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ARTICLE

Communicating scientific uncertainty during the COVID-19 pandemic: A turning point for journalism?

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Abstract

The COVID-19 pandemic exposed media professionals to the complex challenge of communicating scientific uncertainty. Using an automated, dictionary-based approach, we examined how different types of publications addressed scientific uncertainty at both the onset and the declared end of the pandemic. In the early stages of this health crisis, both general interest and science-focused media showed increased scientific uncertainty scores, with specialised outlets using scientific uncertainty markers more frequently. When the pandemic was declared over, science-focused publications maintained high scientific uncertainty levels across all stories, while general interest media reverted to pre-COVID-19 levels. The findings provide insights for journalists and science communicators.

Keywords

Health communication; Science and media; Science writing

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1 ▪ Context

The pursuit of knowledge often implies complexities and challenges, but science proposes a framework to tackle them. Science advances our understanding of the intricate systems around us through its constant questioning and reevaluation, a slow process that involves uncertainty [Provenzi & Barello, 2020]. Scientific uncertainty is a marker of intellectual humility, showing that the world is unpredictable and variable and that our understanding of it constantly improves but will never be complete; it is "a check against the arrogance of assuming deterministic control over natural phenomena" [Marcot, 2020, p. 2]. There are different flavours of scientific uncertainty — it can stem from a gap in knowledge, limitations in models or statistical assumptions, the lack of scientific consensus on specific matters, or simply unknown unknowns [Gustafson & Rice, 2019]. The inherent doubt that surrounds scientific endeavours is a fundamental feature of science, not a flaw, because it pushes researchers to refine and expand their work, explore new hypotheses, and conduct novel studies [Kampourakis & McCain, 2019].

Despite the scientific uncertainty's established role, it is often misunderstood or misrepresented by those tasked with disseminating scientific knowledge, including science communicators and journalists [Lehmkuhl & Peters, 2016; Guenther et al., 2019; Stollorz, 2021; Ratcliff, 2021; Fleerackers, Riedlinger et al., 2022]. Although there is a trend toward acknowledging scientific uncertainty in certain contexts of science communication [Ruhrmann et al., 2015; Guenther & Ruhrmann, 2016], journalists often fail to recognise its importance [Stocking & Holstein, 2009; Guenther & Ruhrmann, 2016], maintaining the tendency of portraying science as more certain than it is [Lehmkuhl & Peters, 2016; Guenther et al., 2019; Stollorz, 2021; van Schalkwyk & Dudek, 2022], or believe their audiences prefer straightforward information [Stocking & Holstein, 2009].

Journalists make critical decisions, choosing the scientific findings they cover and the angle they use, often operating under time constraints and having limited resources [Murcott & Williams, 2013; Bottesini et al., 2023]. Additionally, in recent years, science journalism has faced crises driven by increasing digitisation and an evolving media landscape, which resulted in job losses [Guenther, 2019] and personnel fluctuations, issues potentially exacerbated during the COVID-19 pandemic [Dawson et al., 2023].

Understanding the role scientific uncertainty plays and explaining it to diverse audiences requires a complex set of skills, which includes a good grasp of the scientific method and robust journalistic expertise. Both are necessary to introduce scientific uncertainty in a manner that represents science honestly, and maintains or enhances the public's confidence in the scientific pursuit [Kreps & Kriner, 2020; van der Bles et al., 2019]. In fact, journalists' perceptions of their audiences' expectations and their intent to maintain public trust in science and experts often play a key role in deciding whether to include or omit scientific uncertainty [Guenther & Ruhrmann, 2016]. While some media professionals and researchers argued that conveying scientific uncertainty can be detrimental and can decrease the public's trust in experts [Stocking, 1999; Guttman & Lev, 2021], most studies and guides recommend transparency for the same reasons [Frewer et al., 2002; Retzbach & Maier, 2015; Jensen et al., 2017; Gustafson & Rice, 2019; Hendriks & Jucks, 2020; Han et al., 2021]. Some researchers argue that while downplaying scientific uncertainty may be effective in the short term, it can have adverse long-term consequences [Kreps & Kriner, 2020].

When scientific uncertainty is conveyed, journalists typically include the need for future research, the limitations of studies, the ongoing debates within the scientific community, and the chances of particular situations or events happening [Painter & Ashe, 2012; Bailey et al., 2014]. Sometimes, scientific uncertainty is discussed in the context of risk [Guenther & Ruhrmann, 2013]. Topic-wise, journalistic materials on medicine and natural sciences tend to include more scientific uncertainty compared to other niches of science journalism [Guenther et al., 2019].

