoculation decay experiment (Study 1).

Materials and Measures

The main dependent variable for this study was the perceived scientific consensus on human-caused global warming, presented on a percentage slider scale (M = 84.10, SD = 16.77). The question asked to the participants is *"To the best of your knowledge, what percentage of*

climate scientists have concluded that human-caused climate change is happening? (0% to 100%)", with the correct answer being 97% [40].

This study also introduced a new set of memory and motivation variables, as well as a range of measures that are related to inoculation effects and the memory-motivation model. Our main measure for memory was an objective, performance-based, inoculation intervention content recall test that we designed for this study. It included 12 questions, including 8 yes-or-no questions (e.g., *Which of the following did you learn about in the messages from the first part of the survey?*; *False petitions*, *Yes/No*) and 4 multiple choice questions (e.g., *What was the message from the first part of the survey about?*; a – *The scientific consensus on climate change*, b – *Financial policy in the United States*, c – *The political side of bowling*, d – *Vaccination intentions*, e – *None of these options is correct*), which were combined into an index variable that we refer to as "memory" in this study (0–12; $M = 7.54$, $SD = 2.09$). For exploratory purposes, a set of subjective memory measures specifically created for this study was included as well, including *self-reported remembrance* (e.g., *"How well do you remember the messages about climate change you saw earlier in the survey?"*, Likert scale 1–7; $M = 3.96$, $SD = 1.86$), 4 open questions (e.g., *"What do you remember about the first half of the survey?"*), and 3 questions related to interference that were combined into an interference index (e.g., *"In the past two weeks, I have heard conflicting arguments about climate change"*; Likert scale 1–7, *Not at all true–Very true*; $M = 8.93$, $SD = 4.66$).

Next to memory questions, we implemented a range of motivation measures. Our main measure for motivation was *motivational threat* [41,42], which is seen as the most predictive measure of threat-based motivation for inoculation-induced resistance to misinformation [41,42]. We calculated this variable using a mean index of 3 Likert scale questions (e.g., *"Thinking about*

climate change misinformation motivates me to resist misinformation", 1–7, *Strongly disagree–Strongly agree*; *M* = 5.20, *SD* = 1.50). In addition, as exploratory measures for the memory-motivation model, we also included measures for *apprehensive threat*, *fear*, *issue involvement*, *issue accessibility*, and *issue talk* [27,38,41–45], which can be found in Table 4.

Table 1
Overview of Exploratory Measures of Study 1

Construct	Type	*M*	*SD*
Apprehensive Threat	6 Likert-scale questions (e.g., *"Thinking about climate change misinformation I feel threatened"*; 1–7, *Strongly disagree–Strongly agree*	3.92	1.73
Fear	Mean index of 3 Likert scale questions (e.g., *"Thinking about climate change misinformation I feel fearful"*; 1–7, *None of this feeling–A great deal of this feeling*)	3.96	1.92
Issue Involvement	Index score of "choose one option from this pair" questions (e.g., *"Which option of each pair best describes how much climate change means to you?"*; *Insignificant*, *Significant*), converted to a 1–7 score	6.27	1.76
Issue Accessibility	Single Likert scale item (*"Compared to other issues, how often do you think about climate change?*"; 1–7, *Never–Very often*)	3.95	1.60
Issue Talk	Index of 3 questions converted to a score from 1–7, including 2 Likert scale questions (e.g., *"In the past two weeks, how often did you talk about or discuss climate change with other people"*; 1–7, *Never–Very often*) and 2 choice option list questions (e.g., *"In the past two weeks, how many times did you talk about or discuss climate change?*"; *0*, *1*, *2*, *3*, *4*, *5*, *More than 5*)	2.23	1.23

The original survey files as well as a printout of the full survey can be found on the OSF repository for this study at https://osf.io/9zxje/?view_only=44a8556694b54d09a2e2a9875071de2f.

Deviations From Preregistration

We preregistered that we would exclude participants who did not participate in the follow-up within 5 days after the invitation. However, as the invitations were manual and grouped together, we invited participants 1–3 days earlier than the intended follow-up time. Therefore we have changed the exclusion window to 3 days before or after the intended follow-up time instead.

The analyses used for H3–H7 were slightly different from the preregistered analyses. The preregistration mentioned a repeated measures ANCOVA but as we do not have fully balanced

conditions and we have separate groups for each time point, we instead use a separate ANCOVA for each time point.

Study 2

Intervention

The second paradigm used an interactive online inoculation game called *Bad News*, developed by Roozenbeek and van der Linden [20], in which people take the role of a fake news creator and spreader within a simulated Twitter-environment. To measure the effectiveness, participants rated the reliability of a set of social media posts, and we looked at the reliability ratings of posts that made use of a misinformation technique. For an overview of the *Bad News* intervention and items, see Supplement S22 and Maertens et al. [26].

While the main intervention uses the same *Bad News* inoculation game as in Maertens et al. [26], we worked together with the media platform DROG to design a new, shortened, version of the *Bad News* intervention to serve as a "booster treatment". In this 5-minute version of *Bad News*, available at https://www.getbadnews.com/droggame_book/boostershot-bad-news/, participants are asked to put the skills they have learned in the original *Bad News* to use in a new scenario. They have to choose three disinformation techniques they want to revise and then have to use those disinformation techniques to go through an additional chapter, similar to the original *Bad News*.

We chose the Bad News paradigm for the second range of studies as it 1) describes an applied, implementable, and widespread intervention, and 2) to test the memory-motivation model in a broad-spectrum (i.e, it protects against a wide range of misinformation topics), interactive, inoculation intervention.

Design, Sample, and Procedure

We recruited 1,350 US participants aged 18 or older through Prolific to participate in this study (based on a power = .95, α = .05, accounting for up to 50% effect decay). Participants were randomly allocated to an inoculation group with a posttest at T0 only, an inoculation group with a posttest at T10 only (10 days later), an inoculation group with posttest at T30 only (30 days later), the booster group (with posttest at T30 only), or the control group (with posttest at T0, T10, *and* T30). Some participants in the inoculation group also received a booster treatment at T10. Participants at T0 also received a pretest to be used as a covariate during the study. When we refer to T0 in this study, when not otherwise specified, we refer to the posttest at T0. This design was chosen to avoid the boosting by repeated posttesting that we found in Maertens et al. [26] and enable a clean measure of the long-term effectiveness. We did not separate the groups for the control group (i.e., every participant in the control group received all three posttest measurements) as previous studies had shown that the repeated testing effects in the control group were limited [26,46] The time points were chosen to investigate the potential exponential decay between time points, and as we know from Maertens et al. [26] that the inoculation effect decays between T0 and 2 months later, and that the literature suggests that decay is likely to be found between 2 weeks [28,29] and 6 weeks [47]. The specific days between the recruitment were chosen to match the time points used in Study 1. See Figure 8 for an overview of the study design. Study 2 was approved by the Cambridge Psychology Research Ethics Committee (ref. PRE.2021.086).

As preregistered, participants were excluded when they 1) failed the manipulation check, 2) failed both attention checks, 3) participated in the survey multiple times, or 4) did not complete the entire survey. We also excluded participants who did not participate in the follow-up within 3 days from the intended participation date. This led to a final sample size of *N*

= 674, with an average of 135 participants per group, considerably below the intended $n = 220$ due to a higher-than-expected attrition rate ($T10_{Attrition} = 33.03\%$, $T30_{Attrition} = 47.16\%$; this higher attrition rate may be in part responsible for why some of the hypothesized effects were trending instead of significant). Of the final sample, 54.30% identified as female (41.39% as male; 3.12% as non-binary; 1.04% as transgender, 0.15% as "other"), the average age was 33.18 ($SD = 12.25$, $Mdn = 30$), 53.12% had a higher education degree degree, 66.17% identified as left-wing (22.40% as centrist; 11.42% as right-wing), 68.55% used social media multiple times a day (17.66% once a day, 6.08% weekly, 4.75% less often than weekly, 2.97% never), and 24.63% used Twitter multiple times a day (15.88% once a day, 12.17% weekly, 21.66% less often than weekly, 25.67% never).

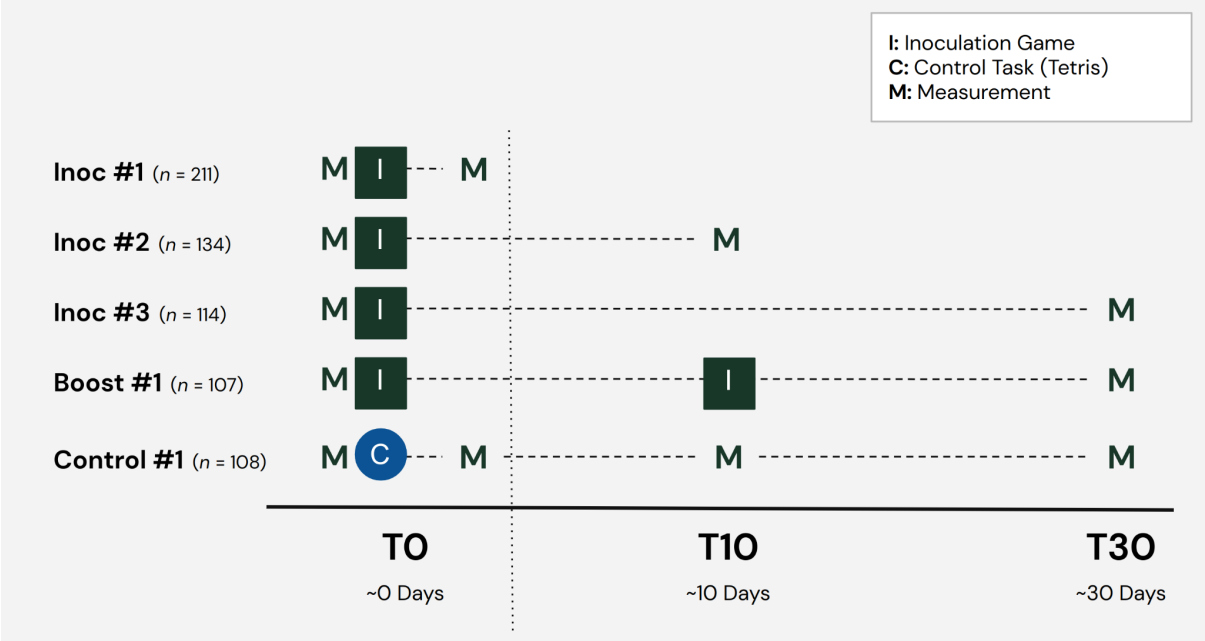

Figure 8. Experimental setup of the *Bad News* inoculation decay study (Study 2).

Deviations From Preregistration

It was preregistered that we would exclude participants who did not participate within five days after the intended follow-up date. We chose to change the window to 3 days before or after that date as we sent out grouped invitations manually 1–3 days before the intended follow-up date.

The preregistration proposes a two-way repeated measures ANCOVA analysis but the design of this study does not allow us to do this, as participants were separated in different groups for different time-points and the booster group did not receive a posttest before T30. We therefore use a one-way ANCOVA analysis for each time point separately and with pre-test as a covariate instead.

Studies 3–5

Intervention

In Studies 3–5 we use a video-based inoculation paradigm. For a detailed description of this paradigm, see Supplement S23 and Roozenbeek, van der Linden, et al. [23]. We chose this final paradigm as it provides 1) a novel form of inoculation that is short and highly scalable, and 2) a test of the memory model for a broad-spectrum, passive (in contrast to the active *Bad News* intervention), inoculation intervention, enabling the further evaluation of the generalisability of the model.

Procedure and Measures

After watching a video (which in the inoculation condition included an affective forewarning—the threat phase—and a technique training, both in function of teaching people how to recognise emotional-language-based misinformation), participants completed a social media post rating task, which involved rating a series of ten either manipulative (i.e., containing a manipulation technique) or neutral (i.e., not using any manipulation) social media posts that

were based on actual news in the field [23,24]. The 10 headlines participants rated came from a pool of 20 items consisting of 10 pairs: for each news story we created a manipulative version and a non-manipulative version conveying the same message, and participants were randomly allocated a neutral or manipulative version of each pair, and all social cues (e.g., likes, names, sources) were redacted from the items. This also meant that the manipulative-to-neutral item ratio varied among participants. This setup allowed us to calculate a clean discernment index without the influence of topics, social cues, or item ratios. Specifically, participants were asked to indicate for each post 1) how manipulative they found the post (our main dependent variable for this study); 2) how confident they were in their ability to assess the post's manipulativeness; 3) how trustworthy they found the post; and 4) how likely they were to share the post with others in their network. This rating task was our main method of assessing the videos' efficacy in terms of improving participants' ability to identify manipulative content: if the inoculation videos are effective, treatment group participants should be significantly better than a control group at discerning manipulative from non-manipulative content, have significantly higher confidence in their ability to do so, find manipulative content less trustworthy than neutral content, and should display significantly less sharing intentions for manipulative content than for neutral content.

In addition, we investigated the underlying mechanisms of the inoculation effect in line with Study 1 and Study 2. We asked a set of questions to assess participants' sense of threat about emotional language on social media and related constructs [27,38,41–45], as well as our own battery of memory questions. See Table 2, the Introduction, and Study 1 (**Methods**), for a more detailed discussion of these measures. As an exploratory measure we also created a measure for *concept mapping*, in which participants had to write down as many concepts related to the theme and intervention as possible in open boxes (*Please write down as many concepts or ideas you*

learned from the video in Part 1 of the survey as you remember; 0–9; *M* = 1.90, *SD* = 1.73), inspired by the memory concept mapping method by Pfau et al. (2005).

