Health Communication

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/hhth20

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HEALTH COMMUNICATION
https://doi.org/10.1080/10410236.2023.2164954

Framing COVID-19 Preprint Research as Uncertain: A Mixed-Method Study of Public Reactions

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ABSTRACT

During the COVID-19 pandemic, journalists were encouraged to convey uncertainty surrounding preliminary scientific evidence, including mentioning when research is unpublished or unverified by peer review. To understand how public audiences interpret this information, we conducted a mixed method study with U.S. adults. Participants read a news article about preprint COVID-19 vaccine research in early April 2021, just as the vaccine was becoming widely available to the U.S. public. We modified the article to test two ways of conveying uncertainty (hedging of scientific claims and mention of preprint status) in a 2 × 2 between-participants factorial design. To complement this, we collected open-ended data to assess participants' understanding of the concept of a scientific preprint. In all, participants who read hedged (vs. unhedged) versions of the article reported less favorable vaccine attitudes and intentions and found the scientists and news reporting less trustworthy. These effects were moderated by participants' epistemic beliefs and their preference for information about scientific uncertainty. However, there was no impact of describing the study as a preprint, and participants' qualitative responses indicated a limited understanding of the concept. We discuss implications of these findings for communicating initial scientific evidence to the public and we outline important next steps for research and theory-building.

The COVID-19 pandemic has been marked by levels of uncertainty unparalleled in the recent history of science and medicine (Charters & McKay, 2020). Faced with many unknowns, scientists raced to conduct research to understand the virus and to develop treatments and vaccines (Koffman et al., 2020; Lurie et al., 2020). Given the urgency surrounding the unfolding global crisis, many researchers bypassed the typically lengthy peer-review process in order to disseminate findings quickly via preprint servers (Brierley et al., 2022; Nelson et al., 2022). News outlets, in turn, reported these unreviewed research findings, and COVID-19-related preprints soon gained more public attention than preprints on any other topic (Fraser et al., 2021). News outlets varied significantly in their reporting of preprint research results, offering differing levels of explanation of preprints and sometimes neglecting to mention their preliminary and unvetted nature (Fleerackers, Riedlinger, et al., 2022; Massarani & Neves, 2022; Oliveira et al., 2021; van Schalkwyk & Dudek, 2022). In response, journalists were urged to "do better" when reporting initial COVID-19 science by conveying the preliminary nature of scientific preprints (Caulfield et al., 2021; Ordway, 2020; Saitz & Schwitzer, 2020). How public audiences respond to such information about preliminary science and preprints is not yet well understood.

Prior research shows that disclosing scientific uncertainty – by highlighting unknowns or emphasizing the preliminary nature of evidence, for example – typically has neutral or favorable effects on public evaluations of source credibility (for a review, see Gustafson & Rice, 2020). However, that body of research was not conducted in the context of a global pandemic. Do public audiences respond favorably to disclosures about uncertain COVID-19 science? And how do they interpret and respond to depictions of preprint research, in particular? Empirical evidence to answer the former question is limited (see Ratcliff et al., 2022). The latter question has only just begun to receive scholarly attention and has not been examined in a COVID-19 context.

To contribute insights, we conducted an experiment to test the effects of conveying the uncertain nature of COVID-19 preprint evidence. We focused on two forms of scientific uncertainty disclosure: (1) qualifying research conclusions with hedging (Jensen, 2008), and (2) describing the research as a "preprint" that is preliminary and unverified by peer review (Fleerackers, Riedlinger, et al., 2022). We used real news coverage of preprint research on the connection between COVID-19 vaccine side effects and vaccine efficacy, modifying it to create four versions to reflect the presence or absence of each disclosure. Data collection took place in early April 2021, just as COVID-19 vaccines were becoming widely available in the U.S. We assessed the impact of uncertainty disclosure on U.S. adults' source evaluations and vaccine attitudes and intentions. To complement these results, we analyzed participants' open-ended accounts of how they understood the concept of a scientific preprint, creating a framework to categorize public preprint understanding.

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Communicating uncertain preprint science to the public

During the COVID-19 pandemic, preprint research, or research posted to online repositories prior to scientific peer review (Berg et al., 2016), became highly relevant to the public information environment. Despite scholars sharing their work with each other via preprints for years, journalists were historically discouraged from reporting on them (Associated Press, 2020; Sheldon, 2018). Yet over 30,000 studies related to COVID-19 were published as preprints on servers such as bioRxiv and medRxiv during the first year of the COVID-19 crisis (Fraser et al., 2021). Media outlets began reporting on preprints to provide the public with much-anticipated updates about the ongoing pandemic (Fleerackers, Riedlinger, et al., 2022; Saitz & Schwitzer, 2020), with more than half of science journalists in one survey relying on preprints in their COVID-19 reporting (Massarani et al., 2021).

Critics have faulted journalists for a lack of cautious and contextualized reporting on preprint COVID-19 research, arguing that public trust in science, medicine, and journalism is at stake (e.g., Caulfield et al., 2021; Saitz & Schwitzer, 2020). Caulfield et al. (2021, p. 411) advised that "[g]reat care should be taken in how research results that haven't been peer reviewed – such as preprints – are represented in the public domain, including emphasizing the preliminary nature of conclusions." Yet how public audiences respond to news reporting on preprint research, including transparency about its uncertain nature, has so far received little empirical attention.

There is limited theory to explain how nonexpert audiences process the communication of uncertainty in science (Paek & Hove, 2020; Ratcliff et al., 2022), but mounting evidence suggests that public reactions to uncertainty disclosure are influenced by message features, such as how the uncertainty is framed (Gustafson & Rice, 2020; Han et al., 2021; Jensen et al., 2017), and by audience characteristics, such as individuals' prior beliefs and attitudes toward science (Gustafson & Rice, 2020; Ratcliff et al., 2021). With regard to communication features, evidence indicates that public audiences respond negatively to messages attributing scientific uncertainty to a lack of expert consensus, but favorably or neutrally to messages attributing uncertainty to gaps in knowledge or the inherently tentative nature of initial evidence (Gustafson & Rice, 2020). These framing effects may depend, in part, on how a person perceives the role of various types of uncertainty in science.

Because preprint research has not undergone formal peer review (Berg et al., 2016), findings can sometimes change in important ways between the time a study is first posted to a preprint server and when (or if) it is eventually published in a peer reviewed journal (Brierley et al., 2022). For instance, although substantive changes to COVID-19 evidence were uncommon between preprint and publication stages (Brierley et al., 2022; Nelson et al., 2022), uncertainty was often reduced during peer review (Nelson et al., 2022). Further, many COVID-19 preprints never made it to journal publication (Drzymalla et al., 2022). This potential for change and for some preprints to remain unpublished may be why major preprint servers, such as bioRxiv and medRxiv, warn that preprint results should not "be reported in the press as conclusive."[1]

Given this, scientific preprints can be associated with multiple levels of uncertainty: uncertainty surrounding specific scientific claims and uncertainty arising from the preliminary nature of preprints. To convey the former, journalists may use *deficient knowledge* framing (Gustafson & Rice, 2020). In scientific contexts, deficient knowledge is often communicated with a combination of lexical and discourse-based hedging (Hyland, 1996; Jensen, 2008; Nanayakkara & Hullman, 2020). *Lexical hedging* expresses tentativeness of evidential claims through modal verbs (e.g., may, might, could, suggest), while *discourse-based hedging* is an explicit admission of lack of knowledge (e.g., "We do not know whether . . ."; Hyland, 1996, p. 272). Disclosing a study's *preprint status* is another way of conveying scientific uncertainty (Fleerackers, Riedlinger, et al., 2022; Fleerackers, Moorhead, et al., 2022), especially if the concept of a "preprint" is defined or contextualized for the audience (Caulfield et al., 2021). Therefore, in the current study, we tested the impacts of framing preprint research as uncertain via hedging and disclosure of preprint status. We describe each element of our conceptual framework in the following sections and present a diagram in Figure 1.