Scientific uncertainty played a central role during the COVID-19 pandemic [Ratcliff et al., 2022], a disruptive global crisis with effects on journalism that are not yet fully understood. This pandemic offers a unique opportunity for analysing the role journalism played in disseminating rapidly evolving scientific information during a time of declining public trust in both the journalism and the scientific world. This health crisis, which served as a "crash course in scientific uncertainty" [Mandavilli, 2021], exerted a "multitude of profound effects" on science journalism, offering "an opportunity to rethink the meaning and practices" of media professionals [Quandt & Wahl-Jorgensen, 2021]. Since disruptive incidents can challenge editorial practices, routines and norms [Ustad Figenschou & Thorbjørnsrud, 2017; García-Avilés, 2021], the COVID-19 pandemic can have the potential to reshape how media professionals report on evolving scientific knowledge and communicate scientific uncertainty to the public.

2 ▪ Theoretical considerations

This study aims to investigate whether a major event such as the COVID-19 pandemic can challenge how journalists communicate scientific uncertainty. To assess the impact of such events on journalistic practices, we analysed articles published during the COVID-19 pandemic, which highlighted the challenges of reporting on scientific uncertainty.

During the early stages of this health crisis, information was often incomplete, contradictory, or inaccurate [Ratcliff et al., 2022]. Researchers felt pressured to present findings rapidly, even when they were preliminary [Callaway, 2020], and journalists had the complex task of navigating an overwhelming volume of information. As the number of COVID-19 cases grew, the pandemic became the main story in both science-focused and general interest media [Krawczyk et al., 2021]. Journalists faced multiple challenges. These include the complexity of covering science in the making [Litvinenko et al., 2022; Jamil, 2023], increased workload [Massarani et al., 2021], limited resources available and insufficient training [Jamil, 2023], threats to press freedom [Papadopoulou & Maniou, 2021; Litvinenko et al., 2022], spread of misinformation [Krause et al., 2020; López-García et al., 2021; Massarani et al., 2021; Perreault & Perreault, 2021], and issues related to mental health [Osmann et al., 2021; Šimunjak, 2022]. Covering ongoing science was particularly challenging due to the ambiguity and disagreements surrounding COVID-19 metrics [Pentzold et al., 2021], the high volume of non-peer-reviewed papers available online [Fraser et al., 2021], and the typical characteristics of crisis situations [van Schalkwyk & Dudek, 2022]. Not all coverage was thorough or accurate [Ratcliff et al., 2022]. Media professionals without a scientific background and the expertise to verify the quality of scientific studies [Fleerackers, Moorhead et al., 2022] occasionally cited sources that did not follow the scientific consensus, giving a platform to viewpoints unsupported by evidence [Perreault & Perreault, 2021].

When it comes to scientific uncertainty during the COVID-19 pandemic, some studies show that journalists who typically cover science had a better understanding of the concept compared to non-specialist reporters [Capurro et al., 2021]. Although journalists' perception of their audiences also plays a role, this may also influence how uncertainty is communicated. Previous research has shown that science-focused publications tend to rely on specialised journalists, while general interest media often employ, at least in part, generalist reporters and/or editors to cover science [Mukiza, 2022; Anderson & Dudo, 2023], who are often less expensive [Dunwoody, 2020]. Generalist reporters may not adhere to up-to-date science journalism guidelines [Stollorz, 2021; van Schalkwyk & Dudek, 2022; Fleerackers, Riedlinger et al., 2022] and may lack the specialised knowledge needed to critically assess scientific findings, potentially leading to oversimplifications or omissions. In general interest media, scientific uncertainty was rather downplayed than exaggerated during the COVID-19 pandemic [Ratcliff et al., 2022]. When covering unproven medication, these outlets rarely mentioned that evidence was limited [Watson et al., 2024]. The overall scientific quality of the stories published by general interest media was described as "moderate", with populist-right-oriented publications tending to be on the lower end of scientific rigour [Mach et al., 2021]. By contrast, specialised media likely approached pandemic coverage with a stronger focus on scientific accuracy and nuance. Given these observed differences in how scientific uncertainty is communicated across various types of outlets, it can be expected that articles from science-focused publications are more likely to report scientific uncertainty than those from general interest media.