Table 2
Overview of Exploratory Measures of Study 3

Construct	Type	*M*	*SD*
Objective Memory	Index (0–12) of 4 multiple choice questions (example item: *What example was given in the video for "using emotional language in news headlines"?*; choice options: o *Changing a headline from "serious accident" into "horrific accident"*, o *Using a radio broadcast to trigger emotions*, o *Triggering emotions by employing emojis*, o *None of these options is correct*) and 8 yes-or-no questions (general question: *Which of the following did you learn about in the video that you watched in part 1 of this survey?*; example entry: *The role of fear and outrage*; choice options: o *No*, o *Yes*)	7.31	2.43
Self-Reported Remembrance	Single-item Likert scale (1–7); example item: *"How well do you remember the video you saw at the beginning of this survey?"*; 1 *I remember nothing*, to 7 *I remember everything*	3.61	1.90
Self-Reported Interference	Index (1–7) of 3 Likert items; example item: *"In the past two weeks, I have seen many videos about emotional language"*; 1 *Not at all true*, to 7 *Very true*	2.76	1.61
Motivational Threat	Index (1–7) of 3 Likert items; example item: *"Thinking about the idea of emotional language on social media motivates me to resist misinformation"*, 1 *Strongly disagree*, to 7 *Strongly agree*)	4.88	1.45
Apprehensive Threat	Index (1–7) of 7 Likert items; example item: *"Thinking about emotionally manipulative language on social media, I feel threatened"*, 1 *Strongly disagree*, to 7 *Strongly agree*)	3.32	1.67
Fear	Mean index of 3 Likert items; example item: *"Thinking about emotionally manipulative language on social media I feel fearful"*; 1 *None of this feeling*, to 7 *A great deal of this feeling*)	3.00	1.77
Issue Involvement	Index (1–7) of 6 "choose one option from this pair" questions (e.g., *"Which option of each pair best describes how much deception by emotionally manipulative language on social media means to you?*"; *Insignificant*, *Significant*)	4.81	2.49
Issue Accessibility	Index (1–7) of 2 Likert items; example item: *"Compared to other issues, how often do you think about the issue of manipulative news (e.g., using emotional language)*"; 1 *Never*, 7 *Very often*)	3.70	1.60
Issue Talk	Index (1–7) of 3 questions, including 2 Likert scale questions (e.g., *"In the past two weeks, how often did you talk about talk about the issue of emotional language on social media*"; 1 *Never*, 7 *Very often*) and 2 choice option list questions (e.g., *"In the past two weeks, how many times did you talk about or discuss the issue of manipulative news (e.g., using emotional language)?*"; *0*, *1*, *2*, *3*, *4*, *5*, *More than 5*)	2.37	1.38

To explore further covariates we also measured *misinformation susceptibility* (as measured through the 8-item Misinformation Susceptibility Test or MIST-8; Maertens et al., 2022; 0–8; *M* = 5.98, *SD* = 1.70), *conspiracy mentality* (CMQ; Bruder et al., 2013; 1–7; *M* = 4.58, *SD* = 1.30), the level of *trust* in politicians, family members, journalists, and civil servants, *party affiliation*, *political self-identification*, and self-reported *ideology* in terms of social (1–7; *M* = 3.96, *SD* = 1.74) and economic (1–7; *M* = 4.35, *SD* = 1.70) issues. Finally, all participants responded to the same series of demographic questions: age, gender, education level, racial

background, country of residence, news consumption behavior, whether English is their first language, and their favorite media outlet.

The Qualtrics files and the full PDF printout of the surveys can be found on the OSF repository for this study at https://osf.io/zrq87/?view_only=375c0632fca0444fa07c2bc46a59187b.

Sample

In all three studies participants were recruited and rewarded for their participation by *Respondi* (an ISO-certified online panel provider). All samples were representative quota samples of the United States based on the age and gender composition data provided by the United States Census Bureau (2019). After recruitment and informed consent, participants took part in a Qualtrics survey and were randomly allocated to one specific condition, followed by a posttest, and in some cases a follow-up. Studies 3–5 were approved by the Cambridge Psychology Research Ethics Committee (ref. PRE.2021.012). All datasets, analysis scripts in R, Qualtrics surveys, preregistrations, and stimuli are available on the OSF repository at https://osf.io/zrq87/?view_only=375c0632fca0444fa07c2bc46a59187b.

Study 3 Specifics

The goals of this study were as follows: 1) to replicate the effect of the emotional language inoculation video from Roozenbeek, van der Linden, et al. [23], 2) to identify differential effect sizes depending on video length (the full-length 1:48 min video and its shorter version of 0:30 min), 3) to determine the decay percentage after a two-week period, 4) to explore the role of memory and threat in inoculation effects, and 5) to explore if the inoculation effect is moderated by covariates such as conspiratorial thinking, misinformation susceptibility, and political polarization. To answer these questions, we conducted a preregistered longitudinal randomized

controlled trial with power = 0.95 and α = 0.05 for an effect size of $d = 0.490$ [based on 23]. The recruited sample size was $N = 2{,}895$, with a reduction to $N = 2{,}219$ when counting complete responses only and after—as preregistered—removing participants who failed both the manipulation and the attention check, participated multiple times, or entered the same response to each of the items of the dependent variable. In our final sample, 50.70% identified as female (48.26% as male; 0.86% as non-binary; 0.05% as "other"; 0.14% preferred not to answer), the average age was 46.00 ($SD = 16.41$, $Mdn = 46$), 66.70% had a higher education degree (1.85% did not finish high school), 31.73% identified as left-wing (32.85% as centrist; 35.42% as right-wing), 37.72% identifies most as Democrat (29.61% as Independent; 30.28% as Republican), 39.84% checked the news multiple times a day (34.84% once a day; 14.65% weekly; 8.43% less often than weekly; 2.25% never), 54.08% uses social media multiple times a day (23.43% once a day; 9.55% weekly; 5.36% less often than weekly; 7.57% never), 29.11% used YouTube multiple times a day (22.89% once a day; 26.32% weekly; 16.09% less often than weekly; 5.59% never), and 6.17% uses YouTube for news consumption multiple times a day (12.89% once a day; 16.54% weekly; 23.98% less often than weekly; 40.42% never). In Study 3, the rating task was administered at two different time points: T0 (immediately after watching the video) and T10 (two weeks after watching the video). Participants were randomly assigned to one of six conditions (see Figure 9 for an overview): the short inoculation condition (with posttest at T0 or at T10), the long inoculation condition (with posttest at T0 or T10), or the control condition (with posttest at T0 or T10). The rationale for this design, and specifically for the splitting in different sample groups per posttest time point, is to eliminate repeated testing effects, which could lead to unwanted effect-boosting confounds in the measurement of decay [26]. Note that "T0" represents the day of the intervention, and as there was no pretest, we refer

to“T0” as the posttest at “T0” (unless otherwise specified). This study was preregistered on the AsPredicted platform at https://aspredicted.org/WL8_LSK, and all analysis scripts in R, items, and Qualtrics survey files can be found on the OSF repository at https://osf.io/zrq87/?view_only=375c0632fca0444fa07c2bc46a59187b.

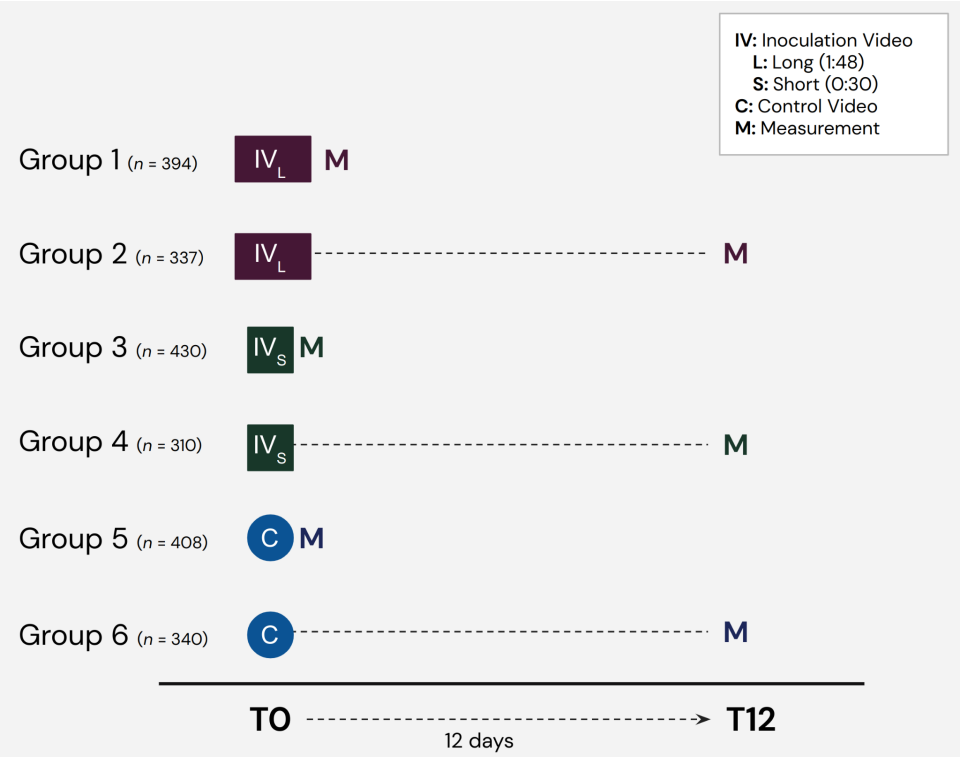

Figure 9. The experimental design of Study 3.

Study 4 Specifics

The basis of the video-based inoculation paradigm, including the dependent variables, are the same as in Study 3. New in Study 4 is that we include only the short videos (0 min 30 sec), have a larger sample size, and include multiple time points (4, 10, and 30 days). In total, we recruited $N = 5{,}191$ participants to T0, with random allocation to each condition (see Figure 10 for an overview). After—in line with the preregistration protocol—removing participants that

failed both the manipulation check and attention check, participated in the survey more than once, entered the same response to all items of the dependent variable, or did not complete the entire survey, a total of $N = 4{,}821$ participants remained. Of our final sample, 51.73% identified as female (47.65% as male; 0.44% as non-binary; 0.10% as "other"; 0.08% preferred not to answer), the average age was 45.79 ($SD = 16.46$, $Mdn = 45$), 65.63% has a higher education degree (1.35% did not finish high school), 30.47% identifies as left-wing (35.51% as centrist; 34.02% as right-wing), 35.86% identifies most as Democrat (32.03% as Independent; 29.25% as Republican), 36.57% checks the news multiple times a day (35.72% once a day; 14.87% weekly; 9.83% less often than weekly; 3.01% never), 51.05% uses social media multiple times a day (25.16% once a day; 10.81% weekly; 6.16% less often than weekly; 6.82% never), 27.11% uses YouTube multiple times a day (22.59% once a day; 27.84% weekly; 16.74% less often than weekly; 5.73% never), and 5.83% uses YouTube for news consumption multiple times a day (11.28% once a day; 15.25% weekly; 22.13% less often than weekly; 45.51% never). Participant attrition levels were lower than the predicted percentages: 24.6% for T10, 28.2% T30, and 39.7% for T4.

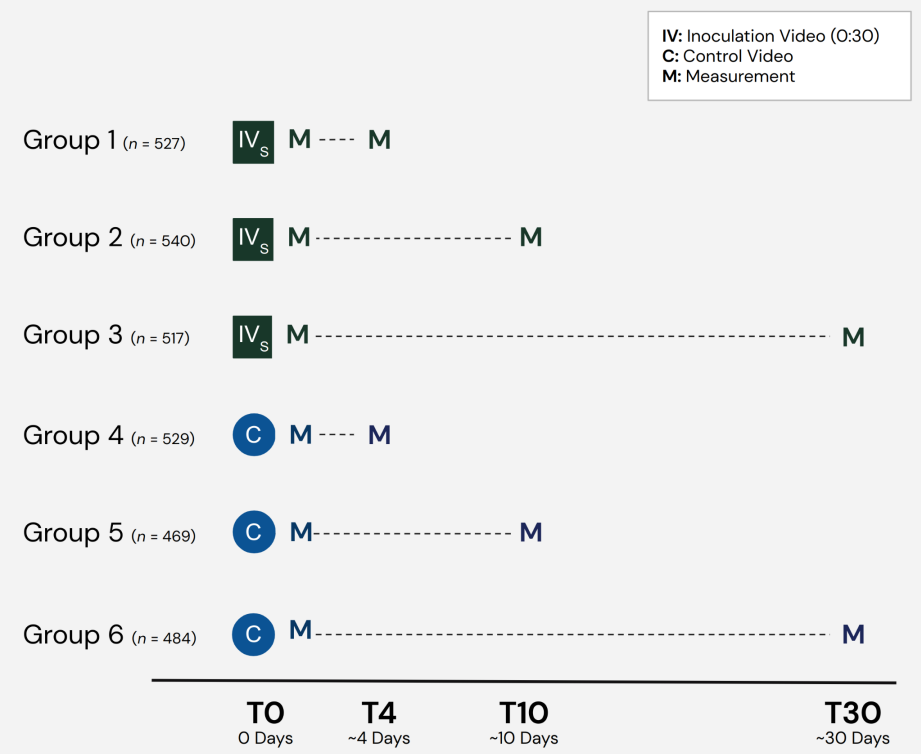

Figure 10. The experimental design of Study 4.

Study 5 Specifics

In Study 5 we built further on the design of Study 4, as well as Study 1 and Study 2, by combining multiple videos to test booster effects over time. In this final study we aimed to test and disentangle the two effects that drive inoculation effects: the threat component, and the preemptive refutation [15,25]. All participants were exposed to two different videos, a first video at T0, and a second video at T10 (*Mdn* = 9 days later). The first video was either the control video or the short inoculation used in Study 4. The second video was the same control or inoculation video repeated, a "threat booster" video focused on increasing levels of threat and motivation, or a "memory booster" video focused on reminding people of what they learned in the original intervention. We designed the threat booster video in such a way that it employed emotional music and warned people about manipulative online content, but it did not explain the methods

that are used to mislead people nor use any of the content from the original video (i.e., only threat, no refutational preemption). The memory booster on the other hand omitted the emotional music and affective forewarnings, but it did repeat the explanation of the techniques that can be used to mislead people using emotional language with similar content to the original video. Finally, all participants took the manipulativeness discernment test at T0 and at T30 (*Mdn* = 29 days later). This allowed us to disentangle and link effects at immediate posttest and at later posttest to enable testing the memory-motivation model. All participants were randomly allocated to the different video combinations (see Figure 11 for an overview).

In total, we recorded 6,164 survey responses at T0. As preregistered, we excluded incomplete and low-quality responses, leading to a T0 sample size of 5,703. Finally, we removed participants that did not participate in all three parts of the survey or did not participate in the follow-up sessions within 3 days before or after the intended time (T10: 10 days after, T30: 30 days after). This led to a final sample size of 2,220, with an average of 444 participants per group. This is slightly below but close to the intended 548 participants per group (participant attrition from T0 to T30 was 61%, slightly above the estimated 55%). In our final sample, 55.14% identified as female (44.50% as male; 0.23% as non-binary; 0.09% as “other”; 0.05% preferred not to answer), the average age was 53.29 (*SD* = 14.48, *Mdn* = 55), 67.48% has a higher education degree (1.40% did not complete high school), 29.19% identifies as left-wing (34.23% as centrist; 36.58% as right-wing), 36.13% identifies most as Democrat (28.87% as Independent; 32.07% as Republican), 40.90% checks the news multiple times a day (36.85% once a day; 12.52% weekly; 7.70% less often than weekly; 2.03% never), 45.68% uses social media multiple times a day (25.09% once a day; 10.90% weekly; 7.21% less often than weekly; 11.13% never), 21.89% uses YouTube multiple times a day (19.77% once a day; 29.59% weekly;

21.08% less often than weekly; 7.66% never), and 5.72% uses YouTube for news consumption multiple times a day (9.86% once a day; 11.49% weekly; 21.62% less often than weekly; 51.31% never).