Effects of uncertainty on evaluations of source credibility

A longstanding argument for disclosing scientific uncertainty is that this transparency enhances perceived credibility of the information and its sources. However, the empirical literature shows mixed effects of hedging on public audience evaluations of source credibility. In non-pandemic health contexts, several studies found that news articles with hedged reporting of scientific claims were rated as more balanced and trustworthy – dimensions of *news credibility* (Yale et al., 2015) – compared to unhedged versions (Jensen, 2008; Ratcliff & Wicke, 2022; Ratcliff et al., 2018). These positive effects occurred only when the uncertainty disclosure was attributed to the scientists responsible for the research, not unaffiliated scientists – where, rather than being construed as transparency, it may have been perceived as lack of consensus. Studies also found that affiliated scientist sources were perceived as more trustworthy and ethical in hedged (vs. unhedged) news articles (Jensen, 2008; Ratcliff et al., 2021; Steijaert et al., 2021). These studies focused on health topics such as cancer and precision medicine. In climate science contexts, however, studies found that hedging had no effect on trust in the scientists (Hendriks & Jucks, 2020) or led to lower ratings of the journalist's trustworthiness and statistician's competence (van der Bles et al., 2020). This suggests that the effects of disclosing uncertainty may depend in part on the scientific context.

In COVID-19 contexts, the effects of hedging have largely been neutral or unfavorable (see Ratcliff et al., 2022). For instance, in messaging about the efficacy of masks for reducing COVID-19 transmission, Janssen et al. (2021) found no effect of lexical hedging (qualifying claims with "suggest," "possibly," "could," etc.) on public perceptions of scientists' competence and trustworthiness – two dimensions of *expert source credibility* (McCroskey & Teven, 1999). Similarly, in messages about vaccine efficacy, Kelp et al. (2022) found no impact of hedging (a combination of lexical hedges and describing the evidence as "preliminary" and requiring more research) on

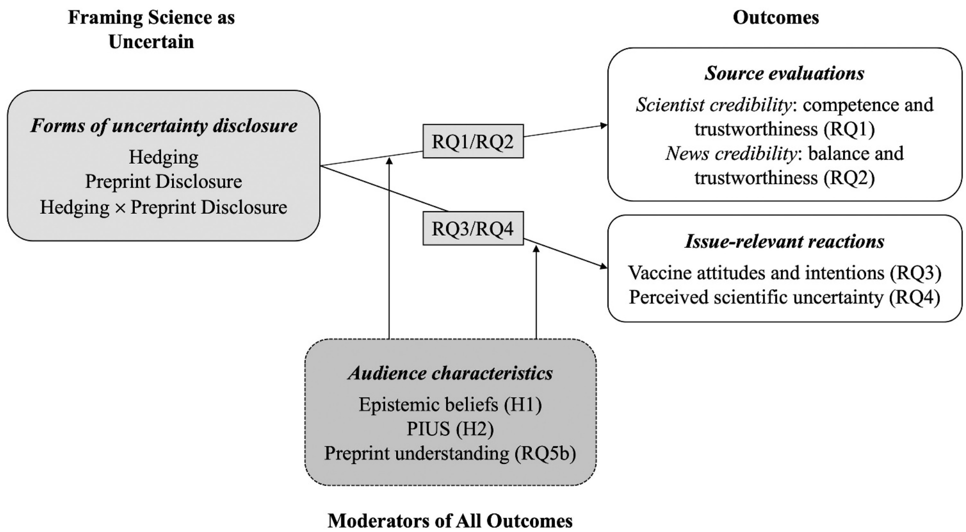

Figure 1. Conceptual diagram of hypothesized relationships.

trust in the information or its source. However, Simonovic and Taber (2022) found that discourse-based hedging in scientific messages about the nature of COVID-19 generated lower trust in public health officials. Similarly, Kreps and Kriner (2020) found that discourse-based hedging regarding epidemiological predictions led to less public trust in and support for science.

To date, very little is known about how general audiences respond to disclosure of preprint status. Studies suggest that many nonexperts do not understand the term "preprint" and fail to differentiate between peer reviewed and unreviewed scientific sources (Cyr et al., 2021) unless provided with an explanation of the peer review process and a statement that the work in question has not yet been peer reviewed (Wingen et al., 2022). There is some evidence that individuals perceive preprint research as less credible when it is explicitly described as not peer reviewed (Wingen et al., 2022). Yet research in this area is still emerging. In particular, it remains to be seen whether public audiences perceive the *sources* of preprint disclosure, such as scientists describing their research and journalists reporting on it, as more or less credible. It is possible that nonexperts respond favorably to the mention of preprint status, interpreting it as a transparent admission of the preliminary nature of the evidence. On the other hand, nonexperts may view scientific conclusions based on preprint research as not having consensus from the scientific community, given that it has not yet been peer reviewed, which, in turn, may generate unfavorable reactions toward the sources (Gustafson & Rice, 2020).

Overall, the effects of communicating uncertainty about scientific claims based on preprint research are largely untested, representing an important knowledge gap to be filled. In light of the limited evidence, we began with the following research questions:

RQ1: Will (a) hedging, (b) preprint disclosure, or (c) a hedging × preprint interaction influence perceptions of the source scientists' credibility (i.e., competence and trustworthiness)?

RQ2: Will (a) hedging, (b) preprint disclosure, or (c) a hedging × preprint interaction influence perceptions of the news article's credibility (i.e., balance and trustworthiness)?

Effects of uncertainty on issue-relevant attitudes and behaviors

The effects of uncertainty disclosure on public perceptions of scientific issues and issue-relevant decisions have also been mixed. Existing studies have primarily concentrated on the impact of exposure to consensus uncertainty, which typically generates unfavorable effects on issue attitudes and behavioral intentions (see Gustafson & Rice, 2020). In contrast, studies of discourse-based hedging found no impact on a range of outcomes, such as cancer prevention fatalism (Jensen et al., 2017), willingness to share health data for research (Ratcliff et al., 2021), and commitment to climate-friendly behavior (Hendriks & Jucks, 2020). Specific to vaccines, Xu et al. (2021) found that hedging of MMR vaccine messages (i.e., promoting the vaccine while disclosing possible side effects and uncertainty) had no impact on parents' intentions to vaccinate their children. Conversely, Han et al. (2018) found that hedging regarding vaccine efficacy resulted in lower vaccine intentions; however, the vaccine and disease in that study were hypothetical.

Specific to COVID-19, Han et al. (2021) found that messages that conveyed uncertainty about the nature of the virus and efficacy of the vaccine using discourse-based hedging had no impact on intentions to perform precautionary behaviors, including vaccine uptake. In contrast, Kelp et al. (2022) found that college students who received hedged messages about COVID-19 vaccines perceived the vaccines to be less effective and had lower intention to get vaccinated.