Hypothesis 1: Articles from science-focused media are more likely to convey scientific uncertainty than those in general interest media.

During the COVID-19 pandemic, the media served a crucial role in keeping the public informed. However, providing audiences with quick, straightforward information while representing science accurately and capturing its nuances — such as scientific uncertainty — was challenging [Ratcliff et al., 2022]. During the COVID-19 pandemic, journalists took on the responsibility of communicating scientific information, trying to counter mis-/disinformation [Perreault & Perreault, 2021]. The media transitioned from traditional Watchdog and Infotainment roles to Public Service [Hallin et al., 2023]. Specialised journalists, more so than non-specialists, demonstrated a better understanding of the rationale behind continuously evolving health guidelines and assumed greater responsibility for disseminating accurate scientific information [Capurro et al., 2021]. Examining how outlets reported on this crisis could provide valuable insights into the role played by media in other public health emergencies, including pandemics. Considering the increased responsibility of journalists to accurately convey scientific information, it is likely that the COVID-19 outbreak in 2020 led to more reporting of scientific uncertainty.

Hypothesis 2: The onset of the COVID-19 outbreak in 2020 resulted in increased reporting of scientific uncertainty.

The COVID-19 pandemic was marked by a high degree of scientific uncertainty, prompting the question of whether this heightened uncertainty was exclusive to COVID-19 reporting or if other science journalism topics from the same period also reflected increased scientific uncertainty. This analysis could reveal whether the unique demands of COVID-19 coverage had a ripple effect, influencing how scientific uncertainty was presented across other topics

of science journalism. The increased responsibility of journalists to convey scientific information would be best observed in relation to content, with COVID-19-related articles expected to exhibit higher levels of scientific uncertainty than non-COVID-19-related articles.

Hypothesis 3: COVID-19-related articles exhibit higher levels of scientific uncertainty compared to non-COVID-19-related science journalism articles.

The COVID-19 pandemic saw a surge of scientific papers published in the form of preprints [Dinis-Oliveira, 2020], which can be problematic. These papers could be presented in a way that emphasises the uncertainty associated with the fact that they have not yet been peer reviewed. However, some authors argue that science journalism stories often lack the necessary detail for readers to critically assess the validity of research [Matthias et al., 2020]. Previous research indicates that journalists often failed to specify when scientific studies were published in the form of preprints, instead referring to them as "research" [Fleerackers, Riedlinger et al., 2022], rarely explaining what the term "preprint" means [Massarani & Neves, 2022]. Given that preprints had not undergone peer review and were frequently reported without clear explanations of their provisional nature, it is important to examine whether COVID-19 articles based on preprints conveyed higher levels of scientific uncertainty compared to those that did not mention preprints directly.

Hypothesis 4: In 2020, COVID-19 articles based on preprints exhibited higher levels of scientific uncertainty compared to articles that did not mention preprints.

3 ▪ Methods

3.1 ▪ *Data selection*

The focus of the current investigation was on the first three months of the COVID-19 pandemic (March 1, 2020–May 31, 2020), a period marked by a surge in scientific papers on the virus and the disease, often yielding conflicting results [Kousha & Thelwall, 2020; Dinis-Oliveira, 2020]. For comparison, three additional timeframes were considered: (1) the following three months of the COVID-19 pandemic (June 1, 2020–August 31, 2020); those exact six months (2) three years before the pandemic (March 1, 2017–August 31, 2017); and (3) three years after (March 1, 2023–August 31, 2023). The year 2023 was chosen because the World Health Organization [2023] declared the COVID-19 pandemic over on May 5, 2023, despite the continued spread of the virus. These intervals were selected to analyse how journalistic practices of communicating scientific uncertainty have evolved over time. They allowed us to observe the scientific uncertainty spike at the beginning of the COVID-19 pandemic and the subsequent period in which communication surrounding the health crisis started to stabilise. The 2017 pre-COVID-19 pandemic data served as a baseline for comparison, while the 2023 data was used to detect potential shifts in the communication of scientific uncertainty.