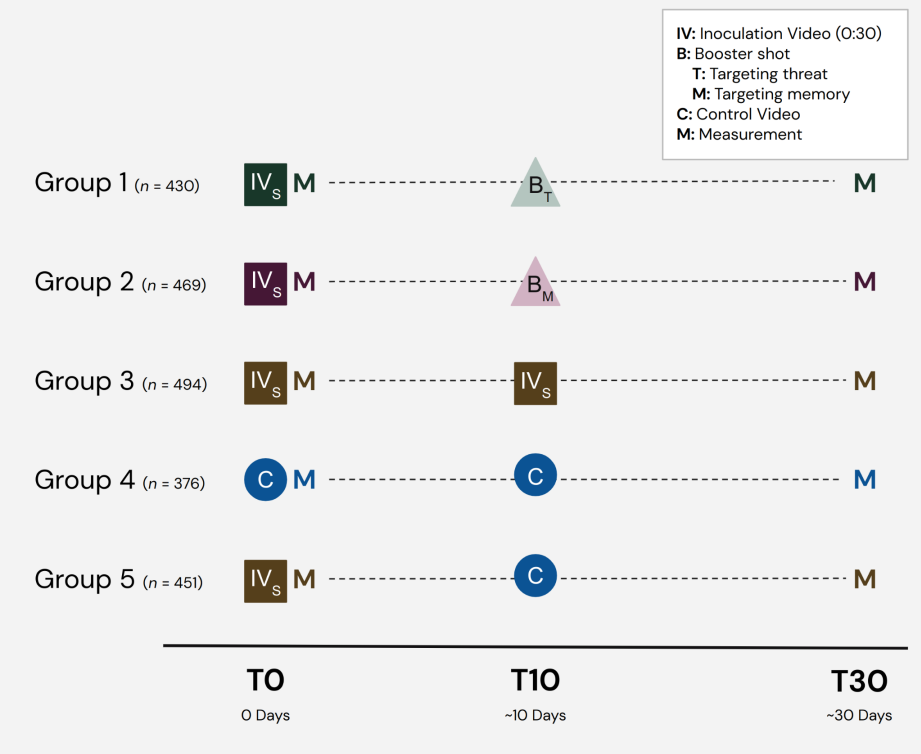

Figure 11. The experimental design of Study 5.

Acknowledgements

We would like to thank Cecilie Steenbuch Traberg for her help with creating the stimuli (social media posts). We also want to thank Luke Newbold, Sean Sears, and Studio You in London for creating the videos. Finally, a huge thanks to DROG, TILT, and Gusmanson Design for helping create the Bad News game.

Author Contributions

RM, JR, JS, SL, VM, BG, and SvdL all contributed to designing the project, research materials, and experimental designs. RM led the work on initial conceptualisation, project management, data collection, and data analysis, and wrote the first version of the manuscript. RM, JR, JS, SL, VM, BG, RX, and SvdL all contributed to the review and revision process, improving the writing, data interpretation, and literature analysis. SvdL had an additional responsibility for supervising the project and ensuring the quality of the work.

Competing Interests

The authors declare no competing interests.

Additional Information

Supplementary Information is available for this paper. Correspondence and requests for materials should be addressed to Dr Rakoen Maertens (rm938@cam.ac.uk).

Supplement

S1 Figure

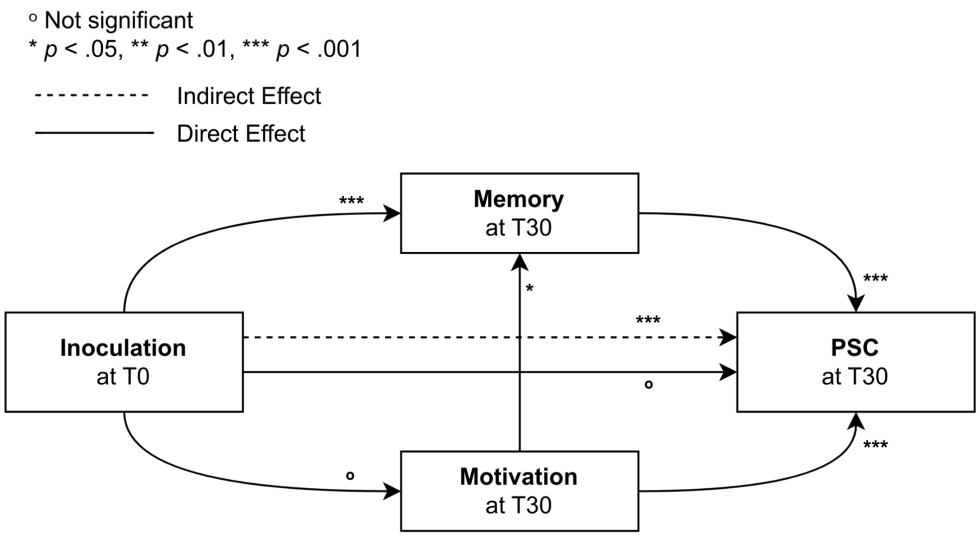

Figure S1. SEM Analysis of the memory-motivation model at T30 in Study 1.

S2 Analysis

Table for Analysis S2

Memory-Motivation Model Estimates at T30 in Study 1, N = *689*

Effect	*z*	*p*	β	95% CI		*SE*
				LL	*UL*	
Indirect						
Inoc.T0 ⇒ Memory.T30 ⇒ PSC.T30	**6.323**	**< .001**	**0.237**	**0.164**	**0.311**	**0.038**
Inoc.T0 ⇒ Motivation.T30 ⇒ PSC.T30	0.779	.436	0.019	-0.029	0.068	0.025
Inoc.T0 ⇒ Motivation.T30 ⇒ Memory.T30 ⇒ PSC.T30	0.744	.457	0.002	-0.003	0.006	0.002
Component						
Inoc.T0 ⇒ Memory.T30	**10.634**	**< .001**	**0.816**	**0.665**	**0.966**	**0.077**
Memory.T30 ⇒ PSC.T30	**7.864**	**< .001**	**0.291**	**0.218**	**0.363**	**0.037**
Inoc.T0 ⇒ Motivation.T30	0.782	.434	0.065	-0.098	0.228	0.083
Motivation.T30 ⇒ PSC.T30	**8.632**	**< .001**	**0.296**	**0.229**	**0.363**	**0.034**
Motivation.T30 ⇒ Memory.T30	**2.509**	**.012**	**0.088**	**0.019**	**0.157**	**0.035**
Direct						
Inoc.T0 ⇒ PSC.T30	0.945	.345	0.076	-0.082	0.233	0.080
Total						
Inoc.T0 ⇒ PSC.T30	**4.063**	**< .001**	**0.334**	**0.173**	**0.495**	**0.082**

We found that, in line with the hypothesis, that there was a direct effect of inoculation memory on the PSC at T0, $z = 5.51$, $p < .001$, β = 0.230, 95% CI [0.148, 0.311], at T10 (8 days), $z = 7.93$, $p < .001$, β = 0.316, 95% CI [0.227, 0.406], and at T30 (29 days), $z = 7.86$, $p < .001$, β = 0.291, 95% CI [0.218, 0.363]. Similarly, a direct effect was found of motivation on the PSC at T0, $z = 4.77$, $p < .001$, β = 0.177, 95% CI [0.104, 0.250], T10, $z = 4.96$, $p < .001$, β = 0.200, 95% CI [0.121, 0.280], and at T30, $z = 2.51$, $p = .012$, β = 0.088, 95% CI [0.019, 0.157]. Meanwhile, the inoculation intervention had a direct influence on memory at T0, $z = 12.93$, $p < .001$, β = 0.907, 95% CI [0.769, 1.044], at T10, $z = 11.97$, $p < .001$, β = 0.926, 95% CI [0.774, 1.077], and at T30, $z = 10.63$, $p < .001$, β = 0.816, 95% CI [0.665, 0.966]. Also motivation had an impact on memory at T0, $z = 4.94$, $p < .001$, β = 0.173, 95% CI [0.105, 0.242], at T10, $z = 2.45$, $p = .014$, β = 0.095, 95% CI [0.019, 0.170], and at T30, $z = 2.51$, $p = .012$, β = 0.088, 95% CI [0.019, 0.157].

The intervention did not have a direct influence on motivation at T0, $z = 0.51$, $p = .608$, $\beta = 0.041$, 95% CI [-0.116, 0.199], at T10, $z = 1.26$, $p = .207$, $\beta = 0.111$, 95% CI [-0.061, 0.283], or at T30, $z = 0.78$, $p = 0.434$, $\beta = 0.065$, 95% CI [-0.098, 0.228]. Finally, the inoculation intervention had an indirect influence on the PSC mediated by memory at T0, [H8a] $z = 5.07$, $p < .001$, $\beta = 0.208$, 95% CI [0.128, 0.289], T10, [H8b] $z = 6.00$, $p < .001$, $\beta = 0.293$, 95% CI [0.197, 0.388], and at T30, [H8c] $z = 6.32$, $p < .001$, $\beta = 0.237$, 95% CI [0.164, 0.311], providing evidence in line with the memory-motivation model. While not preregistered, to investigate the nature of the mediation model further, we also looked at the direct effect of inoculation on the PSC at T30, and found that it was not significant $z = 0.95$, $p = .341$, $\beta = 0.076$, 95% CI [-0.082, 0.233], while the indirect effect was significant $z = 4.06$, $p < .001$, $\beta = 0.334$, 95% CI [0.173, 0.495]. This provides evidence for full mediation.

S3 Analysis

Dominance Analysis

Table for Analysis S3

Dominance Analysis in Study 1, at T30, N = *689*

Variable	Dominance
Memory	82%
Issue Involvement	4%
Issue Accessibility	4%
Apprehensive Threat	4%
Motivational Threat	2%
Self-Reported Remembrance	1%
Fear	1%
Issue Talk	1%

Looking further into the mechanisms of the inoculation effect, setting out to find out what the strongest predictor is of the inoculation effect, we implement a dominance analysis with the T30 data of a wide range of predictors of the inoculation outcome mentioned in the literature. Dominance analysis is a method to investigate the relative importance of each predictor variable in a regression model by calculating the additional variance explained (R^2) of each variable in all possible model combinations with these variables and then performing pairwise comparisons for each of these subsets to establish which variable was more important (i.e., more dominant), leading to a percentage of the cases where one variable was dominant above the other variables (Budescu, 1993). This allowed us to identify which predictors were the most essential predictors. We use the T30 data as this time point is most relevant in terms of uncovering the mechanisms behind the long-term effectiveness. The analysis demonstrated that memory was by far the most dominant predictor of the inoculation effect (82%).

S4 Figure

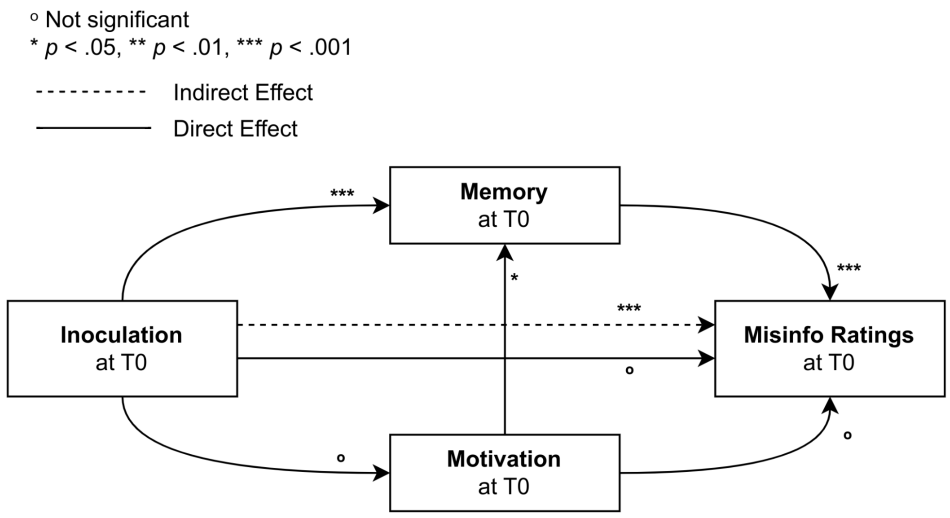

Figure S4. SEM analysis of the memory-motivation model at T0 in Study 2 ($N = 319$).

S5 Analysis

Table for Analysis S5

Memory-Motivation Model Estimates at T0 in Study 2, N = *319*

Effect	*z*	*p*	β	95% CI		*SE*
				LL	*UL*	
Indirect						
Inoc.T0 ⇒ Memory.T0 ⇒ Fake.T0	**-4.898**	**< .001**	**-0.548**	**-0.767**	**-0.329**	**0.112**
Inoc.T0 ⇒ Motivation.T0 ⇒ Fake.T0	-0.452	.651	-0.005	-0.028	0.018	0.012
Inoc.T0 ⇒ Motivation.T0 ⇒ Memory.T0 ⇒ Fake.T0	-0.454	.650	-0.002	-0.009	0.006	0.004
Component						
Inoc.T0 ⇒ Memory.T0	**17.564**	**< .001**	**1.472**	**1.308**	**1.636**	**0.084**
Memory.T0 ⇒ Fake.T0	**-5.100**	**< .001**	**-0.372**	**-0.515**	**-0.229**	**0.073**
Inoc.T0 ⇒ Motivation.T0	0.466	.641	0.055	-0.176	0.287	0.118
Motivation.T0 ⇒ Fake.T0	-1.853	.064	-0.097	-0.199	0.006	0.052
Motivation.T0 ⇒ Memory.T0	**2.133**	**.033**	**0.085**	**0.007**	**0.163**	**0.040**
Direct						
Inoc.T0 ⇒ Fake.T0	0.249	.803	0.038	-0.262	0.338	0.153
Total						
Inoc.T0 ⇒ Fake.T0	**-4.503**	**< .001**	**-0.517**	**-0.741**	**-0.292**	**0.115**

We found, in line with [H7], that memory had a direct influence on fake news reliability ratings at T0 [H7a], $z = -5.10$, $p < .001$, $\beta = -0.372$, 95% CI [-0.515, -0.229], at T10 [H7b], $z = -3.14$, $p = .002$, $\beta = -0.225$, 95% CI [-0.365, -0.084], and at T30 [H7c], $z = -4.16$, $p < .001$, $\beta = -0.242$, 95% CI [-0.355, -0.128]. However, motivational threat was not a significant predictor of fake news reliability ratings at T0 [H7a], $z = -1.85$, $p = .064$, $\beta = -0.097$, 95% CI [-0.199, 0.006], at T10 [H7b], $z = -0.15$, $p = .883$, $\beta = -0.009$, 95% CI [-0.133, 0.114], or at T30 [H7c], $z = -1.18$, $p = .238$, $\beta = -0.064$, 95% CI [-0.169, 0.042]. Motivation did significantly influence memory formation at T0, $z = 2.13$, $p = .033$, $\beta = 0.085$, 95% CI [0.007, 0.163], in line with the memory-motivation model.