On the whole, the research on whether conveying scientific uncertainty influences issue-relevant attitudes and behaviors has been relatively sparse and yields mixed findings. Further, to our knowledge, there is no research examining the impact of preprint disclosure on attitudes and intentions related to scientific issues. The mixed and frequently neutral results described previously raise another important question: to what extent do nonexperts perceive uncertainty when it is communicated? Do people register hedging and preprint disclosure as indicators that the science is uncertain, or are these disclosure strategies too subtle to be noticed by the untrained eye? With regard to preprints, especially, we lack insight about how public audiences interpret this information and whether it is received in the same way as other forms of scientific uncertainty disclosure, such as hedging. Therefore, we asked the following:

RQ3: Will (a) hedging, (b) preprint disclosure, or (c) a hedging × preprint interaction influence vaccine attitudes or intention to get the vaccine?

RQ4: Will (a) hedging, (b) preprint disclosure, or (c) a hedging × preprint interaction influence perception that the science is uncertain?

The moderating influence of audience characteristics

In addition to varied formats of scientific uncertainty disclosure, a second plausible explanation for mixed findings in the literature is heterogeneity in public audiences (Gustafson & Rice, 2020). An emerging body of research suggests that beliefs about the nature of scientific knowledge, preference for information about uncertainty, and understanding of specific scientific concepts are all likely to influence how people respond to the communication of scientific uncertainty.

Medical epistemic beliefs

Epistemic beliefs reflect people's views about the nature of knowledge and process of knowledge creation. In the context of medicine, people can perceive scientific knowledge as evolving and fallible (i.e., view it as an ongoing *process*) or as stable and unchanging (i.e., view it as *fixed*; Kienhues & Bromme, 2012). In a recent study, people who viewed science as stable and unchanging were more likely to say they expected journalists to deliver definitive information about the COVID-19 pandemic (Post et al., 2021). It is logical that beliefs about the nature of medical science would affect a person's response to disclosure of scientific uncertainty about COVID-19 vaccines. Those who view science as a process probably expect uncertainty about new discoveries, and for them, disclosure is a gesture of transparency while claims of certainty may evoke suspicion. Further, believing uncertainty is inherent in science might make one more apt to recognize its disclosure. Conversely, those who believe scientific knowledge is fixed might view scientific uncertainty as a marker of low-quality research and (to the extent that they perceive it) react unfavorably to its disclosure. Therefore, we predicted the following:

H1: When uncertainty is disclosed, people with process-oriented epistemic beliefs will (a) perceive more scientific uncertainty, (b) rate the source scientists more credible, (c) rate the news article more credible, (d) report more positive vaccine attitudes, and (e) report greater intention to vaccinate.

Preference for information about scientific uncertainty

Public audiences express varied information preferences for learning about new scientific discoveries (Ratcliff & Wicke, 2022). Some people, regardless of their beliefs about the nature of science, want to learn about uncertain evidence, while others prefer to learn only about certain, conclusive, or actionable results. For the same piece of evidence, some individuals want to know the fuller picture (including complexities, limitations, and caveats) while others prefer a streamlined depiction of the results. For instance, members of the German public were shown various forms of communication about COVID-19 and most preferred the versions containing fuller depictions of scientific uncertainty (Wegwarth et al., 2020). Another COVID-19 study with Germans found correlations between having a need for definite information and preferring that news articles present conclusive information about the pandemic (Post et al., 2021). In our previous research (Ratcliff & Wicke, 2022), we developed and tested the Preference for Information about Uncertain Science (PIUS) scale, which measures preferences for learning about tentative discoveries and the caveats and limitations of scientific research. In our prior study, framing science as uncertain (vs. certain) led to higher ratings of scientist trustworthiness and news credibility when PIUS was high, but had the opposite effect when PIUS was low. In light of those results, we expected the following:

H2: When uncertainty is disclosed, people with higher PIUS will (a) perceive more scientific uncertainty, (b) rate the source scientists more credible, (c) rate the news article more credible, (d) report more positive vaccine attitudes, and (e) report greater intention to vaccinate.

Understanding the concept of a scientific preprint

As previously described, there is very little research on how public audiences understand preprint research. Definitions of the concept of a preprint are varied, even within academic communities (Chiarelli et al., 2019). In the life sciences, one commonly accepted definition of a *preprint* is a complete scientific manuscript which the authors post to a public server prior to formal peer review and publication in a scientific journal (Berg et al., 2016). In line with this definition, preprints may be understood as *released publicly*, *not yet peer reviewed*, and *not yet published in a scientific journal*. Additionally, given that study conclusions can change between posting to a preprint server and publication in a peer-reviewed journal (Brierley et al., 2022; Nelson et al., 2022), preprints may be understood as providing *preliminary evidence* (Caulfield et al., 2021). Preprint research is sometimes contextualized in news reporting as having some or all of these characteristics (Fleerackers, Riedlinger, et al., 2022; Ordway, 2020; van Schalkwyk & Dudek, 2022; Wingen et al., 2022), yet it remains unclear whether public audiences understand preprints in these ways. Accordingly, we used an open-ended question to examine whether participants' understanding of the term aligned with any of these four definitions. We then created a coded variable in order to assess whether their understanding moderated the effects of preprint disclosure, guided by the overarching research question:

RQ5: (a) How do people understand the term "preprint" and (b) does this understanding moderate message-level and issue-level outcomes?

Materials and methods

An OSF project page for this study (https://osf.io/w4djv) contains our dataset and a copy of our Supplemental Files.

Participants and procedures

We collected data for this study during the second week of April 2021. We used Qualtrics Panel Services to recruit a sample of U.S. adults stratified by gender and education. From 433 responses collected, we removed 18 cases that did not meet our *a priori* quality criteria: that is, the participants (a) did not correctly answer two questions about the scientific study described in the article or (b) spent less than one-third of the median time on the stimulus page. The final sample (N = 415) was roughly half female (53%) and half had a formal education beyond 12th grade (51%). Median age was 41 (range: 18–85). There were slightly more Democrats (58%) than Republicans (42%). Full participant characteristics are reported in the Supplemental Files.

This experiment used a 2 × 2 between-participants factorial design, where the message factors were *hedging* (present/absent) and *preprint status* (disclosed/not disclosed). After completing a pretest questionnaire with measures of individual characteristics, participants were randomly assigned to one of the four message conditions. Participants read the news article and then evaluated the article's content. The IRB at University of Utah approved the study (IRB 00131482).

Experimental stimulus

To create experimental conditions, we modified a news report from *Scientific American* (Sutherland, 2021) describing preprint research about the relationship between COVID-19 vaccine side effects and vaccine efficacy. This research suggested that a person may be protected from COVID-19 – meaning their immune system was activated and created antibodies – regardless of whether they experienced side effects after the shot (e.g., chills, body aches, or fatigue). In other words, the uncertainty pertained to whether vaccine side effects indicate efficacy, not whether the vaccine is effective in general. The affiliated ("source") scientists stated that they considered their findings preliminary and acknowledged that many unknowns remained, including why some people experience side effects from the vaccine while others don't. The original news report described the study as "a preprint study recently posted online and not yet evaluated by outside experts."