Online articles were extracted from one of the largest English-speaking general interest media (daily newspaper *The Guardian*) alongside three prominent science-focused publications (*Scientific American*, *National Geographic*, and *Quanta Magazine*). The general interest publication was considered because most readers typically depend on such outlets for science news [Funk et al., 2017], and previous studies on other publications such as

The New York Times or *Business Insider* showed even weaker scientific uncertainty framing compared to *The Guardian* [Fleerackers, Riedlinger et al., 2022]. All outlets were chosen for their wide readership (while *Quanta*'s website has a smaller readership, it has numerous syndication partners), authoritative voice, and established reputation for high-quality reporting [Bold, 2018; Elyamany, 2019; Edmonds, 2020; Grau, 2022]. The science-focused publications are based in the US but have a global readership. *The Guardian* is headquartered in the UK, but it employed a team of approximately 60 editors, reporters, and correspondents in the US [Guardian News & Media, 2014]. Its size and resources were more comparable to those of the science-focused publications analysed, as opposed to other large general interest outlets headquartered in the US. Additionally, articles from this general interest publication were freely accessible and not placed behind a paywall, unlike outlets such as *The New York Times*, which only temporarily lowered paywalls for select COVID-19-related content. The inclusion of three science-focused outlets, which publish fewer articles and have fewer resources compared to general interest publications like *The Guardian*, allowed for a more balanced and more detailed examination of specialised scientific journalism within a manageable dataset.

Journalistic materials from general interest media were extracted using the website's application programming interface (API), which ensured a systematic collection of the data. The keywords used for the query were *study* and *research** (at least one reference to any of the words: *research*, *researchers*, *researchers*, and *researched*), as these words are commonly used by journalists reporting on scientific studies and novel research [Facsnet, 2023; Science News, 2024]. Articles from science-focused publications were identified through Google searches that used the same keywords. The data collection excluded journalistic materials that did not qualify as standalone articles but fell under different types of online content, such as pages profiling authors, op-eds, tag pages, and *The Guardian's Live updates* section. Additionally, blog posts and podcast episodes were eliminated.

In total, N = 4,399 articles were considered for this study. More information about the methodology and the classification and selection methods is described in section 3.3.

3.2 ▪ *Uncertainty measurements*

Our study uses quantitative content analysis to assess the prevalence of scientific uncertainty in general interest and science-focused media. Due to the large number of articles that needed to be processed, we used a dictionary-based approach, building a custom set of words [Neuendorf, 2017] associated with scientific uncertainty. This method has several advantages: efficiency, consistency and scalability, as well as its potential to reduce human error, since human-coded content requires assessing intercoder reliability, as inconsistencies between coders can affect the validity of manual content analysis [Conway, 2006].

To build our dictionary, we integrated several pre-existing dictionaries for scientific uncertainty used in the context of communicating scientific results, all of which had been previously developed and validated. By combining these resources, we created a tool that captures a wide range of linguistic markers associated with scientific uncertainty. Additionally, we manually scored the articles alongside the automatic scoring and tested the tool's results on a random sample of articles (N = 25) from our dataset to confirm that it accurately flagged scientific uncertainty markers. Our dictionary included two lists of words described in the scientific uncertainty dictionary created by Zerva et al. [2017]: Admission of

Lack of Knowledge and Strong Speculation. The first category featured linguistic markers used to showcase gaps in knowledge or understanding: “unclear”, “unknown”, “to the best of our knowledge”, and “yet unclear”. The second category comprised terms that strongly suggest the lack of definitive scientific evidence, such as “hypothesize”, “speculate”, “possibly”, and “propose”. We also employed Dral et al. [2011]’s dictionary for scientific uncertainty, which was made of 13 scientific uncertainty markers such as “approximately”, “around”, “perhaps”, and “somewhat”. In addition, we used words and expressions identified by Kreye et al. [2022], who studied how scientific uncertainty evolved over time during a complex event, a situation analogous to the COVID-19 pandemic. The Kreye et al. [2022] dictionary included terms like “speculat*”, “hesita*”, “ambivalen*”, “doubt*”, “(im)probabl*”, “ambigu*”, “*istrustful”. All markers were assigned equal weight, for simplification purposes. When a specific term was part of more than one dictionary, it was only considered once.

3.3 ▪ *Dataset description*

To isolate the factors of interest for the current study (i.e., materials that included scientific uncertainty, materials that quoted scientific studies), our approach to dataset classification prioritised false negatives over false positives with restrictive inclusion criteria. While some relevant articles may have been excluded (false negatives), those included were certain to discuss research and scientific uncertainty, minimising the risk of incorrectly classifying unrelated content as relevant (false positives). The advantage of this approach is higher precision and reliability in identifying relevant articles. the trade-off is the potential exclusion of some materials that address scientific uncertainty. While this approach carries some risk, it was preferred over the alternative of introducing false positives, which could create artifact effects and lead to misinterpretation of the results.