Further in line with the memory hypothesis of H7, inoculation had an indirect effect on fake news detection outcome mediated through memory at T0 [H7a], $z = -4.90$, $p < .001$, $\beta =$

-0.548, 95% CI [-0.767, -0.329], at T10 [H7b], z = -2.94, p = .003, β = -0.215, 95% CI [-0.358, -0.072], and at T30 [H7c], z = -3.62, p < .001, β = -0.192, 95% CI [-0.296, -0.088]. Although not preregistered, we also looked at whether the direct effect of the inoculation intervention was still significant at T0 when accounting for memory, and we found that the direct effect was no longer significant, z = 0.25, p = .803, β = 0.038, 95% CI [-0.262, 0.338].

S6 Analysis

Dominance Analysis

Table for Analysis S6
Dominance Analysis in Study 2, at T30, N = *329*

Variable	Dominance
Memory	60%
Motivational Threat	17%
Issue Talk	14%
Issue Accessibility	7%
Self-Reported Remembrance	1%
Issue Involvement	1%
Apprehensive Threat	1%
Fear	0%

We performed a dominance analysis on the possible predictors of the fake news reliability rating at T30 (see the methods section of Study 1 for an explanation of dominance analysis). We found that memory was the dominant predictor, followed by motivational threat. In addition, although not preregistered, a Pearson correlation test reveals a significant negative correlation between memory and fake news reliability ratings in the inoculated groups, $t(564) = -8.69$, $p < .001$, $r = -.344$, 95% CI [-.414, -.269], as well as a significant negative correlation between memory and time, $t(564) = -5.77$, $p < .001$, $r = -.236$, 95% CI [-.312, -.157], similar to the positive correlation between fake news reliability ratings in the inoculation group and time, $t(564) = 3.94$, $p < .001$, $r = .164$, 95% CI [.082, .243].

S7 Analysis

To test our main hypotheses for the "manipulativeness" measure (i.e., manipulative language discernment), we preregistered a two-way (3x2) ANOVA analysis. We found that the omnibus test is significant, $F(5, 2213) = 15.64$, $p < .001$, indicating that we can continue to test our contrasts as planned. As preregistered, we then conducted a series of Tukey-corrected ANOVA contrast tests to test hypotheses H1.1–H1.3. We found that the inoculation effect for the long inoculation video as compared to the control video is significant, $M_{diff} = 0.75$, $t(2213) = 7.43$, $p_{tukey} < .001$, $d = 0.525$, 95% CI [0.385, 0.664], providing evidence in line with H1.1a. Also the short inoculation video compared to the control video leads to a significant effect $M_{diff} = 0.63$, $t(2213) = 6.36$, $p_{tukey} < .001$, $d = 0.439$, 95% CI [0.303, 0.575], in line with H1.1b. The above analyses indicate significant medium effect sizes both for the long inoculation video and for the short inoculation video, replicating the original study (Roozenbeek, van der Linden, et al., 2022), in favor of H1.1: both videos significantly improve participants' ability to discern manipulative from non-manipulative content. Now that the baseline effect is established, we can compare the short and the long inoculation videos and explore the decay over time.

We now test the contrast of the manipulative discernment scores after the short and long video. The videos did not show a significantly different effect from one another in terms of T0 effect sizes $M_{diff} = 0.12$, $t(2213) = 1.22$, $p_{tukey} = .826$, $d = 0.085$, 95% CI [-0.051, 0.222], advising rejection of H1.2, indicating that the long and short videos are equally effective in the immediate post-test. Comparing the T12 (*Mdn* = 12 days after T0) and T0 decay in the long inoculation condition, we found that a significant decay takes place, $M_{diff} = -0.36$, $t(2213) = -3.43$, $p_{tukey} = .008$, $d = -0.255$, 95% CI [-0.400, -0.109]. Moreover, after this decay, the inoculation effect was no longer significantly different from the control condition $M_{diff} = 0.24$, $t(2213) = 2.23$, $p_{tukey} =$

.227, d = 0.171, 95% CI [0.020, 0.322]. A similar result can be found when comparing T12 to T0 of the short inoculation videos M_{diff} = -0.31, t(2213) = -2.90, p_{tukey} = .044, d = -0.216, 95% CI [-0.362, -0.070], and when comparing T12 short inoculation to T12 control M_{diff} = 0.18, t(2213) = 1.58, p_{tukey} = .611, d = 0.124, 95% CI [-0.030, 0.278]. These decay analyses indicate that there is full decay of the inoculation effect when measuring 12 days after T0, leading to the rejection of H1.3. See Figure S8 for a visual plot of manipulativeness discernment (Panel A) and memory (Panel B) over time. Although not preregistered, we also ran the above analyses with the confidence, trustworthiness, and sharing intent measures. Here, similar to the analyses for manipulativeness, we found significant effects for T0 (each in the expected direction), and significant decay to the extent that the effect is no longer significant when the Tukey p-value correction is administered, except for trustworthiness discernment in the long video. A larger sample would be needed to determine the presence of a reduced effect. All effects were driven by the scores for the manipulative items, with minimal change for non-manipulative items.

S8 Figure

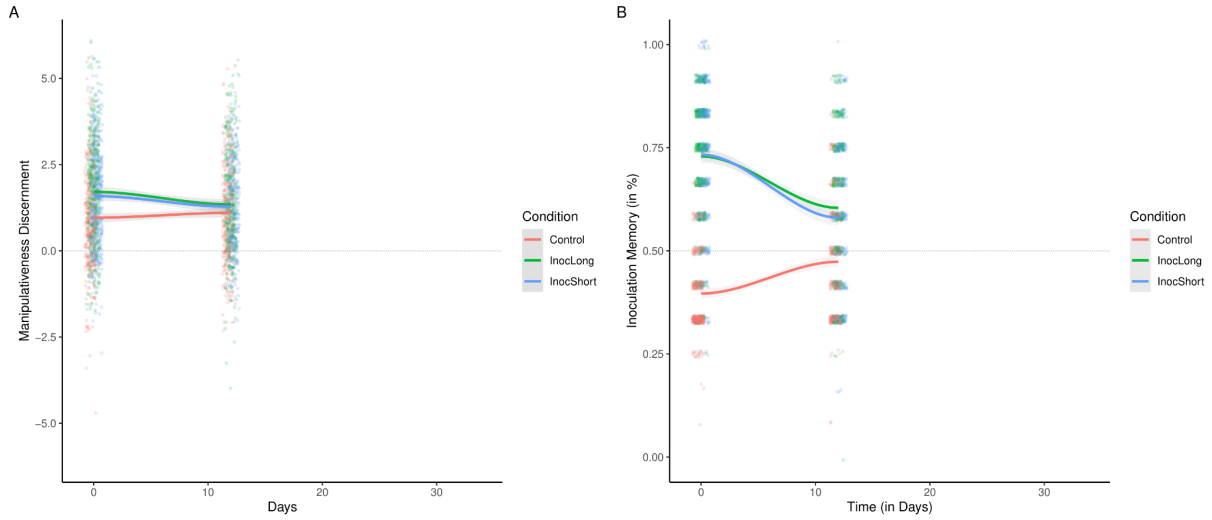

Figure S8. Visual plot of "manipulativeness discernment" (Panel A) and inoculation memory (Panel B) in Study 3. Days represents the time elapsed after the intervention. Inoc is the inoculation intervention (Long: 1 minute 48 seconds; Short: 30 seconds). Error bands represent 95% confidence intervals. $N = 2{,}219$.

S9 Analysis

As preregistered, we tested hypothesis H2.1 by running an ANOVA with manipulativeness discernment as the dependent variable and group (inoculated or not) as the independent variable, with the full T0 dataset (N = 4,821). We found that the ANOVA omnibus test is significant, $F(1, 4819) = 134.73$, $p < .001$. To test H2.1, we looked at the main effect of the intervention at T0 and found that the inoculation effect is significant, $M_{diff} = 0.47$, $t(4819) = 11.61$, $p_{tukey} < .001$, $d = 0.335$, 95% CI [0.278, 0.391].

To test the decay hypotheses H2.2, H2.3, and H2.4, we made use of an ANCOVA with T0 discernment as a covariate, post-posttest discernment as a dependent variable, and group and evaluation date as independent variables. In addition, we now used all time points, and only include data from participants who completed the follow-up within 3 days from the intended follow-up date (N = 3,066, $Mdn_{BetweenDays,T4} = 4$, $Mdn_{BetweenDays,T10} = 8$, $Mdn_{BetweenDays,T30} = 29$). The omnibus test was significant, $F(3060) = 12.66$, $p < .001$. In line with our expectations, we found evidence for the stability of the effect over 4 days, with a significant effect compared to the control group, $M_{diff} = 0.53$, $t(3060) = 6.10$, $p_{tukey} < .001$, $d = 0.375$, 95% CI [0.254, 0.496], and no significant change in the inoculation groups between the two time points, $M_{diff} = 0.18$, $t(6124) = 2.54$, $p_{tukey} = .178$, $d = 0.128$, 95% CI [0.029, 0.226]. After 8 days we found that the effect was still significant compared to the control group, $M_{diff} = 0.41$, $t(3060) = 4.56$, $p_{tukey} < .001$, $d = 0.288$, 95% CI [0.164, 0.412], and—contrary to our expectations—that there was no significant change between T0 and T10 in the inoculation groups, $M_{diff} = 0.04$, $t(6124) = 0.54$, $p_{tukey} > .999$, $d = 0.027$, 95% CI [-0.070, 0.125]. After 29 days we found that, in line with our preregistered hypothesis, that the inoculation effect is no longer significant compared to the control group, $M_{diff} = 0.18$, $t(3060) = 2.05$, $p_{tukey} = .315$, $d = 0.130$, 95% CI [0.006, 0.254], but without a significant

decay in the inoculation group when comparing T30 to T0, M_{diff} = -0.01, $t(6124) = 2.05$, $p_{tukey} > .999$, d = -0.010, 95% CI [-0.109, 0.089]. See Figure S10 for a plot of manipulativeness discernment (Panel A) and memory (Panel B) over time.

To test H2.5 and H2.6 and compare the mechanisms with the results from Study 1 and Study 2, we modeled an SEM model using the *lavaan* package in R (Rosseel, 2012) with second posttest memory and motivational threat as mediators for the manipulativeness discernment at second posttest, and T0 inoculation as the predictor variable, allowing direct effects from inoculation to memory, motivational threat, and discernment, and direct effects from memory and motivational threat to discernment. See Figure S11 for a schematic visualization of the model and its direct and indirect relationships, and Table S12 for its model estimates. As predicted, we found that memory directly predicts the inoculation effect at a later time point, $t(3062) = 7.78$, $p < .001$, $\beta = 0.169$, 95% CI [0.126, 0.212], as did motivation, $t(3062) = 7.85$, $p < .001$, $\beta = 0.138$, 95% CI [0.104, 0.173]. As can be seen in Table S12, all indirect and all component effects were significant with a significant total effect of the inoculation intervention, $t(3062) = 7.32$, $p < .001$, $\beta = 0.262$, 95% CI [0.192, 0.333], and no significant direct effect of the intervention, $t(3062) = 1.07$, $p = .238$, $\beta = 0.047$, 95% CI [-0.038, 0.131], providing evidence for full mediation.

S10 Figure

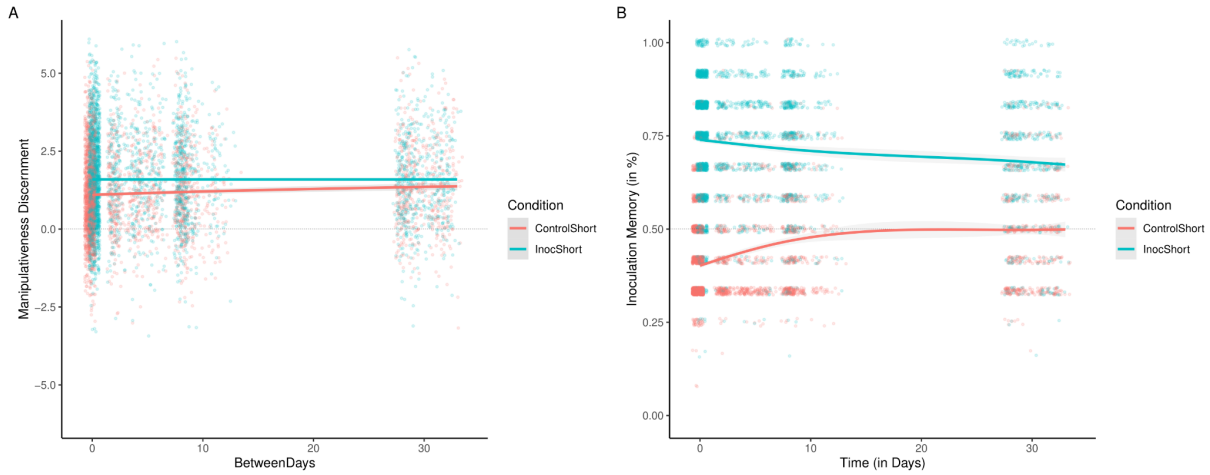

Figure S10. Visual plot of "manipulativeness discernment" (Panel A) and inoculation memory (Panel B) in Study 4. Control and InocShort represent the 30-second control and inoculation videos. Days represent the time passed since the inoculation intervention. Error bands represent 95% confidence intervals. $N = 3{,}066$.

S11 Figure

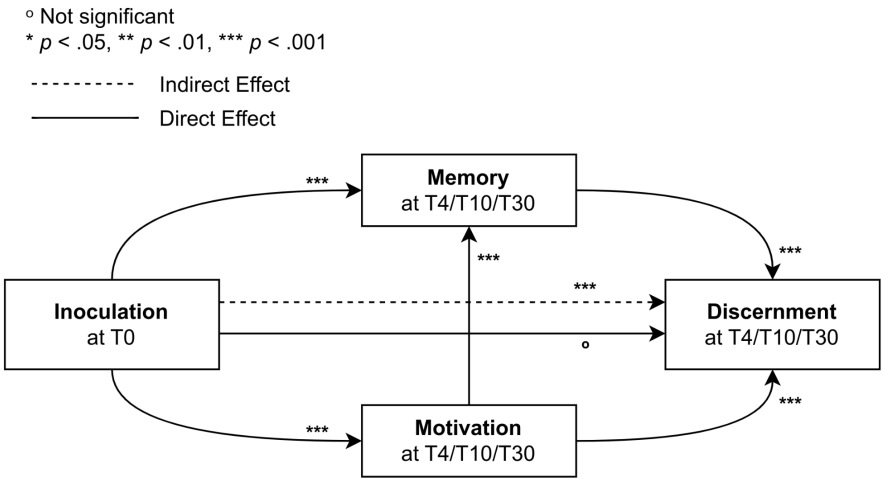

Figure S11. The memory-motivation model of inoculation in Study 4 (N = 3,066).