We modified the news article to create four versions in a fully crossed, 2 (hedging: present/absent) × 2 (preprint disclosure: present/absent) design. The preprint disclosure included a mention of the study's preprint status and a brief explanation of the term "preprint," similar to the original news report. The version without preprint disclosure omitted these references and simply referred to "a study." The hedged versions contained both lexical and discourse-based hedging, similar to the original news report and in line with past experimental messages (e.g., Jensen, 2008; Ratcliff et al., 2018) and with the *deficient knowledge* uncertainty frame in Gustafson and Rice's (2020) typology. Given that scientific claims are often qualified using a combination of both types of hedges, we were not interested in testing each form of hedging separately. For *lexical hedging*, the scientific claims were framed with speculative language (e.g., "suggests," "might offer," "could"), compared to assertive language (e.g., "shows," "offers," "will") in the unhedged versions (Hyland, 1996; Nanayakkara & Hullman, 2020). For *discourse-based hedging*, the affiliated scientists disclosed that they did not yet know why people react differently to the vaccine (Hyland, 1996; Jensen, 2008). Importantly, all four versions contained an assertion of confidence about the vaccine's effectiveness, which was copied from the original news article.[2] In this statement, an affiliated researcher said, "The big take-home message is that not having side effects is no reason to worry about the efficacy of the vaccine." We present the full experimental messages in the Supplemental Files.

Measures

Demographic measures included age, income, gender, political affiliation (Republican or Democrat), and education level (high school or less vs. some college or more).

Perceived scientific uncertainty

We asked participants whether the evidence supporting the article's conclusion seemed *certain*, *known for sure*, *established*, *without any doubt*, *settled*, and *able to be firmly relied on* (1 = *strongly disagree*, 7 = *strongly agree*). The six-item scale was reversed to represent uncertainty for analyses (uncertain: M = 3.25, SD = 1.31; α = .94).

Credibility of the source scientists

We used an expert source credibility scale (McCroskey & Teven, 1999) to assess two dimensions of scientist credibility: competence and trustworthiness. Participants reported whether they found the scientists responsible for the research to be *intelligent, expert, competent*, and *trained* (representing competence) and *trustworthy, honest, phony (reversed)*, and *ethical* (representing trustworthiness), on scales from 1 = *strongly disagree* to 5 = *strongly agree*. Prior research indicates that each dimension is ideally treated as a discrete variable in analyses (McCroskey & Teven, 1999). Reliability was significantly improved without the items *trained* and *phony*, so we removed these. The final three-item subscales were reliable for competence (M = 4.00, SD = .82, α = .89) and trustworthiness (M = 3.93, SD = .88, α = .91).

Credibility of the news article

Conceptually, news credibility is a multi-dimensional construct, but past research has questioned whether the public consistently perceives this nuance (Yale et al., 2015). Thus, news credibility can be treated as a single- or multi-dimensional scale, depending on the goals of the research. For this study, we adapted two subscales from a larger news credibility scale (Yale et al., 2015) to assess evaluations of the reporting. Participants were asked if the news article depicted the scientific study in a way that was balanced (*fair*, *accurately represented*, *realistic*, and *open-minded*) and trustworthy (*honest*, *ethical*, *trustworthy*, and *reliable*), on scales from 1 = *not at all* to 7 = *very much*. To best address our research questions, we treated each dimension as a separate variable in analyses. The four-item scales were reliable for balance ($M = 5.49$, $SD = 1.38$; $\alpha = .92$) and trustworthiness ($M = 5.47$, $SD = 1.41$; $\alpha = .94$).

Vaccine attitudes

We used a seven-item semantic differential scale asking participants to report their opinions about receiving a COVID-19 vaccine. Anchors for the seven-point scale were *worthless/valuable, bad/good, harmful/beneficial, not helpful/helpful, unproductive/productive, foolish/wise*, and *not useful/useful* ($M = 5.48$, $SD = 1.74$, $\alpha = .97$).

Vaccine intentions

Using a single item, we asked participants about their intention to receive a COVID-19 vaccine when it is available (1 = *extremely unlikely*, 7 = *extremely likely*; $M = 5.39$, $SD = 2.19$).

Medical epistemic beliefs

We used the five-item Stability of Medical Knowledge subscale from a larger, multidimensional epistemic beliefs scale (Kienhues & Bromme, 2012) to capture whether individuals view medical science as an ongoing and fallible process. Participants rated agreement with statements such as "Even medical knowledge has to be revised over and over" and "It is natural for the viewpoints in medical research to change over time." Higher values indicate *process*-oriented expectations of scientific knowledge, while lower values indicate *fixed* expectations (1 = *strongly disagree*, 5 = *strongly agree*; $M = 3.89$, $SD = .69$, $\alpha = .81$). All items are listed in the Supplemental Files.

PIUS

We used a scale developed in previous research (Ratcliff & Wicke, 2022) to assess participants' preference for learning about tentative science. The measure was completed posttest to avoid contaminating participants' experience of the stimuli, and we verified that participants' condition did not affect their response.[3] Participants rated agreement with seven statements (see Box 1) on a scale from 1 = *strongly disagree* to 5 = *strongly agree* ($M = 3.90$, $SD = .87$, $\alpha = .91$).

Understanding the concept of a preprint

We used an open-ended question to capture participants' understanding of the term "preprint." Specifically, we asked: "When you see the term 'preprint' in a scientific news article, what do you think that means?" We asked the question posttest in order to avoid priming participants' processing of the stimulus.[4] Two authors (AF and CR) developed a coding scheme to categorize responses. The coding scheme contained predefined categories based on our conceptualization of the term "preprint," as described previously (i.e., a scientific paper that is *released publicly*, *not peer reviewed*, and/or *not published in a scientific journal*). We also included a category for whether participants described the term as an indication of *preliminary scientific evidence*.

To classify all other responses, we included categories for "I don't know" and "blank or irrelevant" responses, as well as an "other" category for all responses that did not fit in one of the predefined categories. Codes for each category were present = 1, absent = 0. With the exception of "other," categories were not mutually exclusive. Two authors (AF and CR) dual-coded a random subset of 125 responses. Intercoder reliability was acceptable: Krippendorff's alpha ranged from .78–.94 for the primary categories of interest and .71–1.00 for the remaining categories (see Table 1). The full codebook is presented in the Supplemental Files.

Power analysis

According to G*Power (Faul et al., 2007), the final sample size ($N = 415$) provided adequate power (.80; Cohen, 1992) to consistently detect effects as small as $f = 0.14$ for the 2×2 factorial design.

Analytic approach

We conducted all statistical analyses using SPSS version 26. We created two message factors, dummy coded as: hedging (absent = 0, present = 1) and preprint status disclosure (absent = 0, present = 1). We used two-way ANOVAs to test main and interaction effects of the two message factors on each outcome variable (RQ1–RQ4). To answer RQ5, we first classified all text responses according to the coding scheme described in the Measures section. To produce a descriptive summary (RQ5a), we tallied the number of participants who gave a definition that fit each category. To examine understanding as a moderator (RQ5b), we created a dichotomous variable to represent accurate preprint understanding. If participants

Box 1. PIUS scale items.

(1) I like it when scientists describe the limitations of their studies, in addition to the benefits.
(2) I like it when the caveats of a scientific study are fully explained.
(3) I like to learn about new scientific discoveries, even if they're too preliminary to be acted upon.
(4) Science journalists should describe the uncertainties or unknowns when reporting about a scientific discovery.
(5) I like to know about the limitations and caveats surrounding new research findings.
(6) I like to learn about new scientific discoveries, even if they don't yet translate to solutions in the real world.
(7) When learning about a new scientific discovery, I want to know how well the evidence supports a particular claim.

Notes: Participants responded to the prompt: "In general, how much do you agree with the following statements?" Source: Ratcliff, Wicke, 2022.

Table 1. Understanding of preprint status (coded responses).