Scientific uncertainty was conceptualised as both a quantitative variable to be employed in time evolution analysis (total counts as scientific uncertainty score) and a qualitative variable used in frequency comparisons (“high uncertainty” or “HU” for above-median scientific uncertainty scores and “low uncertainty” or “LU” for below-median scientific uncertainty scores). In line with the restrictive inclusion criteria, median values were included in the “low uncertainty” category.

To examine journalistic trends in relation to the COVID-19 pandemic, we divided the articles into two categories: one made of materials with at least three mentions of the words *covid* and *coronavirus*, and another one which excluded these words entirely. These terms were directly associated with the COVID-19 pandemic and were common throughout the entire timeframe (2020–2023), unlike other keywords, which were typically present at different stages of the health crisis. The use of *covid* and *coronavirus* as consistent markers allowed us to capture pandemic-related journalistic materials conservatively, while excluding articles with only passing references to the crisis. We chose this because the COVID-19 pandemic saw a wide array of articles mentioning the virus or the disease spanning over multiple beats, from sports to economy to science.

Furthermore, for COVID-19-related journalistic materials published in 2020, we also looked at direct mentions of the word *preprint* and other similar indicators that the journalistic material included references to studies that have yet to be peer reviewed. The list of relevant terms was developed using insights from Fleerackers, Riedlinger et al. [2022] and was refined through a manual analysis to identify additional markers indicative of pre-peer review

Table 1. Descriptive statistics.

Variable	*Statistics*
Uncertainty score	Min = 0, Max = 173,
	Mean =17.92 (sd = 13.99), Median = 15
Level of uncertainty:	
High uncertainty, HU (> 15)	2,069 (47.03%)
Low uncertainty, LU (<= 15)	2,330 (52.97%)
Text type:	
Science-focused	1,002 (22.78%)
General interest	3,397 (77.22%)
Publication time frames:	
March 1, 2017–August 31, 2017	1,578 (35.87%)
March 1, 2020–May 31, 2020	683 (15.53%)
June 1, 2020–August 31, 2020	679 (15.44%)
March 1, 2023–August 31, 2023	1,459 (33.16%)
Publication year:	
2017	1,578 (35.87%)
2020	1,362 (30.96%)
2023	1,459 (33.17%)
Covid-19-related articles (texts for 2020):	
Yes	651 (47.80%)
No	711 (52.20%)
"Preprint" (in Covid-19-related articles from 2020):	
Preprint mentioned	68 (10.45%)
Preprint not mentioned	583 (89.55%)

status. The final list included terms such as *awaiting peer review*, *not peer reviewed*, *not yet peer reviewed*, *undergoing peer review*, *unreviewed*, *submitted for review*, *in review stage*, *pre-publication*, *pending peer review*, and *awaiting review*.

The variables were operationalised as shown in Table 1, with the corresponding descriptive statistics presented.

4 ▪ Results

The Hypotheses in this study examined potential shifts in how general and science-focused media conveyed scientific uncertainty. The study examined temporal trends by comparing the onset of the COVID-19 pandemic in 2020 with three years before and after the onset (i.e., 2017 and 2023). All analyses were performed using R Statistical Software [v4.2.1; R Core Team, 2022]. Manipulation of data, data visualization and test statistics were obtained by employing the *tidyverse* R package [v2.0.0; Wickham et al., 2019], *ggpubr* [v0.4.0; Kassambara, 2020], *ggplot2* [v3.5.1; Wickham, 2009], *ggstatsplot* [v0.9.5; Patil, 2021], *ggsignif* [v0.6.3; Ahlmann-Eltze & Patil, 2021], and *RColorBrewer* [v1.1.3; Neuwirth, 2022].