S12 Table

Table S12

*Memory-Motivation Model Estimates in Study 4 (*N = *3,066)*

Effect	*z*	*p*	β	95% CI		*SE*
				LL	*UL*	
Indirect						
Inoc.T0 ⇒ Memory.T4/T10/T30 ⇒ Discernment.T4/T10/T30	**7.638**	**< .001**	**0.197**	**0.147**	**0.248**	**0.026**
Inoc.T0 ⇒ Motivation.T4/T10/T30 ⇒ Discernment.T4/T10/T30	**3.136**	**.002**	**0.017**	**0.006**	**0.028**	**0.005**
Inoc.T0 ⇒ Motivation.T4/T10/T30 ⇒ Memory.T4/T10/T30 ⇒ Discernment.T4/T10/T30	**2.576**	**.010**	**0.001**	**0.000**	**0.002**	**0.001**
Component						
Inoc.T0 ⇒ Memory.T4/T10/T30	**39.974**	**< .001**	**1.167**	**1.110**	**1.224**	**0.029**
Memory.T4/T10/T30 ⇒ Discernment.T4/T10/T30	**7.782**	**< .001**	**0.169**	**0.127**	**0.212**	**0.022**
Inoc.T0 ⇒ Motivation.T4/T10/T30	**3.420**	**< .001**	**0.123**	**0.053**	**0.194**	**0.036**
Motivation.T4/T10/T30 ⇒ Discernment.T4/T10/T30	**7.853**	**< .001**	**0.138**	**0.104**	**0.173**	**0.018**
Motivation.T4/T10/T30 ⇒ Memory.T4/T10/T30	**4.531**	**< .001**	**0.066**	**0.038**	**0.095**	**0.015**
Direct						
Inoc.T0 ⇒ Discernment.T4/T10/T30	1.073	.283	0.047	-0.038	0.131	0.043
Total						
Inoc.T0 ⇒ Discernment.T4/T10/T30	**7.322**	**< .001**	**0.262**	**0.192**	**0.333**	**0.036**

S13 Analysis

Table for Analysis S13

*Memory-Motivation Model Estimates in Study 5 (*N *= 2,220)*

Effect	*z*	*p*	β	95% CI		*SE*
				LL	*UL*	
Indirect						
BoosterA.T10 ⇒ Motivation.T30 ⇒ Discernment.T30	1.149	.251	0.009	-0.006	0.024	0.008
Inoc2.T10 ⇒ Motivation.T30 ⇒ Discernment.T30	0.835	.403	0.006	-0.008	0.020	0.007
Inoc2.T10 ⇒ Memory.T30 ⇒ Discernment.T30	**5.567**	**< .001**	**0.074**	**0.048**	**0.099**	**0.013**
BoosterB.T10 ⇒ Memory.T30 ⇒ Discernment.T30	**4.883**	**< .001**	**0.064**	**0.038**	**0.089**	**0.013**
Inoc1.T0 ⇒ Motivation.T0 ⇒ Motivation.T30 ⇒ Discernment.T30	**2.345**	**.019**	**0.011**	**0.002**	**0.020**	**0.005**
Inoc1.T0 ⇒ Memory.T0 ⇒ Memory.T30 ⇒ Discernment.T30	**10.497**	**< .001**	**0.228**	**0.186**	**0.271**	**0.022**
Inoc1.T0 ⇒ Motivation.T0 ⇒ Memory.T0 ⇒ Memory.T30 ⇒ Discernment.T30	**2.129**	**.033**	**0.001**	**0.000**	**0.003**	**0.001**
Component						
BoosterA.T10 ⇒ Motivation.T30	1.162	.245	0.056	-0.039	0.152	0.049
Motivation.T30 ⇒ Discernment.T30	**7.764**	**< .001**	**0.156**	**0.117**	**0.196**	**0.020**
Inoc2.T10 ⇒ Motivation.T30	0.840	.401	0.039	-0.052	0.129	0.046
Inoc2.T10 ⇒ Memory.T30	**6.316**	**< .001**	**0.284**	**0.196**	**0.372**	**0.045**
Memory.T30 ⇒ Discernment.T30	**11.787**	**< .001**	**0.259**	**0.216**	**0.302**	**0.022**
BoosterB.T10 ⇒ Memory.T30	**5.365**	**< .001**	**0.245**	**0.156**	**0.335**	**0.046**
Inoc1.T0 ⇒ Motivation.T0	**2.471**	**.013**	**0.140**	**0.029**	**0.250**	**0.056**
Motivation.T0 ⇒ Motivation.T30	**26.356**	**< .001**	**0.488**	**0.452**	**0.525**	**0.019**
Inoc1.T0 ⇒ Memory.T0	**40.009**	**< .001**	**1.718**	**1.634**	**1.802**	**0.043**
Memory.T0 ⇒ Memory.T30	**28.238**	**< .001**	**0.513**	**0.477**	**0.549**	**0.018**
Motivation.T0 ⇒ Memory.T0	**4.546**	**< .001**	**0.073**	**0.042**	**0.105**	**0.016**
Direct						
BoosterA.T10 ⇒ Discernment.T30	0.017	.986	0.001	-0.124	0.126	0.064
Inoc2.T10 ⇒ Discernment.T30	-1.095	.274	-0.068	-0.189	0.054	0.062
BoosterB.T10 ⇒ Discernment.T30	**2.002**	**.045**	**0.126**	**0.003**	**0.248**	**0.063**
Inoc1.T0 ⇒ Discernment.T30	-0.652	.515	-0.045	-0.180	0.090	0.069
Total						
BoosterA.T10 ⇒ Discernment.T30	0.416	.677	0.028	-0.103	0.159	0.067
Inoc2.T10 ⇒ Discernment.T30	0.297	.766	0.019	-0.107	0.146	0.065
BoosterB.T10 ⇒ Discernment.T30	**3.179**	**.001**	**0.208**	**0.080**	**0.336**	**0.065**
Inoc1.T0 ⇒ Discernment.T30	**3.302**	**< .001**	**0.228**	**0.093**	**0.364**	**0.069**

We found evidence for partial mediation at T0, with memory, $b = 0.22$, $t(2216) = 13.24$, $p < .001$, $\beta = 0.351$, 95% CI [0.299, 0.403], and motivation, $b = 0.08$, $t(2216) = 3.89$, $p < .001$, $\beta = 0.079$, 95% CI [0.039, 0.118], having an effect on manipulativeness discernment, but meanwhile keeping intact a direct effect of inoculation, $b = 0.32$, $t(2216) = 3.13$, $p = .002$, $\beta = 0.220$, 95% CI [0.082, 0.358]. At T30 we found full mediation, with inoculation no longer being significant directly, $b = 0.05$, $t(2216) = 0.526$, $p = .599$, $\beta = 0.031$, 95% CI [-0.085, 0.148], but memory, $b = 0.17$, $t(2216) = 11.58$, $p < .001$, $\beta = 0.249$, 95% CI [0.215, 0.303], and motivation, $b = 0.16$, $t(2216) = 7.77$, $p < .001$, $\beta = 0.158$, 95% CI [0.118, 0.198], having a remaining influence, whilst inoculation directly influenced memory, $b = 2.50$, $t(2217) = 22.11$, $p < .001$, $\beta = 1.133$, 95% CI [1.032, 1.233], and motivation, $b = 0.28$, $t(2217) = 3.44$, $p < .001$, $\beta = 0.194$, 95% CI [0.084, 0.305]. See Figure 3 for an overview of the inoculation effect for each memory category (Panel E) and a bar graph of the memory scores (Panel F) for each time point in Study 5.

The data in this study allowed us to go one step further in our SEM analyses than Study 1 and Study 2 allowed, as due to the immediate posttest *and* a second posttest at a later date, we now have longitudinal data for the mapping of paths between time points. To test the memory-motivation model in its entirety, we therefore created an SEM model that includes inoculation at T0, memory at T0 *and* T30, motivation at T0 *and* T30, and the booster interventions at T10. See Figure 4 for a simplified visual representation of the memory-motivation SEM model at T30. As can be seen from the estimates provided in the estimates table and the visual summary (Figure 4), the video inoculation effects work indirectly via memory and motivation, with the largest effects for memory, both for inoculation on memory, and for memory on manipulativeness discernment performance. The role of motivation seems to be particularly important for the T0 memory formation and relatedly, the motivation

booster presented at T10 did not provide any additional benefits for performance or motivation at T30. Meanwhile, the memory booster presented at T10 successfully managed to boost the inoculation effect at T30 by boosting the inoculation memory, which in turn was the best predictor for the effect retention at T30. These findings are in line with the memory-motivation model of inoculation.

S14 Analysis

Mechanisms of Inoculation

Table for Analysis S14

Dominance Analysis in Study 5, at T30, N = *2,220*

Variable	Dominance
Memory	41%
Motivational Threat	27%
Fear	10%
Apprehensive Threat	9%
Issue Involvement	8%
Issue Talk	2%
Issue Accessibility	2%
Self-Reported Remembrance	0%

We performed a dominance analysis to investigate the most dominant predictors of the inoculation effect at T30, and found that memory (41% dominance) and motivational threat (27%) were the best predictors of inoculation longevity. To further demonstrate the role of memory in inoculation, we looked at the effect of the inoculation intervention for people who have a good memory of the intervention at T30, and found a large effect, $M_{diff} = 1.01$, $t(896) = 10.76$, $p_{tukey} < .001$, $d = 0.728$, 95% CI [0.591, 0.865], for manipulativeness at 29 days, while only a small effect was found for those with an average memory of the intervention, $M_{diff} = 0.31$, $t(1471) = 3.68$, $p_{tukey} < .001$, $d = 0.220$, 95% CI [0.102, 0.337].

S15 Figure

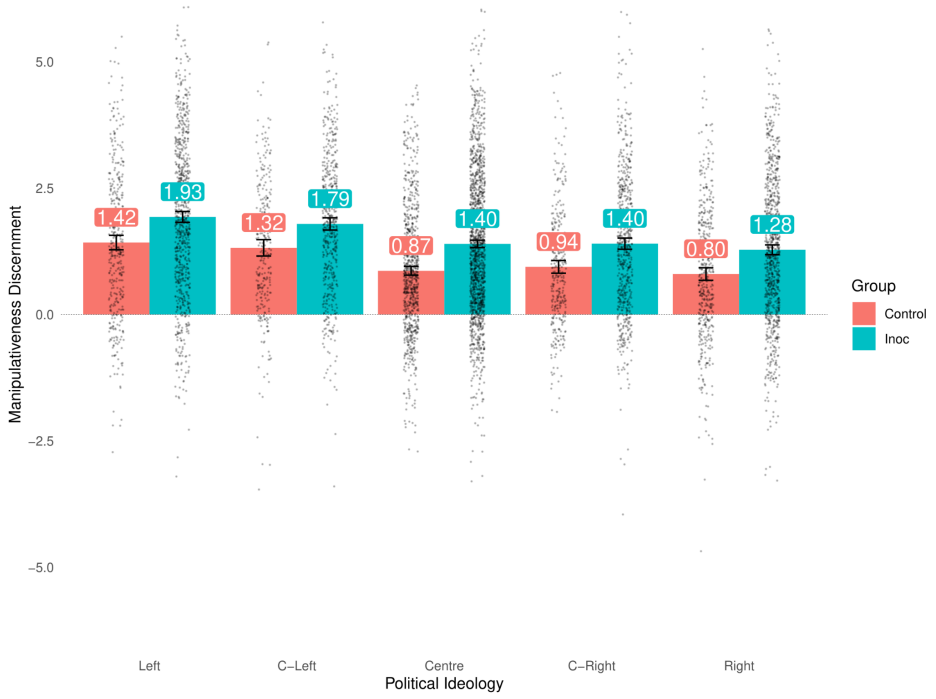

Figure S15. Inoculation effect across political leaning in the combined sample ($N_{datapoints}$ = 6,518). Error bars represent the 95% confidence interval.

S16 Figure

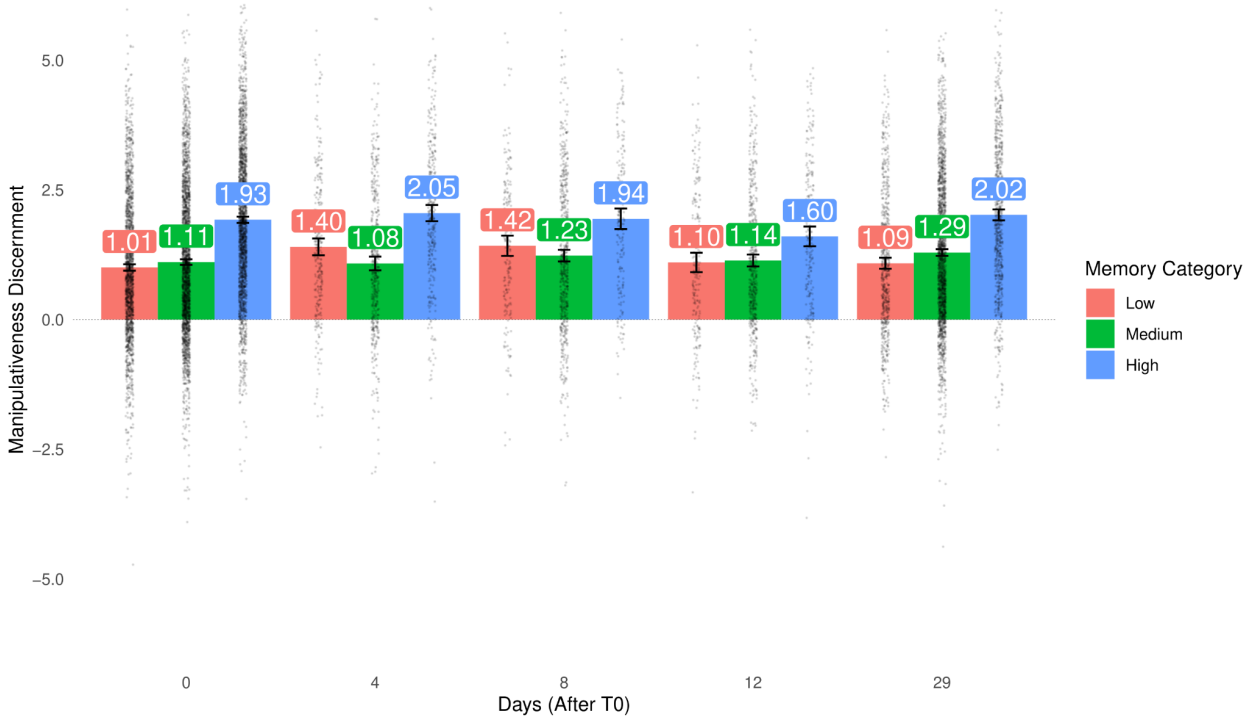

Figure S16. The inoculation effect separated by inoculation memory recall and time after the intervention (in days) in the combined sample ($N_{\text{datapoints}}$ = 12,791).