Response Category (ICR)	Number of Instances	Example Responses
Not peer reviewed ($\alpha = .91$)	19 (4.7%)	"It hasn't been peer reviewed yet." (ID 184) "This article has not been read by other scientists yet to critique it." (ID 218) "Maybe it's a draft of a study's findings or before it's been peer reviewed." (ID 122)
Released publicly ($\alpha = .94$)	5 (1.2%)	"A paper before it's publication made available to the public." (ID 88) "It is an entire project of the research paper that is published publicly." (ID 142)
Not published in scientific journal ($\alpha = .93$)	23 (5.7%)	"Hasn't been published in a peer reviewed journal?" (ID 168) "A newer version of a scientific manuscript that is not yet part of the scientific record." (ID 246)
Total number of responses that included at least one of the three responses above: 39 (9.7%)†		
Preliminary results ($\alpha = .78$)	61 (15.1%)	"Preprint study would be like preliminary findings that aren't published as fact." (ID 108) "Not the final findings and there's still research needed to be done before a conclusion is made." (ID 131) "The study is not fully complete or proven, or widely accepted, and therefore it has not been printed in scientific journals. It is still being tested, but enough info/proof is there to go ahead and start publishing findings and results." (ID 198)
Total number of responses that included at least one of the four responses above: 104 (25.1%)†		
Other ($\alpha = .76$)	233 (57.8%)	"The beginning of what will be printed at another time." (ID 241) "They found some good news about study." (ID 233) "Before it is printed in mass media." (214)
Doesn't know ($\alpha = 1.00$)	54 (13.4%)	"No idea." (ID 19) "I do not know what that term means." (ID 216)
Irrelevant/blank ($\alpha = .71$)	25 (6.2%)	"N/A." (ID 158) "None." (ID 138)

N = 403*. Categories are not mutually exclusive, with the exception of "other." For ICR, we report Krippendorff's Alpha. The full codebook is presented in the Supplemental Files.

†Chi-square tests indicated that these responses did not appear to be influenced by experimental condition (see Supplemental Files).

*From the original sample of 415, we omitted 12 responses that were obviously copied from the Internet. These were identified by performing a Google search for the terms "preprint" and "what is a preprint" and comparing the definitions provided by the first three search hits against participants' responses. These responses were excluded from the final analyses of the open-ended data.

understood the term "preprint" to signify at least one of the four primary definitions, the response was coded as 1; otherwise, it was coded 0. To test moderation (H1–H2 and RQ5b), we used Model 1 in the PROCESS macro (v3.5.1, see Hayes, 2018).

Results

We report bivariate correlations between all study variables in the Supplemental Files.

Main and interaction effects of uncertainty disclosure

Those who read hedged messages found the scientists less credible (i.e., competent and trustworthy; RQ1a) and found the news reporting less credible (i.e., balanced and trustworthy; RQ2a), while there was no impact of preprint disclosure (RQ1b and RQ2b) nor a hedging × preprint interaction (RQ1c and RQ2c). Hedged messages also produced less positive vaccine attitudes and intentions (RQ3a), while there was no impact of preprint disclosure (RQ3b) nor a hedging × preprint interaction (RQ3c). Participants who read hedged messages perceived more scientific uncertainty (RQ4a), but there was no impact of preprint disclosure (RQ4b) or a hedging × preprint interaction on perceived uncertainty (RQ4c). Means, standard deviations, and effect sizes are reported by message factor in Tables 2 and 3, and by message condition in the Supplemental Files. In the Discussion, we speculate about possible reasons for the unfavorable effects of hedging, and we report moderating factors below.

Moderating effects of audience characteristics

Given that no main or interaction effects emerged for preprint disclosure, we performed moderation analyses with just the hedging factor as a predictor, creating more parsimonious and interpretable models. The Johnson-Neyman technique was used to probe interactions and identify regions of significance at different values of the moderator (Hayes, 2018). For simplicity, we report statistics only for significant effects. Figures depicting these interactions are available in the Supplemental Files.

Table 2. Main effects of hedging.

	Unhedged ($N = 217$)	Hedged ($N = 198$)	Between-participants Effects
Perceived uncertainty	3.09 (1.28)	3.43 (1.32)	$F(1, 411) = 6.90$, $p = .009$, $\eta_p^2 = .017$, $d = .26$
News balance	5.68 (1.25)	5.28 (1.48)	$F(1, 411) = 9.10$, $p = .003$, $\eta_p^2 = .022$, $d = .29$
News trustworthiness	5.63 (1.31)	5.29 (1.49)	$F(1, 411) = 5.98$, $p = .015$, $\eta_p^2 = .014$, $d = .24$
Scientist competence	4.09 (.76)	3.91 (.87)	$F(1, 411) = 5.53$, $p = .019$, $\eta_p^2 = .013$, $d = .22$
Scientist trustworthiness	4.02 (.86)	3.83 (.90)	$F(1, 411) = 4.62$, $p = .032$, $\eta_p^2 = .011$, $d = .22$
Vaccine attitudes	5.65 (1.68)	5.29 (1.79)	$F(1, 411) = 4.65$, $p = .032$, $\eta_p^2 = .011$, $d = .21$
Intention to get vaccine	5.60 (2.07)	5.15 (2.29)	$F(1, 411) = 4.55$, $p = .034$, $\eta_p^2 = .011$, $d = .21$

The table reports means for each level of the message factor (*SD*s in parentheses) and main effects of hedging. All mean pairs were significantly different.

Table 3. Main effects of preprint disclosure.

	No Disclosure (N = 208)	Preprint Disclosure (N = 207)	Between-participants Effects
Perceived uncertainty	3.28 (1.26)	3.22 (1.36)	$F(1, 411) = .28, p = .600, \eta_p^2 = .001, d = .05$
News balance	5.50 (1.46)	5.48 (1.28)	$F(1, 411) = .004, p = .948, \eta_p^2 = .000, d = .01$
News trustworthiness	5.46 (1.45)	5.48 (1.37)	$F(1, 411) = .05, p = .830, \eta_p^2 = .000, d = .01$
Scientist competence	4.00 (.81)	4.01 (.82)	$F(1, 411) = .02, p = .877, \eta_p^2 = .000, d = .01$
Scientist trustworthiness	3.89 (.90)	3.97 (.86)	$F(1, 411) = .94, p = .334, \eta_p^2 = .002, d = .09$
Vaccine attitudes	5.50 (1.76)	5.45 (1.73)	$F(1, 411) = .08, p = .785, \eta_p^2 = .000, d = .03$
Intention to get vaccine	5.27 (2.31)	5.50 (2.06)	$F(1, 411) = 1.13, p = .289, \eta_p^2 = .003, d = .11$

The table reports means for each level of the message factor (SDs in parentheses) and main effects of preprint disclosure. No mean pairs were significantly different.

Epistemic beliefs

Medical epistemic beliefs moderated the effects of hedging on vaccine attitudes and intentions. However, there were no moderating effects for perceived scientific uncertainty, source scientist credibility (i.e., competence and trustworthiness), or news article credibility (i.e., balance and trustworthiness). Therefore, only H1d and H1e were supported, as detailed below.

Vaccine attitudes. Hedging negatively affected vaccine attitudes only for those with less process-oriented beliefs ($M \leq 3.89$ on a 5-point scale; ~47% of sample). For those with very strong process-oriented epistemic beliefs ($M \geq 4.83$; ~9% of sample), hedging had a positive effect on attitudes. For the rest of the sample, hedging had no statistically significant effect (interaction coefficient = .95, $p < .001$).