Hypothesis 1 and 2 considered timely changes from 2017 to 2020 and 2023, focusing on the COVID-19 pandemic's first three months (March–May) and the subsequent period (June–August). As illustrated in Figure 1, the trend shifted across the years. In 2017, general

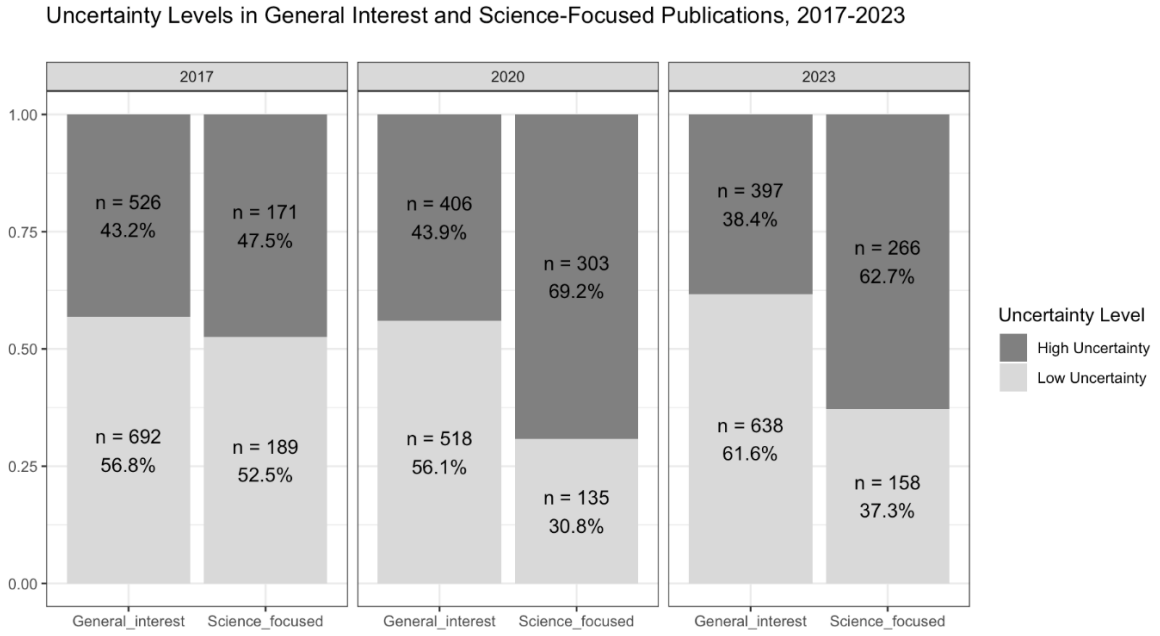

Figure 1. Scientific uncertainty levels in general interest and science-focused media.

interest and science-focused media did not differ significantly in terms of including scientific uncertainty in their communication ($\chi^2 = 13.38$, $p = .15$, $\phi = .03$), but 2020 represented a year of disruption ($\chi^2 = 75.84$, $p < .01$, $\phi = .23$) that maintained later into 2023 ($\chi^2 = 72.10$, $p < .01$, $\phi = .22$) with science-focused publications including higher scientific uncertainty.

The results revealed 2020 as a year of a shift in writing practices of conveying scientific uncertainty. If, in 2017, no significant difference was observed in the level of scientific uncertainty communicated by the general and science-focused media, from 2020, the strategy departed between the two types of outlets: science-focused publications proposed materials containing a higher level of scientific uncertainty, and general media reverted to low scientific uncertainty. This trend of science-focused publications containing high scientific uncertainty while general interest media opting for low scientific uncertainty remained the same by 2023. While science-focused media tend to contain relatively high scientific uncertainty, both pandemic and post-pandemic, general interest media only deal with high scientific uncertainty exceptionally.

Looking into the monthly changes, as shown in Figure 2 below, the onset of the COVID-19 pandemic impacted journalists' writing practices regarding scientific uncertainty. In 2017, excluding a short departure in April, the scientific uncertainty score drew similar trend lines (uncertainty scores around or below 15) for general and science-focused publications (*Kruskal-Wallis H* = 2.69, $p = .10$, $\eta^2 < .01$). However, the communication strategies appeared to have departed after the onset of the COVID-19 crisis (March–May), with science-focused publications constantly increasing the scientific uncertainty until June while general interest media continually decreasing it after the first month (*Kruskal-Wallis H* = 139.25, $p < .01$, $\eta^2 = .10$). After June 2020, the general interest media bounced back to levels similar to those in 2017 (uncertainty scores around or below 15), while science-focused publications kept the scientific uncertainty reporting at higher levels (uncertainty scores above 15). The difference between the two outlet types was still visible in 2023 (*Kruskal-Wallis H* = 95.04, $p < .01$, $\eta^2 = .07$).