S17 Analysis

Concept Mapping

As a final exploratory analysis we used a concept mapping question as a qualitative analysis of participants' memory recall. Participants were asked to write down concepts they remembered from the original video in an open box, before they received directed memory questions. We used natural language processing packages in R (*SnowballC*, Bouchet-Valat, 2020; *tm*, Theußl et al., 2012; *wordcloud*, Fellows et al., 2018) to clean the text data and mapped the data by counting the frequency of the words entered. The results of this question show that the inoculated groups have a distinct memory network at T30, showing that even before prompting participants with direct memory questions, they were able to recall key concepts of the inoculation intervention (e.g., "emotional", "manipulative", "language"). The control group participants recalled concepts from the control video (e.g., "eye", "macular", "degeneration").

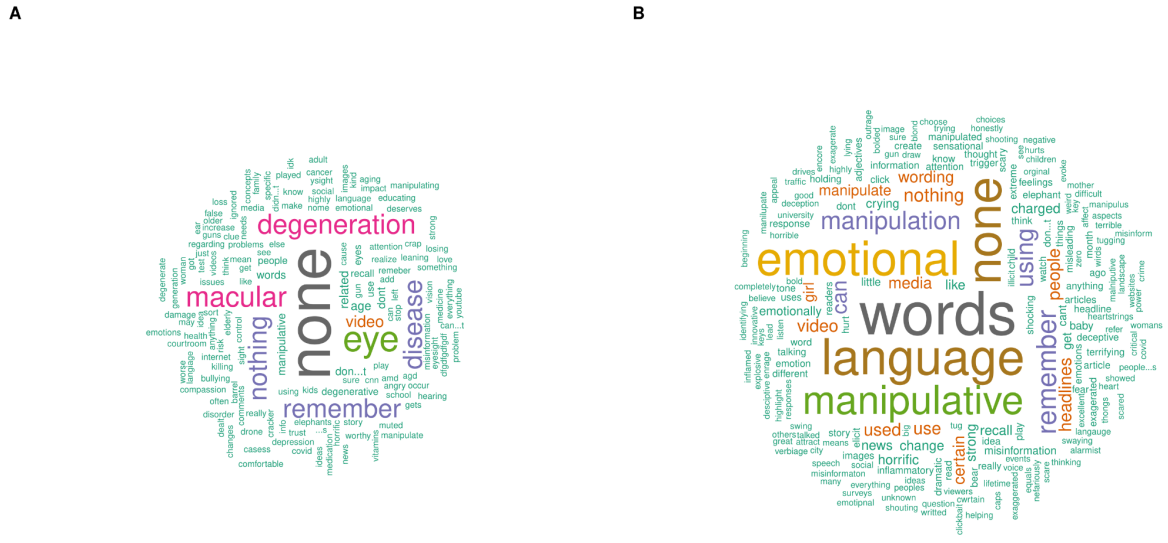

Figure for Analysis S17. Word cloud of memory recall question responses at T30 for participants in the control group (Panel A) and in the inoculation group that received a memory booster (Panel B). Larger words represent a higher occurrence of the word. $N = 626$.

S18 Discussion

In Maertens et al. (2020), we found that text-based, passive, therapeutic, issue-specific inoculation interventions are effective, replicating the results of previous research (van der Linden et al., 2017; Cook et al., 2017), and can remain fully effective for at least one week, while the effect of a consensus-message-based treatment without inoculation does not. This indicates that even when inoculation is passive, a strong initial effect can be established. In **Study 1**, we expanded on this study to test the memory-motivation model using objective and subjective measures of the model's components, and included longer timeframes (T30 *Mdn* = 29 days). The effect after week was in line with the meta-analytic effect size of inoculation (d_{Study2} = 0.46 $d_{MetaAnalysis}$ = 0.43; Banas & Rains, 2010), and reduced by 39% after one month (d_{0days} = 0.46, d_{8days} = 0.38, d_{29days} = 0.28). These studies indicate that the inoculation effect remains intact for at least 1 month without any booster intervention with text-based inoculation messages on climate change, but that light decay takes place. This is in line with findings by a recent study by Ivanov et al. (2018), who reported significant decay after 6 weeks but not after 4 weeks, as well as the meta-analysis by Banas and Rains (2010), that reported decay to typically start to take place after 2 weeks. Meanwhile, we found the first evidence that a booster intervention—in this case a repetition of the original inoculation message—can boost the effect to prevent any decay from happening, in particular by boosting memory of the intervention (d_{0days} = 0.46, $d_{29days,NoBoost}$ = 0.28, $d_{29days,Boost}$ = 0.48). This finding is in line with Ivanov et al. (2018) who found a repeated inoculation message to be effective at lengthening the inoculation effect. Investigating the underlying mechanisms showed that motivational threat and issue involvement are predictors of the outcome variable, but that objective memory of the inoculation intervention was the strongest predictor of the inoculation effect over time. We also found that motivation had a positive

influence on inoculation memory, in line with the predictions of the memory-motivation model. However, there was no evidence for an effect of the intervention on motivation. As we also found that motivation directly influenced the outcome variable, an important question for future research is whether we can improve our inoculation interventions in order to elicit more motivation (Compton, 2021; Compton et al., 2022).

In Maertens et al. (2021), we investigated the same questions in a gamified, active, broad, prophylactic, inoculation paradigm. We found that repeated testing can serve as an inoculation booster, allowing for the inoculation to remain fully intact for up to 3 months, potentially due to memory strengthening that comes with testing. However, when not testing repeatedly, the effect was no longer significant after 2 months. The study also showed that these findings were not due to item or item ratio effects. In **Study 2**, we expanded on this study by removing the repeated testing confound and splitting the sample in groups per posttest time point, and adding the same set of questions about memory and motivation. we replicated the main effect of the *Bad News* game, with a larger effect than the typical effect size found in inoculation interventions (d_{Study4} = 0.78, $d_{\text{MetaAnalysis}}$ = 0.43; Banas & Rains, 2010), but also found that when an immediate posttest is not included, the inoculation effect is no longer significant after 9 days, a faster effect decay than anticipated. When looking into the mechanisms, memory arises as the most dominant predictor, followed by motivational threat. Meanwhile, those high in memory did show an inoculation effect at 9 days and at 29 days, and a new and short version of the *Bad News* presented after 9 days worked well as a memory booster—although not enough to show a general inoculation effect after 29 days. A test of the memory-motivation model revealed new insights that are different from the climate change paradigm. In this paradigm, only memory was a significant predictor of the outcome measure. Motivation did not have an influence on the outcome measure,

nor did the inoculation intervention have an effect on motivation. However, motivation on its own did have a significant effect on memory formation at T0. In line with the findings from the climate change paradigm, we found evidence for a full mediation of the inoculation effect through memory. These findings provide a second evidence base for the memory-motivation model, and evokes similar questions about the role of motivation in inoculation paradigms (Compton, 2021; Compton et al., 2022): is it less important than previously thought, or did we fail to capture or move it appropriately?

In **Study 3**, we explored the same questions in a scalable, video-based, passive, broad, prophylactic form of inoculation. The study shows that both a short and long inoculation video can serve as an effective inoculation intervention, and that they are similarly effective, with an effect size similar to the meta-analytic effect size of inoculation interventions ($d_{\text{LongVideo}} = 0.53$, $d_{\text{ShortVideo}} = 0.44$, $d_{\text{MetaAnalysis}} = 0.43$; Banas & Rains, 2010). When no immediate posttest is included, we can see a quick inoculation effect decay after the intervention in the course of the first two weeks, paralleled by a similar decay curve for memory. However, when an immediate posttest is implemented, the video inoculation effect can remain effective for up to at least 29 days, with limited decay ($d_{\text{Exp3,0days}} = 0.30$, $d_{\text{Exp3,29days}} = 0.23$). When investigating the mechanisms, memory was again the most dominant predictor of the inoculation outcome. In addition, to disentangle the mechanisms further and explore the potential of booster interventions, we tested three booster videos, a repetition of the original video, a threat-focused booster, and a technique memory booster. Both the memory booster video and the repeated original inoculation video served successfully to boost inoculation memory, while the threat booster video did not impact memory performance and failed to increase motivation. Similar to Study 1 and Study 2, both memory and motivation were significant predictors of the inoculation effect. However, this time

the original intervention did have a direct positive impact on motivation as well, which could mean that different types of inoculation interventions work through different mechanisms. Different from the previous two tests of the memory-motivation model, we now were able to disentangle T0 and T30 effects, and found that the intervention successfully improved memory *and* motivation at T0, and that motivation improved memory at T0, which in turn increased the inoculation effect at T30 through memory at T30, in line with the memory-motivation model predictions.

The studies in this paper represent a first look at developing a memory paradigm for inoculation. Many of the choices made in this work, including the choice of measures for memory and motivation, the causal ordering of the SEM models, and the used inoculation interventions, mean that the validity of the model needs to be thoroughly and independently tested before it can become the new standard. Nevertheless, taken together, these first direct measures of the mechanisms behind the longevity of the inoculation effect, explored across 5 studies (9 experiments) and 3 paradigms, suggest that a memory-motivation theory is a new feasible paradigm to consider and explore further. It also helps to formulate a data-driven answer to the main research question presented at the beginning of the paper: *"Can we explain the resistance to persuasion decay process using a memory-motivation theory of inoculation decay?"*. Not only did we find evidence for a role of memory in the explanation of the inoculation effects, the data suggests that it presents a better explanation of the longevity of the effects than the traditional account based on threat and motivation (Compton, 2013; McGuire, 1961a, 1961b, 1962, 1964, 1973; McGuire & Papageorgis, 1961, 1962). We do not find evidence for the need for an endured sense of threat for the inoculated persons to defend themselves against misinformation attacks at later time points, although we do find some evidence that

motivation helps and that it could improve how much people learned from the inoculation intervention. In other words, these findings provide crucial new insights into resistance to persuasion. While threat and motivation have often been mentioned as a crucial aspect of inoculation, and proposed to be elicited as part of the "affective forewarning" in inoculation messages, literature studies show that the original authors and the first generation of inoculation scholars often did not manipulate nor measure it (Compton, 2013, 2021; Compton et al., 2022), although recently more research has been done that establishes its role (Banas & Richards, 2017; Ivanov, 2012; Richards & Banas, 2018). In the text-based and gamified interventions we did not manage to manipulate motivational threat through our inoculation intervention, and therefore might have missed a crucial aspect of what constitutes an inoculation intervention, but we did manage to do so in the video-based intervention. All studies in this paper are congruent however in their finding that motivation can have a role, but that the role of memory is typically larger. Therefore, the data in this work provides a strong basis for an alternative theory positing that inoculation can be modeled as memory networks and trained accordingly (Pfau et al., 2005), opening up new possibilities by implementing insights from cognitive psychology related to learning, memory strengthening, and forgetting (Collins & Loftus, 1975; Ebbinghaus, 1885; Frankland & Bontempi, 2005; Hardt et al., 2013; Murre & Dros, 2015; Murty & Dickerson, 2016; Smith, 1998). The model proposed in the Introduction of this paper provides an example of such a model. Although promising, it has to be taken into account that this is a primitive first version of the model and needs to be replicated and tested in different forms in future research. It is for example possible that there are important aspects of inoculation interventions that moderate the relationships between the variables in the model. Some interventions may for example work by manipulating motivational threat in a different way (e.g., some inoculation

interventions may work via memory, others via motivation, and others by manipulating both). There are also many alternative SEM models that could theoretically be viable instead of the currently used one, for example with a different causal ordering (e.g., it is possible that memory at T0 influences motivation at T0 instead of the other way around). Future research will need to disentangle these mechanisms and effects further.

S19 Discussion

Not only does the new memory-based approach present theoretical relevance, it also presents a practical benefit for intervention developers and policy makers, as we can now start to form an answer to the empirical question of this hypothesis: *"What is the shape of the inoculation effect decay curve and can booster interventions remediate the decay?"*. Plotting the data from all three paradigms together, we do indeed find a decay curve that resembles an exponential function, what one would expect when looking at an Ebbinghaus forgetting curve (Ebbinghaus, 1885; Murre & Dros, 2015). The below figure depicts the inoculation effect curve over time for each of the interventions in the first column, taken from Study 1, Study 2, and Study 3, and their respective memory forgetting curve in the second column. For the plot of Study 3 we combined the datasets of the three experiments, taking the control group and single inoculation group from Experiment 1, and grouping all second posttests from the inoculation groups from Experiments 2–3 as booster groups due to repeated testing and the various booster interventions. To simplify the plot the time points were grouped based on the median days after T0 (i.e., T10 = 9 days, T20 = 29 days). As can be seen, the decay curves of the inoculation effects are remarkably similar to the forgetting curves of the inoculation memory. When taking into account that the memory measures were newly created for each study and had not been validated before, and that each of the inoculation interventions had both very different modes of presentation (*text-based*, *gamified*, *video-based*) as well as very different outcome measures (*perceived scientific consensus*, *reliability rating of fake news*, and *discernment of manipulativeness*), this congruence is a promising first step towards unveiling the true decay curve of inoculation effects. In panel A and panel B, we can see that there is a strong inoculation effect for text-based inoculation as well as a strong memory, but that they, in a similar fashion,

decay over time in what closely resembles an exponential curve, with some memory and some inoculation effect remaining after 29 days. When boosted almost the full inoculation effect together with the full inoculation memory remains. A very similar pattern can be found for the gamified intervention in panel C and panel D. Despite the effect no longer being significant after 9 days, we do see the congruence between the inoculation effect and the memory forgetting curve. Finally, in the video-based intervention, as seen in panel E and F, we again find that the memory forgetting curve, as well as the booster curve, is closely mirroring the inoculation effect pattern. In addition, we find that after 1–2 weeks, the effect is no longer significant, but when boosted, the effect decays much slower than it decayed initially, and the same can be found for the inoculation memory. This shows what we would expect from a forgetting curve, namely, that once the memory is strengthened, the decay afterwards is slower (Ebbinghaus, 1885; Murre & Dros, 2015). The contrasts between the effectiveness of the interventions, and whether they are still significant after 1–2 weeks or not, could be explained by differing decay curves as well as by differing initial effectiveness. The results depicted here indicate that there is some uniformity in the decay curves across interventions, but also some variety in the rate of the decay. Whether this is a side effect of the different outcome measures or the small variations in the memory questions, or due to actual differences in effects or memory strength, will need to be explored in future research.