Vaccine intentions. Hedging negatively affected vaccine intentions only for those with less process-oriented beliefs ($M \leq 3.92$ on a 5-point scale; ~47% of sample). For the rest of the sample, hedging had no statistically significant effect (interaction coefficient = .89, $p = .005$).

Preference for information about scientific uncertainty

PIUS moderated the impact of hedging on all outcomes except perceived scientific uncertainty. Thus, H2a was not supported, while H2b – H2e were supported, as described below.

Credibility of the source scientists. Hedging generated less perceived *competence* of the scientists only among those with low PIUS ($M \leq 3.81$ on a 5-point scale; ~40% of sample). For the rest of the sample, hedging had no statistically significant effect (interaction coefficient = .21, $p = .005$). Additionally, hedging generated less perceived *trustworthiness* of the scientists only among those with low PIUS ($M \leq 3.76$ on a 5-point scale; ~40% of sample). For the rest of the sample, there was no statistically significant effect (interaction coefficient = .28, $p < .001$).

Credibility of the news article. Those with lower PIUS ($M \leq 4.11$ on a 5-point scale; ~56% of sample) found the reporting in the hedged versions less *balanced*. For the rest of the sample, there was no statistically significant impact (interaction coefficient = .29, $p = .039$). Additionally, those with lower PIUS ($M \leq 3.89$ on a 5-point scale; ~48% of sample) found the reporting in the hedged versions less *trustworthy*, while for the rest of the sample, there was no statistically significant effect (interaction coefficient = .46, $p = .002$).

Vaccine attitudes. Hedging had a negative effect on attitudes for those with lower PIUS ($M \leq 3.82$ on a 5-point scale; ~40% of sample), while for the rest of the sample, there was no statistically significant effect (interaction coefficient = .68, $p < .001$).

Vaccine intentions. Hedging had a negative effect on intentions for those with lower PIUS ($M \leq 3.83$ on a 5-point scale; ~40% of sample), while for the rest of the sample, there was no statistically significant effect (interaction coefficient = .88, $p < .001$).

Exploratory analyses of political party and education

Given the links between education and political ideology and beliefs about COVID-19 information (Gerretsen et al., 2021; Nagler et al., 2020; Rutjens et al., 2022), we conducted *post hoc* tests of whether political affiliation and education were additional moderators of the effects of hedging on evaluations of credibility or vaccine attitudes and intentions. Both variables were correlated with all outcomes, and education (but not political party) correlated positively with PIUS (see Supplemental Files). However, neither political affiliation nor education moderated the impact of hedging on any outcome.

Understanding of preprint status

Answering RQ5a, participants' open-ended responses indicated that most had a limited understanding of the concept of a preprint. A small proportion (roughly 10%) of participants defined "preprint" as *posted publicly*, *not peer reviewed*, and/or *not published in a scientific journal.* Around 15% defined it as indicating *preliminary evidence*. Combined, a total of 25% of the sample defined "preprint" in at least one of these four ways. As detailed in the Supplemental Files, results of chi-square tests showed no evidence that experimental condition (receiving hedged content, preprint disclosure, or both) influenced participants' responses.

Roughly 13% of participants said they did not know the meaning of the term, while 6% provided a blank or irrelevant response. A majority (58%) provided "other" definitions, which often indicated that participants thought of "preprint" as pertaining to the status of the draft (e.g., "Working on the final edits to become the print article," ID 226) or the status of the news article (e.g., "Before it is fully published on all mainstream media outlets," ID 137). Some "other" responses were clearly incorrect, while others appeared technically correct but did not fit our predefined categories or were too ambiguous to tell. Therefore, while we refer to responses that contained at least one of the four primary definitions as "accurate," we avoid classifying the remainder of responses as "inaccurate." It may be that a higher proportion of participants did understand the nature of preprints but did not articulate this in a way that aligned with our coding scheme. We present exemplar responses in Table 1 and additional examples in the Supplemental Files.

To address RQ5b, which asked whether preprint understanding moderates the effects of preprint disclosure, we used a dichotomous variable to represent preprint understanding (1 = participant defined "preprint" in line with at least one of the four primary categories; 0 = all other responses). We treated the preprint factor as a predictor and used a separate model to test each outcome. Preprint understanding did not moderate the path between preprint disclosure and any outcome.

Discussion

During the COVID-19 pandemic, public communicators – including journalists, public health officials, government leaders, and scientists – struggled to effectively convey emerging COVID-19 science to the public (Abdool Karim, 2022; Caulfield et al., 2021; Fleerackers et al., 2022). The need for timely information led to an increase in the reporting of early and unverified scientific evidence, including preprint research (Fleerackers et al., 2022; Fraser et al., 2021; Massarani & Neves, 2022; van Schalkwyk & Dudek, 2022). Communicators were urged to be transparent about the preliminary nature of this research (Caulfield et al., 2021; Ordway, 2020; Saitz & Schwitzer, 2020). However, little is known about how public audiences respond to information about uncertain COVID-19 science, especially preprint science.

To contribute insights, we tested the effects of transparency in news reporting of COVID-19 vaccine research in early April 2021, as the vaccine was becoming widely available to the U.S. public. We adapted a news article from *Scientific American* about findings from preprint research on the link between vaccine side effects and vaccine efficacy (Sutherland, 2021). The original news article contained two forms of uncertainty disclosure: hedging (i.e., deficient knowledge) and mention of the study's preprint status (i.e., preliminary evidence). We modified it to create four versions of the article, with either hedged or unhedged scientific claims, and either presence or absence of preprint status disclosure. The preprint disclosure included a brief explanation of the term "preprint" as in the original article. In all versions, we retained the affiliated scientists' original claim that the vaccine was likely to be effective even in the absence of side effects.

Negative reactions to hedging but not preprint disclosure

Participants did not appear to interpret preprint disclosure as an indicator of uncertain science. There were no effects of preprint disclosure on perceived scientific uncertainty or any other outcome (see Table 3). However, hedged versions of the article generated greater perceived uncertainty and lower perceived credibility of both the affiliated scientist sources and the news reporting. Hedging also generated less favorable attitudes toward the vaccine and lower intention to receive it. These effects were small in magnitude (see Table 2) and emerged for only part of the sample, as we discuss later. Yet the pattern of results was somewhat surprising given the subtlety of the message manipulations, which closely matched the original news article and conveyed uncertainty about the link between side effects and vaccine efficacy, not about vaccine efficacy in general. Potentially, individuals were particularly attuned to subtle uncertainty cues due to the timing and topic of the study. Although research in other scientific contexts has often found positive effects of hedging in news articles (e.g., Jensen, 2008; Steijaert et al., 2021), our results align with several studies in COVID-19 contexts (see Ratcliff et al., 2022). This suggests that public reactions to disclosure of deficient knowledge may be unique for domains like COVID-19, aligning with Gustafson and Rice's (2020) suggestion that people accept different levels of uncertainty for different issues. More work is needed to understand which scientific issues or communication contexts are associated with low uncertainty tolerance and why. In the next section, we explore possible explanations for why an aversion to hedged messages manifested in the current study.