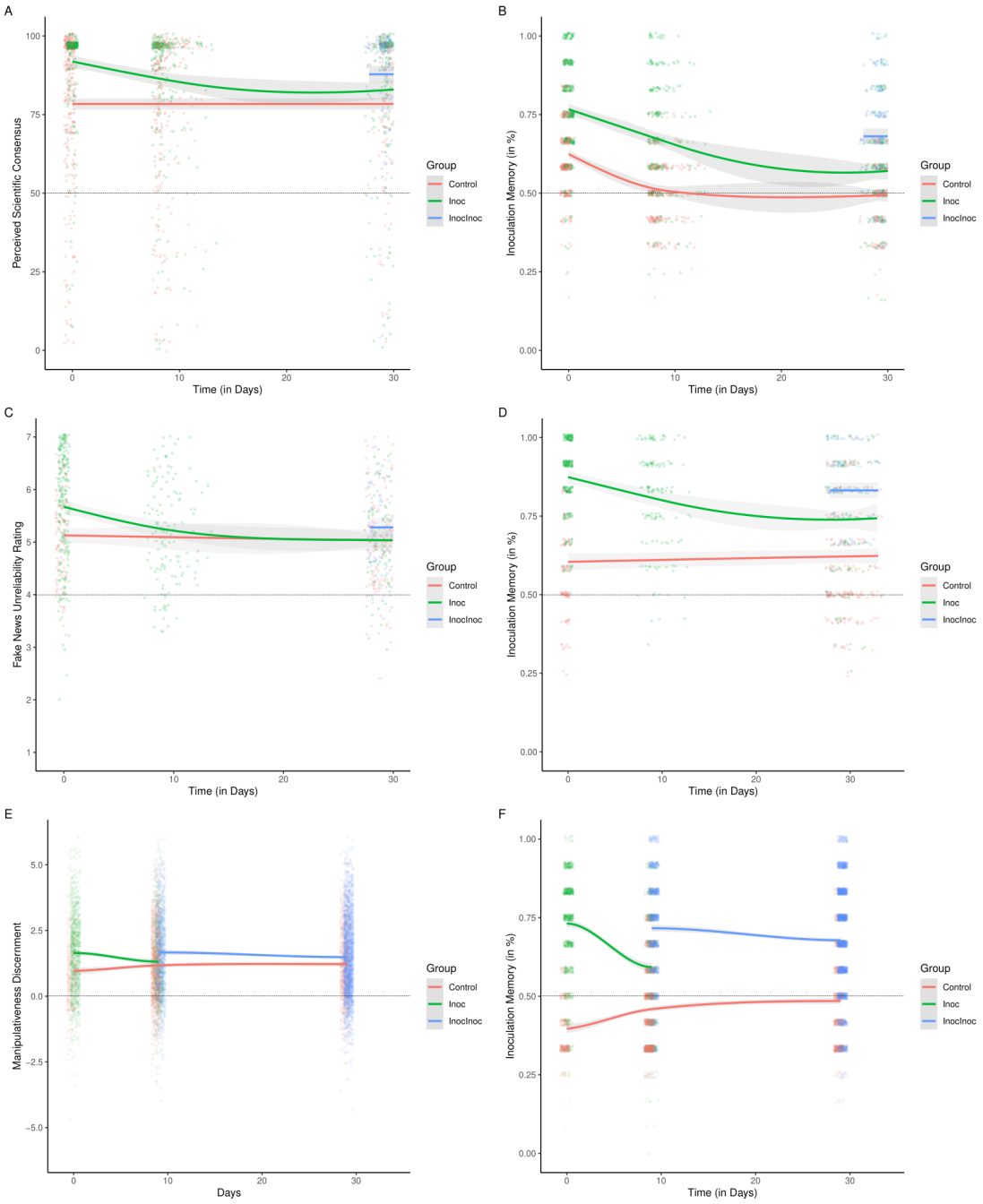

Figure for Discussion S19. Line graphs of the inoculation effects (first column) and the objective inoculation memory (second columns) for each of the three intervention paradigms (A, B: text-based inoculation, $N_{datapoints}$ = 5,475; C, D: gamified inoculation, $N_{datapoints}$ = 2,022; E, F: video-based inoculation, $N_{datapoints}$ = 7,505). Inoc = single inoculation group. InocInoc = boosted inoculation group. Error bands represent 95% confidence intervals.

S20 Discussion

The study of the long-term effectiveness of inoculation effects should not be limited to the decay of resistance to persuasion, as Hill et al. (2013, p. 542) stressed:

> *"Decay of the effects of political persuasion is too important to be ignored, as it routinely has been. It is a basic feature of mass persuasion in most if not all political contexts. Scholars should therefore try harder to build measurement of decay into their research designs."*

We would go further than this statement and stress that during the literature review for this paper, it became clear that important theories are often accepted with limited or no longitudinal research. This is not surprising: longitudinal research, especially with multiple timepoints and long-interval follow-ups, is both costly and difficult to run. A recent review of framing research highlights that long-term effects are often not measured, and that most longitudinal studies do not look beyond two weeks (Lecheler & de Vreese, 2016). Similarly, in a meta-analysis of behavioural intervention studies regarding action on climate change, Nisa et al. (2019, p. 9) stressed that they *"could not provide a definitive answer on persistent effects per specific type of intervention due to the small number of papers that reported follow-up effects"*. Within this work we developed and tested various formats of different longitudinal designs for each inoculation paradigm, with and without booster treatments. We looked beyond the standard single-treatment study and mapped long-term cognitive changes, thereby providing valuable insights relevant for the wider field of psychology, and inviting other researchers to consider a longitudinal design in their future studies as well.

During this journey, three important methodological questions—that were previously unanswered for inoculation research—were explored: item effects, testing effects, and psychometric validity. In Roozenbeek et al. (2021), we looked at the potential confound of the inoculation effect interpretations caused by the use of a pretest and the researcher's choice of items as the dependent variable for misinformation reliability ratings. The research showed that there is no evidence for an effect caused by the implementation of a pretest, but that the specific choice of items has an influence on the effect size found. In this case the effect remained significant despite the change in items, but recent research by Roozenbeek, Traberg, et al. (2022) replicated the item effect and found that the effect can even change in direction when items are different for the pre and post tests. In other words, researchers have to be careful when choosing their items, and it stresses the need to work towards standardized item sets.

Despite there being no evidence for pretesting effects, the other studies in this work made clear that there are two other testing effects that we do need to take into account: the immediate posttest and repeated posttests. The small difference in design between Maertens et al. (2021; with immediate posttest) and **Study 2** (without immediate posttest), and between **Study 3** (without immediate posttest) and **Studies 4–5** (with immediate posttest), demonstrated that the use of an immediate posttest potentially serves as an immediate memory booster. This is an important finding both for intervention implementation guidelines and for intervention evaluation science. It shows that an immediate posttest may not be advisable for evaluations of the long-term effectiveness evaluation of an intervention. While it could be argued that participants learn how to respond to particular items, we did not find evidence for this in **Studies 3–5**, where participants had to discern the manipulativeness of a random set of headlines from a larger pool of social media posts at each time point, with the possibility that items of the same

topic switch from manipulative to neutral between time points. Similar to the immediate posttest effect, the difference in design between Maertens et al. (2021), Experiment 1 (with immediate posttest *and* repeated posttests at multiple time points) and Maertens et al. (2021), Experiment 2 (with immediate posttest but *no* additional repeated posttests until the final time point), shows that repeating a posttest at multiple time points may serve as an additional booster on top of the immediate posttest. Also this finding fits into findings from the literature outside of the inoculation scholarship, in particular from cognitive psychology, with previous research finding similar learning effects by repeated testing (Karpicke & Roediger, 2008; Linton, 1975; Roediger & Karpicke, 2006a, 2006b). Combined, the immediate posttest and the repeated posttest effects indicate that one should ideally use a design that exposes each participant to a maximum of one posttest (e.g., with each participant or group of participants receiving the posttest at a different point in time after the intervention, similar to **Study 1**, **Study 2**, and **Study 3**). This finding also has a positive side—it indicates that if practitioners are implementing an intervention in the field, it may be useful to consider including a quiz or a feedback mechanism at the end of the intervention to consolidate participants' knowledge, and repeatedly follow-up with the participants of the intervention over time, to further strengthen and increase the longevity of the effects.

S21 Discussion

Although 97% of climate scientists agree that human-caused global warming is happening, misinformation sowing doubt about the consensus influences society (Lewandowsky et al., 2015, 2019). Evidence suggests that debiasing public perception of the scientific consensus can lead to more support for collective action (van der Linden et al., 2015, 2019), but that this can be thwarted by misinformation (Cook et al., 2017; van der Linden et al., 2017). In the seminal study by van der Linden et al. (2017), participants were exposed to a consensus message (a pie chart depicting the scientific consensus; van der Linden et al., 2014), an inoculation message (warning people not to be convinced by false petitions, and how this particular petition is flawed), and a misinformation message (the misleading *Oregon Petition*; Readfearn, 2016). They found that communicating the actual scientific consensus helps, as it helped to debias the *perceived scientific consensus* (i.e., people correct their belief about the scientific consensus), but that misinformation can neutralize all benefits. They also found that an inoculation message was able to protect this benefit by significantly reducing the impact of the misinformation message. The outcome variable measured is the *perceived scientific consensus on human-caused global warming*, on a slider scale from 0%–100%. See the figures below for the complete consensus, misinformation message, and inoculation messages.

In this paradigm, the inoculation message is passive, issue-specific, and therapeutic. Passive, as participants read the messages without interacting with them (i.e., the experimenter provides the counter-arguments for the participant to read and remember). Specific, as it targets only the perceived scientific consensus, and presents a tailored inoculation message that includes a weakened version of the particular misinformation message (i.e., the message is focused on countering a specific piece of climate misinformation). And therapeutic, as on average people

have (inaccurate) pre-existing attitudes regarding the scientific consensus on human-caused global warming (van der Linden et al., 2017).

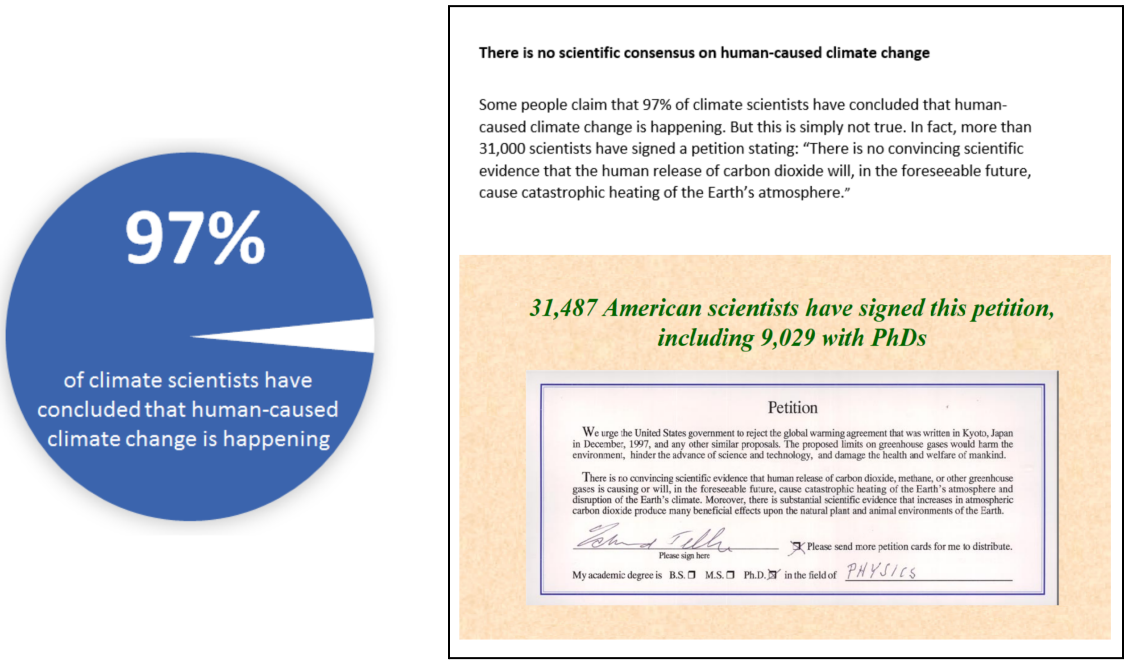

Figure 1 for Discussion S21. Consensus message (left) and misinformation message (right).

Nearly all climate scientists—97%—have concluded that human-caused climate change is happening. Some politically-motivated groups use misleading tactics to try to convince the public that there is a lot of disagreement among scientists. However, scientific research has found that among climate scientists "there is virtually no disagreement that humans are causing climate change".

One such politically motivated group claims to have collected signatures from over 31,000 "scientists" (including over 9,000 who hold Ph.D.'s) on a petition urging the U.S. government to reject any limits on greenhouse gas emissions because; "there is no convincing scientific evidence that human release of carbon dioxide, methane or other greenhouse gases is causing or will, in the foreseeable future, cause catastrophic heating of the Earth's atmosphere and disruption of Earth's climate." They claim that these signatures prove that there is no scientific consensus on human-caused climate change.

This may sound convincing at first. However, several independent investigations have concluded that the "Oregon Petition" is extremely misleading. For instance, many of the signatures on the petition are fake (for example, past signatories have included the long-deceased Charles Darwin, members of the Spice Girls, and fictional characters from Star Wars). Also, although 31,000 may seem like a large number, it actually represents less than 0.3% of all US science graduates (a tiny fraction). Further, nearly all of the legitimate signers have no expertise in climate science at all. In fact, less than 1% of those who signed the petition claim to have any background in Climate or Atmospheric Science. Simply calling yourself a "scientist" does not make someone an expert in climate science. By contrast, 97% of actual climate scientists, agree that human-caused climate change is happening.

Figure 2 for Discussion S21. The inoculation message used in the climate change studies.

S22 Discussion

In this inoculation intervention—which has already been played by over two million people and implemented in some school curricula in the United Kingdom and in Canada—the goal is to gain as many followers as possible by choosing and spreading misinformation messages while at the same time keeping your credibility sufficiently high. It includes the warning component of inoculation by showing the detrimental consequences misinformation can have (i.e., consequences of in-game actions) on topics that feel familiar (e.g., someone who gets fired from their job because of false accusations). This elicits a sense of threat and motivation to resist similar persuasion attempts (i.e., the game warns people, and this motivates them to protect themselves against misinformation).

Unique is that people are exposed to "weakened doses" of broader misinformation *techniques* rather than specific issues, making it broad-spectrum. In other words, if people are inoculated against an entire technique (e.g., conspiracy theorisation), they should gain resistance to different variants of that technique (e.g., different conspiracy theories). It uses a framework of six influential misinformation techniques known as *DEPICT*: ***D****iscrediting opponents* (e.g., creating a cloud of doubt around your opponent)*, appealing to* ***E****motion* (e.g., the use of outrage or highly emotive language to manipulate people), ***P****olarizing audiences* (e.g., using hot-button issues to drive a wedge between two groups), ***I****mpersonation* (e.g., misusing the identity of politicians, experts, or celebrities online), *floating* ***C****onspiracy theories* (e.g., casting doubt on mainstream narratives by providing an attractive story in which a small sinister group of people is responsible for doing harm to many), and ***T****rolling* (e.g., eliciting reactions from people by provoking them online). See Roozenbeek and van der Linden (2019) and van der Linden and Roozenbeek (2020) for a detailed background and overview of these techniques. The active

thinking, content creation, and choices people make for each misinformation technique serves as the cognitive component of the inoculation (i.e., through engaging with the weakened doses of misinformation, people generate preemptive refutations). This intervention serves as a broad-spectrum, active, and mainly prophylactic intervention. Broad, as it protects against a wide spectrum of different misinformation techniques (rather than specific misinformation messages). Active, as the intervention provides an experiential environment with interactive content. And mainly prophylactic, as the protection is aimed towards new information not seen before. See the figure below for an impression. Although we cannot know the players' prior level of exposure to the misinformation tactics when they enter the game, the content of the game is fictional and therefore it can be assumed that there was no prior exposure to the specific content presented. However, participants might have seen or believed some misinformation using these techniques before (e.g., conspiracy theories), and therefore it could be argued that it may also function in parallel as a therapeutic intervention.

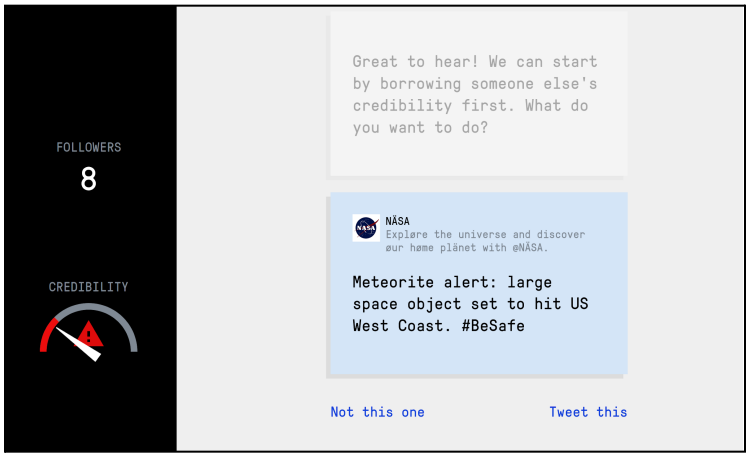

Figure 1 for Discussion S22. Screenshot of the *Bad News* game environment.

It has been shown that *Bad News* is effective at making people detect misinformation (Roozenbeek, Traberg, et al., 2022; Roozenbeek & van der Linden, 2019)—replicated across

cultures (Roozenbeek, van der Linden, et al., 2020)—and at accurately increasing confidence in doing so (Basol et al., 2020). Resistance is measured by letting participants judge the reliability of real news items (that are neutral, non-misleading, and non-manipulative) and fake news items (that use one of the DEPICT techniques) on a 7-point Likert scale (see the figure below for an example), before and after the Bad News intervention. Participants rate the fake news items as less reliable after the intervention, both compared to the pretest and compared to the control group (Roozenbeek & van der Linden, 2019). However, as with the climate change paradigm, the long-term effectiveness of this paradigm has not been tested.

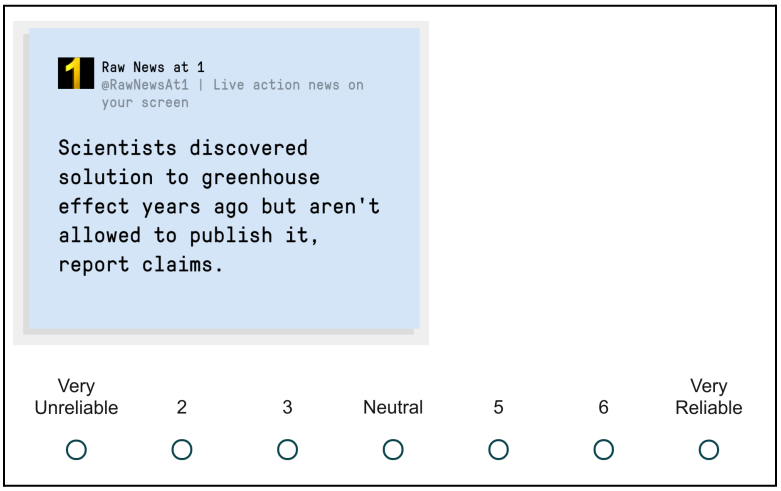

Figure for Discussion S22. Example test item using the conspiracy technique.

S23 Discussion

In a research project between Google Jigsaw, the University of Cambridge, and the University of Bristol, inoculation researchers designed and tested five short videos (~90 seconds), each of which "inoculates" viewers against a manipulation technique commonly encountered in online environments: emotional language (fearmongering), incoherence, false dichotomies, scapegoating, and ad hominem attacks. See https://inoculation.science/inoculation-videos/ for an overview of the inoculation videos. In a first series of large randomized controlled trials (N = 5,416), the videos proved highly effective at 1) improving participants' ability to identify manipulation techniques in social media content; 2) increasing their confidence in their ability to spot such techniques; 3) strengthening their ability to discern trustworthy from untrustworthy content; and 4) improving the quality of their sharing decisions (Roozenbeek, van der Linden, et al., 2022). The videos are currently being rolled out as educational advertisements, and have been watched by over 5 million people. See the figures below for a screenshot of the emotional language video and an example test item.

Figure 1 for Discussion S23. Screenshot of the emotional language inoculation video.

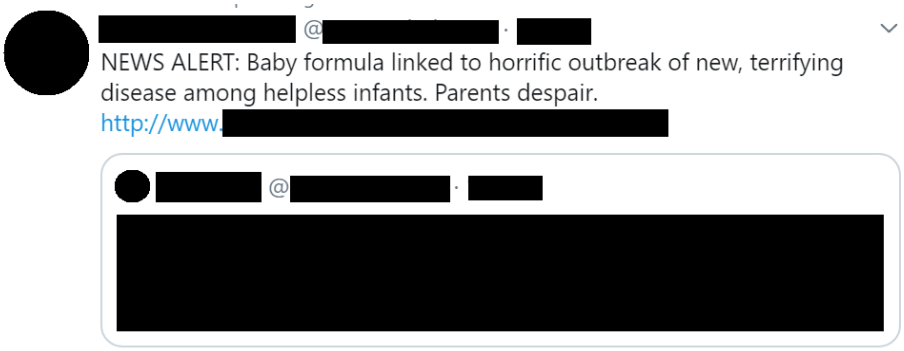

Figure 2 for Discussion S23. Example of a misleading social media item used in Studies 3–5.

In this paradigm, participants watch a short inoculation video and subsequently rate 10 out of 20 possible social media posts (each participant receives the same 10 topics, but within each topic they have to rate either a manipulative or a non-manipulative variant of the item pair) on a 1–7 scale (1—*strongly disagree*, 7—*strongly agree*), for each of the following dimensions: *Manipulativeness* ("This post is manipulative"), *Confidence* ("I am confident in my assessment of this post's manipulativeness"), *Trustworthiness* ("This post is trustworthy"), *Sharing Intention* ("I would share this post with people in my network"). In addition to the 50% chance per topic of seeing the manipulative or non-manipulative variant, 5/10 topics contained only content based on actual social media sources (for both the manipulative and non-manipulative variants), and the other five topics used only fictive items specifically created for this experiment (for both the manipulative and non-manipulative variants). It is therefore possible that there is an imbalance in manipulative compared to non-manipulative items presented, but the ratio of real compared to created items is always balanced. Subsequently, a discriminative ability index for manipulativeness, trustworthiness, and sharing is calculated by subtracting the average scores of neutral posts from the average scores for the manipulative posts. For the confidence measure, results for manipulative and neutral posts are reported separately.

The intervention can be seen as a broad-spectrum, passive, and mainly prophylactic intervention. Broad, as it focuses on a general technique (e.g., *emotional language*) and thus protects against a wider range of potential misinformation messages. Passive, as people watch a video without any possibility to interact. And mainly prophylactic, as it aims to protect people against messages and attacks they are not familiar with. Similar to the Bad News game intervention the content in the video is mostly fictional and therefore prior exposure should be limited, but some participants may be familiar with misinformation featuring the manipulative tactic (e.g., appeal to emotion). It therefore may function as both prophylactic and therapeutic inoculation.

S24 Table

Table S24

Preregistered Hypotheses of Study 1

#	Hypothesis	Evidence	Description
H1	Exposure to misinformation about climate change in the form of a false petition decreases the perceived scientific consensus (PSC) on global warming.	**YES *****	**The misinformation effect was significant.**
H2	Inoculated individuals do not negatively change their perceived scientific consensus (PSC) on global warming after exposure to a misinformation message in the form of a false petition.	**YES *****	**The inoculation effect was significant.**
H3	The inoculation effect described in H2 remains significant for at least 10 days (T10).	**YES *****	**The inoculation effect was still significant after 10 days.**
H4	The inoculation effect described in H2 is no longer significant after 30 days (T30).	**NO**	**The inoculation effect was still significant after 30 days and therefore more robust than hypothesized.**
H5	The inoculation effect described in H2 is still significant after 30 days (T30), when individuals are exposed to a second inoculation message after 10 days (T10).	**YES *****	**The boosted inoculation effect was significant after 30 days.**
H6	Groups exposed to a second inoculation message after 10 days (T10) show increased memory of the inoculation intervention after 30 days (T30) compared to those exposed to only one inoculation message.	**YES *****	**The booster intervention improved memory.**
H7	Groups exposed to a second inoculation message after 10 days (T10) show increased motivational threat after 30 days (T30) compared to those exposed to only one inoculation message.	**NO**	**The booster intervention did not increase motivation.**
H8	The inoculation effect [H8a] immediately after intervention (T0), [H8b] after 10 days (T10), and [H8c] after 30 days (T30) is influenced directly by memory and motivation, and indirectly by the inoculation intervention (mediated by memory and motivation).	**YES *****	**Across the time points, both the indirect inoculation effect and the direct effect of memory and motivation were significant.**

*** $p < .001$, ** $p < .01$, * $p < .05$, ° $p < .10$

S25 Table

Table S25

Preregistered Hypotheses of Study 2

#	Hypothesis	Evidence	Description
H1	People who complete a gamified inoculation intervention (Bad News) rate misleading social media posts as less reliable than people who complete a control task (Tetris).	**YES *****	**The inoculation effect was significant.**
H2	The inoculation effect described in H1 remains significant for at least 10 days (T10).	**MIXED ○**	**The inoculation effect after 10 days was not significant but trending in the predicted direction ($p < .10$).**
H3	The inoculation effect described in H1 is no longer significant after 30 days (T30).	**YES**	**The inoculation effect was no longer significant 30 days after the intervention.**
H4	The inoculation effect described in H1 is still significant after 30 days (T30), when individuals participate in a booster intervention after 10 days (T10).	**MIXED ○**	**The boosted inoculation effect after 30 days was not significant but trending in the predicted direction ($p < .10$).**
H5	People participating in a booster intervention after 10 days (T10) show increased memory of the inoculation intervention after 30 days (T30) compared to the control group.	**YES *****	**The booster significantly improved memory.**
H6	People participating in a booster intervention after 10 days (T10) show increased motivational threat after 30 days (T30) compared to the control group.	**NO**	**The booster did not significantly improve motivation.**
H7	The inoculation effect [H7a] immediately after intervention (T0), [H7b] after 10 days (T10), and [H7c] after 30 days (T30) is influenced directly by memory and motivation, and indirectly by the inoculation intervention (mediated by memory and motivation).	**YES *****	**Across the time points, both the indirect inoculation effect and the direct effect of memory and motivation were significant.**

*** $p < .001$, ** $p < .01$, * $p < .05$, ○ $p < .10$

S26 Table

Table S26

Preregistered Hypotheses of Study 3–5

#	Hypothesis	Evidence	Description
	STUDY 3		
H1.1	People who watched a short inoculation video (H1.1a) or a long inoculation video (H1.1b) are better at discerning manipulative social media posts from neutral social media posts than people who watched a control video.	**YES *****	**The inoculation effect was significant for both short and long inoculation videos.**
H1.2	The inoculation effect of a short inoculation video (0 min 30 sec) is smaller than the inoculation effect of a long inoculation video (1 min 48 sec).	**NO**	**The inoculation effects did not differ significantly between the short and the long videos.**
H1.3	The inoculation effect of a long inoculation video (H1.3a) or a short inoculation video (H1.3b) decays partially but not completely over a period of two weeks.	**NO**	**The inoculation effects were no longer significant after two weeks.**
	STUDY 4		
H2.1	People who watched an inoculation video are better at discerning manipulative social media posts from neutral social media posts than people who watched a control video.	**YES *****	**The inoculation effect was significant.**
H2.2	There is no decay of the inoculation effect of inoculation videos after 4 days (T4).	**YES *****	**The inoculation effect was still significant after 4 days.**
H2.3	There is partial decay of the inoculation effect of inoculation videos after 10 days (T10).	**NO**	**The inoculation effect did not show partial decay.**
H2.4	There is full decay of the inoculation effect of inoculation videos after 30 days (T30).	**YES**	**The inoculation effect was no longer significant after 30 days.**
H2.5	Memory (forgetting) predicts inoculation decay.	**YES *****	**Memory was a significant predictor of effect retention.**
H2.6	Threat (motivation) does not predict inoculation decay.	**NO**	**Motivation was a significant predictor of effect retention.**
	STUDY 5		
H3.1	People who watched an inoculation video are better at discerning manipulative social media posts from neutral social media posts than people who watched a control video.	**YES *****	**The inoculation effect was significant.**
H3.2	The inoculation effect of inoculation videos is no longer significant after 30 days.	**NO**	**The inoculation effect was stronger than hypothesized.**
H3.3	An inoculation video (T0) that is followed by a threat-based booster video 10 days later (T10), is effective at keeping the inoculation effect significant up to 30 days after the T0 inoculation.	**YES ****	**The threat-boosted inoculation effect was significant.**
H3.4	An inoculation video (T0) that is followed by a memory-based booster video 10 days later (T10), is effective at keeping the inoculation effect significant up to 30 days after the T0 inoculation.	**YES *****	**The memory-boosted inoculation effect was significant.**

H3.5	An inoculation video (T0) that is followed by the same inoculation video 10 days later (T10), is effective at keeping the inoculation effect significant up to 30 days after the T0 inoculation.	**YES ****	**The boosted inoculation effect was significant.**
H3.6	Groups exposed to a threat-based booster video at T10 show increased motivation (a), but not memory (b) of the intervention, at T30, compared to those inoculated who did not receive a booster video.	**MIXED**	**The threat-based booster did not significantly increase motivation or memory.**
H3.7	Groups exposed to a memory-based booster video at T10 show increased memory (a) of the inoculation intervention, but not motivation (b), at T30, compared to those inoculated who did not receive a booster video.	**YES *****	**The memory booster significantly improved memory but not motivation.**
H3.8	Groups exposed to a repeated-inoculation booster video at T10 show increased memory (a) of the inoculation intervention and motivation (b) at T30, compared to those inoculated who did not receive a booster video.	**MIXED**	**The re-inoculation booster significantly improved memory but not motivation.**
H3.9	The inoculation effect at T0 (a) and T30 (b) is influenced directly by memory and motivation, and indirectly by the inoculation intervention (mediated by memory and motivation).	**YES *****	**The inoculation effect is significantly mediated by memory and motivation, with only an indirect effect of the inoculation intervention remaining.**

*** $p < .001$, ** $p < .01$, * $p < .05$, ○ $p < .10$

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