Potential reasons for low tolerance of uncertainty in COVID-19 vaccine messages

First, public audiences may be less favorable toward communication of uncertainty about scientific issues that are contentious or characterized by a great deal of conflicting information. Scientific issues like climate change, GMOs, vaccines, and COVID-19 tend to be associated with higher public skepticism, which Rutjens et al. (2022) suggest may be due to political or religious ideologies or the proliferation of misinformation, disinformation, and conspiracy theories in these domains. While political affiliation was not a significant moderator in the current study, it makes sense to continue examining variables associated with ideological beliefs that are linked to science skepticism, in order to probe whether a connection exists between skepticism and responses to uncertainty disclosure. The COVID-19 pandemic was also characterized by a continuous barrage of conflicting or rapidly changing information (Abdool Karim, 2022; Nagler et al., 2020; Ratcliff et al., 2022), potentially making people more sensitive to the communication of uncertainty. Future studies could examine whether perceptions of the information environment for a given issue, such as perceived conflicting information or information overload, influence the effects of hedging on trust and issue-relevant outcomes. Notably, if participants in our study perceived the hedged claims as conflicting with information they had previously heard (i.e., prior claims of certainty[5]), then perceived *consensus uncertainty* could explain negative reactions to the uncertainty disclosure (see Gustafson & Rice, 2020), underscoring the utility of examining the factors that underlie these effects. It also makes sense to examine reactions to the communication of uncertainty over time, to assess whether audiences eventually grow accustomed to uncertainty in a given context or, conversely, reach a tolerance "threshold."

Notably, the topic of the current study combined two contentious topics – COVID-19 and vaccines – which may have magnified negative responses to hedging. COVID-19 vaccines have been met with extensive public skepticism and hesitancy due to misunderstandings about their effectiveness and a proliferation of conspiracy theories (Gerretsen et al., 2021; Rutjens et al., 2022; Tentori et al., 2021). Thus, while people may respond favorably to uncertainty disclosure in other health contexts, and perhaps even other COVID-19 contexts, they may be ambiguity averse when it comes to COVID-19 vaccines or vaccines in general (as suggested by results from Han et al., 2018, 2021; Kelp et al., 2022). Future research could compare the effects of communicating uncertainty about COVID-19 vaccines versus vaccines for other diseases, as well as comparing against non-vaccine COVID-19 topics.

Another explanation for aversion to uncertain COVID-19 information may be that the pandemic was characterized by *extreme* uncertainty. The public faced incomplete, ambiguous, and unreliable information pertaining to many facets of the disease, and this uncertainty was ongoing as both the virus and the scientific evidence base continuously evolved (Abdool Karim, 2022; Charters & McKay, 2020; Koffman et al., 2020). Further, COVID-19 topics may feel more immediate, more relevant, and more consequential to a wider audience compared to topics for which positive effects of hedging have been observed in the general public (e.g., GMOs, cancer, genomics; see Gustafson & Rice, 2020). These factors could have pushed public audiences beyond an uncertainty tolerance threshold, leading to unfavorable effects of hedging in the current study and in other COVID-19 research (see Ratcliff et al., 2022). This may signal a need for unique uncertainty communication strategies for pandemics and other contexts involving extreme (ongoing, multifaceted, and/or high-stakes) uncertainty.

Epistemic beliefs and uncertainty information preferences

Unfavorable reactions to the hedged articles were not universal in this study. They occurred primarily for those who believe medical knowledge is fixed rather than continuously evolving and for those with lower PIUS, each representing roughly half the sample. Additionally, hedging strengthened positive vaccine attitudes for those very high in process-oriented epistemic beliefs. For the rest of participants, hedged claims had no statistically significant impact on outcomes. These results correspond with a cross-sectional survey that found people with a need for definite information and who view science as fixed also preferred journalists to deliver definite COVID-19 scientific advice (Post et al., 2021). Interestingly, in our study, epistemic beliefs only moderated the effects of hedging on vaccine attitudes and intentions, whereas PIUS also moderated evaluations of source credibility. Notably, PIUS and epistemic beliefs were only moderately correlated ($r = .35$; see Supplemental Files). In all, these results suggest that PIUS captures something at least partially distinct from epistemic beliefs, or expectations of uncertainty as a normal part of science. Epistemic beliefs and information preferences thus represent two factors that help to explain variation in public audience reactions to uncertainty communication.

It is unclear why PIUS would affect perceptions of *source credibility* when hedging is present, which is an effect that also emerged in our previous study in a different context (Ratcliff & Wicke, 2022). Perhaps this effect belies an assumption among those with low PIUS that scientific uncertainty is a marker of poor-quality research, which in turn makes those reporting it seem less credible. Alternatively, a desire to avoid uncertain information may simply transfer to evaluations of the communicators. Further work to understand the nature of PIUS, as well as its relationship to other variables commonly studied in this context (e.g., scientific literacy, need for cognitive closure, and ambiguity aversion), will be valuable.

It may seem obvious that people who prefer not to receive information about uncertain science would respond unfavorably to hedging. Yet previous work has not directly captured this preference and tested it as a moderator of message effects. Being able to isolate the portion of the public that is less open to information about uncertainty will help researchers to test transparent communication strategies that may be more favorably received by this subpopulation.[6] Further, it will be useful to disentangle the unique influence of different audience characteristics, as each is likely to have different implications for crafting effective messages about uncertainty.

To advance theory on the effects of communicating uncertainty, the PIUS scale could be a useful tool for examining how and why preference for uncertain information varies for different scientific topics. Finally, it may be fruitful to examine whether PIUS is influenced by communication norms; for instance, does repeated exposure to information about uncertainty, perhaps when framed as a normal part of science, increase preference for fuller disclosure of uncertainty?

Limited public understanding of scientific preprints

Unlike hedging, preprint disclosure had no impact on audience message evaluations, nor vaccine attitudes and intentions. In one sense, this is a positive finding in that transparency about preprint status is unlikely to produce negative public reactions. Yet a likely explanation for the null effects is that most participants lacked the knowledge to differentiate between preprints and peer-reviewed research and did not understand this disclosure as an indicator of preliminary science. The qualitative data supported this explanation. When asked how they interpret the term "preprint" when they see it in a scientific news article, participants' responses indicated that most had a limited understanding of the concept, even among those who received the preprint disclosure message with a brief explanation of the term. In total, only 10% of participants provided definitions of preprint that aligned with those accepted by the scholarly community. Only 15% described the term as an indicator of uncertain or preliminary evidence. Follow-up analyses showed that these responses were unrelated to which message participants received.

While it is possible that participants cursorily skimmed the article, we included data only from participants who passed the attention checks. Further, participants perceived the evidence as uncertain when hedging was present in the message, suggesting a level of attentiveness. Thus, we suspect that most participants simply had no prior frame of reference to process the preprint disclosure and therefore didn't register this information as meaningful. Our results align with other recent findings suggesting that nonexperts have a limited understanding of the concept of preprint research unless they are first provided with a detailed explanation about the nature of peer review (Cyr et al., 2021; Wingen et al., 2022). This means disclosure of preprint status is likely to go unnoticed by a majority of public audiences, who may then assume the science is a vetted part of the scientific record. This is worrisome given that many journalists rely on preprint disclosure to communicate the tentative nature of unreviewed findings (Massarani et al., 2021) or are being encouraged to do so (Caulfield et al., 2021; Ordway, 2020). A simple mention of preprint status or brief explanation of the evidence as preliminary or un-peer reviewed – which is how preprint disclosures typically manifest in news reporting (Fleerackers, Riedlinger, et al., 2022; van Schalkwyk & Dudek, 2022) – may not be sufficient to inform the public. A lengthier explanation, such as the kind proposed by Wingen et al. (2022), may be called for.

Theoretical and practical implications

Currently there is limited theory to explain how public audiences process information about uncertain science (Paek & Hove, 2020; Ratcliff et al., 2022). As scholars work toward developing theory in this area, the results of this study underscore the importance of taking into account both message features (e.g., the type of uncertainty disclosure) and audience characteristics (e.g., epistemic beliefs and information preferences). As previously discussed, theorizing that illuminates why public audiences react differently to uncertainty disclosure depending on the scientific topic or communication context is also critically needed.

From a practical standpoint, we think scientific uncertainty should be appropriately conveyed when journalists and other public communicators report on preprint research, in line with recommendations (e.g., Caulfield et al., 2021; Ordway, 2020). Although being transparent about uncertainty can produce negative reactions in some audience segments, at least in the short term, failing to communicate uncertainty can create perceptions of inconsistency, inaccuracy, or lack of transparency, which may ultimately jeopardize public trust in science and journalism (Abdool Karim, 2022; Saitz & Schwitzer, 2020). Given the ethical imperative to communicate about science accurately and transparently (Figdor, 2017; Medvecky & Leach, 2019), a pressing question is how to convey uncertainty without lowering public trust and willingness to perform recommended public health behaviors. Framing uncertainty about scientific results, including deficient knowledge and preliminary evidence, as a normal part of the research process could help to mitigate negative impacts (see Han et al., 2021; Hodson et al., 2022; Simonovic & Taber, 2022). Related to this, more frequent disclosure of scientific uncertainty in public messaging could, over time, shape public audiences' epistemic beliefs and preference for communication of uncertainty. This highlights the need for more research on how audiences respond to different framings of scientific uncertainty, particularly over time and in contexts in which failing to effectively disclose uncertainty poses grave risks to public wellbeing.

There may also be more effective ways of disclosing preprint status that support audience knowledge of preprints. Preprints are an increasingly prevalent form of scholarly communication, and reporting on them appears to be a new norm for many health and science journalists (Fleerackers, Moorhead, et al., 2022). To support public literacy about preprints, we encourage others to build on our work, further illuminating how audiences view these unreviewed research studies and whether some disclosure frames might enhance understanding.

Limitations of the research

Several limitations of this research should be considered. First, given the topic and timing of the study, more research is needed before concluding that these results will replicate for other scientific issues, including other COVID-19 topics or for COVID-19 vaccine studies at other points during the pandemic. Studies that compare effects across time and across scientific issues will create valuable insights about how audiences respond to uncertainty communication under different circumstances. Second, we conducted this study with only a U.S. sample. Given that studies with German audiences found favorable or neutral orientations toward information about scientific uncertainty in COVID-19 contexts (e.g., Janssen et al., 2021; Wegwarth et al., 2020), it would be fruitful to explore cultural differences in reactions to uncertainty disclosure. Third, we did not measure participants' vaccine status or capture their attitudes and intentions before message exposure, so we were unable to account for their influence on the outcomes. Lastly, while our manipulations focused on disclosing two different types of uncertainty (i.e., deficient knowledge, preliminary evidence related to preprint status), our measure of audience uncertainty perceptions did not distinguish between these two types. Future research could replicate our work using measures that allow participants to specify the types or sources of uncertainty they perceive, including whether they perceive consensus uncertainty, as noted earlier.

Conclusion

Testing public responses to the explicit mention of preprint status in media coverage of scientific research is a novel contribution of this study, with relevance to the communication of COVID-19 evidence and to health and science journalism more broadly (Fleerackers, Riedlinger, et al., 2022; Fleerackers, Moorhead, et al., 2022). We examined the effects of two forms of uncertainty disclosure about preprint science on COVID-19 vaccines. In line with other research (see Ratcliff et al., 2022), conveying scientific uncertainty through hedging produced lower ratings of news article credibility and scientist source credibility, and lower intention to receive a COVID-19 vaccine, among certain segments of the sample. However, disclosing preprint status had no effects. To complement and contextualize these results, we used an open-ended question to assess participants' understanding of the concept of a scientific preprint. Overall, participants exhibited low understanding of the concept. Given the likelihood that preprints will continue to be a tool scientists use to disseminate their research, further work examining the implications of preprints on the public's understanding of research, science, and publishing will continue to be a pressing issue for health communication scholarship.

Notes

1. https://connect.biorxiv.org/relate/content/181
2. We included these statements of assurance, which were present in the original news article, in all conditions to avoid raising doubt about vaccine efficacy, which we believe could have ethical consequences that outweigh the benefits of a cleaner manipulation. Additionally, participants were debriefed about the manipulations after the study and given the chance to read the original news article.
3. Because we administered the PIUS scale posttest, we examined whether participants' condition may have influenced their response to the scale. Participants who received hedged messages reported slightly lower preference for uncertain information ($M = 3.82$, $SD = .88$) than those who received unhedged messages ($M = 3.96$, $SD = .85$), but the difference was not statistically significant ($M_{diff} = .14$, $p = .091$). There was no difference in preference between those who received preprint disclosure ($M = 3.93$, $SD = .83$) versus non-disclosure ($M = 3.87$, $SD = .90$; $M_{diff} = .06$, $p = .480$). Therefore, we assume PIUS was not influenced by the experimental messages.
4. This made it possible for the stimulus to influence participants' open-ended responses, so we used a chi-square test to assess whether people in the preprint disclosure conditions gave more accurate definitions of preprint. As described in the Supplemental Files, there was no evidence of a contaminating effect.
5. The WHO reported in March 2021 that "mild side effects after getting vaccinated . . . are signs that your body is building protection" (WHO, 2021). This claim received widespread news coverage. The information presented in our study pertained to uncertainty about whether a person was still protected in the *absence* of side effects. It is possible that some people misinterpreted this to indicate uncertainty about the link between side effects and efficacy in either direction, which could have created a perception of conflicting information.
6. It will be useful to gain a sense of how common low (or high) PIUS is in the general population. We can offer two data points. When examining the distribution of a continuous variable, the 16^{th}, 50^{th}, and 84^{th} percentiles are useful benchmarks for low, moderate, and high levels (Hayes, 2018). In the current study, mean scale values representing the 16^{th}, 50^{th}, and 84^{th} percentiles of PIUSwere 3.00, 4.00, and 4.86, respectively (range: 1–5). Therefore, negative effects of hedging occurred for participants with low to moderate PIUS ($M \leq 3.76$–4.11, depending on the outcome), and these participants comprised roughly half the sample. We observed a similar distribution in another study (Ratcliff & Wicke, 2022), where mean values representing the 16^{th}, 50^{th}, and 84^{th} percentiles were 3.43, 4.00, and 4.71. In that study, which investigated similar research questions in a different health context, negative effects of hedging on scientist trustworthiness and news credibility occurred only for those with low PIUS (~20%), while positive effects occurred for those with high PIUS (~20%), and the rest of the sample responded neutrally to hedging. The topic of that study was a relatively low-stakes issue, which could explain why responses to hedging were generally more favorable in that study compared to the current study.

Author contributions

CR, AK, and JJ conceptualized the study and developed the questionnaire. CR and RW developed the experimental stimulus. JJ supervised data collection. CR performed quantitative analyses. CR and AF developed the codebook and analyzed the qualitative data. CR, AF, RW, and BH wrote the manuscript and AK and JJ provided substantive comments on the manuscript.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The work was supported by the University of Utah Immunology, Inflammation, and Infectious Disease Initiative [PIs: J. D. Jensen & A. J. King].

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Data availability

Data and supplementary materials are available at https://osf.io/w4djv/.

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