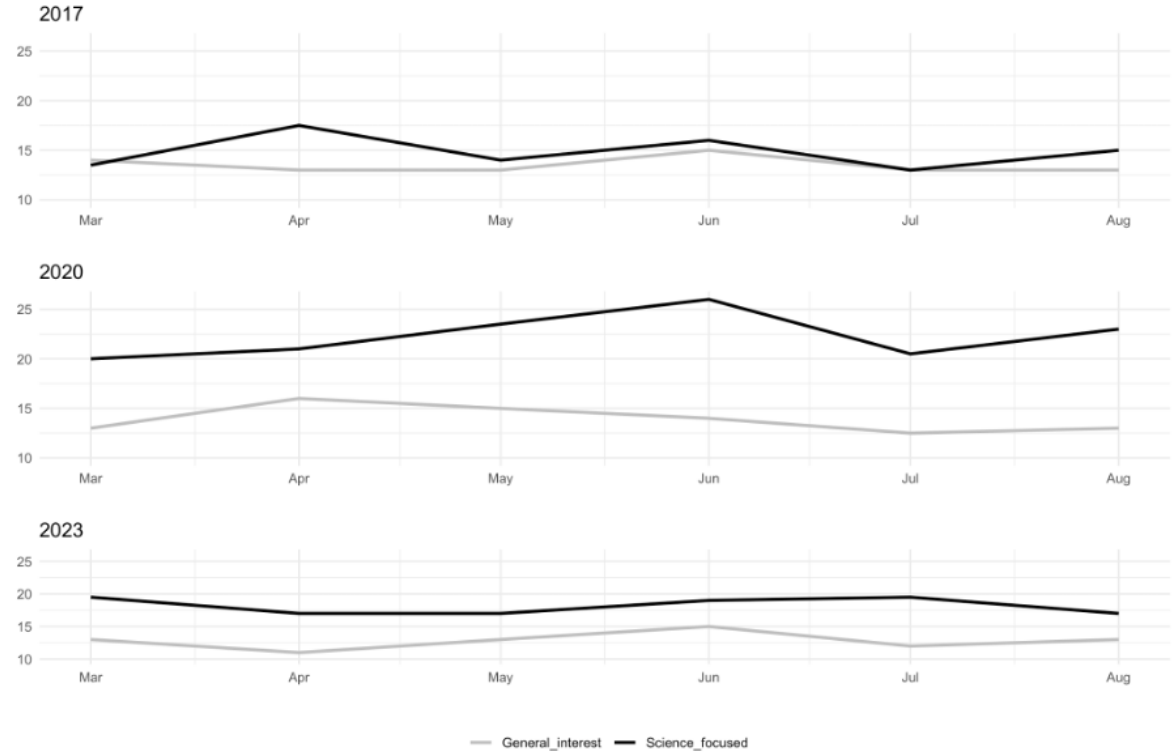

Figure 2. Scientific uncertainty score evolution in 2017, 2020, and 2023 for general interest and science-focused media.

Hypotheses 3 and 4 approached the journalistic practices of conveying scientific uncertainty by considering content, such as the actual conversation around COVID-19 or the journalistic popularisation of preprint studies. This part of the investigation only considers materials from 2020. As shown in Figure 3 below, general interest media had different practices when it came to scientific uncertainty regarding COVID-19 and non-COVID-19 content ($\chi^2 = 69.00$, $p < .01$, $\phi = .27$), while science-focused publications had more consistent practices of conveying scientific uncertainty with the same trend for COVID-19 and non-COVID-19 content ($\chi^2 = 3.85$, $p = .05$, $\phi = .08$). This result is consistent with the sudden spike and bounce back of uncertainty score in the case of general interest media between March 1, 2020 and May 31, 2020, as shown in Figure 2 above. When mentioning preprint studies, journalistic materials published in science-focused outlets did not report higher scientific uncertainty ($\chi^2 = 1.16$, $p = .28$, $\phi = .03$; Figure 4). Neither did general interest media ($\chi = 1.33$, $p = .25$, $\phi = .03$; Figure 4). The null result may be due to the small sample size, as very few materials mentioned preprints directly.

COVID-19 content led to an increase in scientific uncertainty communicated by journalists, but only for general interest media. In other words, general interest media revealed high scientific uncertainty only exceptionally when discussing the COVID-19 pandemic. Science-focused publications had a more consistent practice of conveying scientific uncertainty, and discussed COVID-19 and non-COVID-19 content with similar high scientific uncertainty, revealing a stable understanding of the nature of science. Mentioning preprint studies did not lead any type of publication to report higher scientific uncertainty.

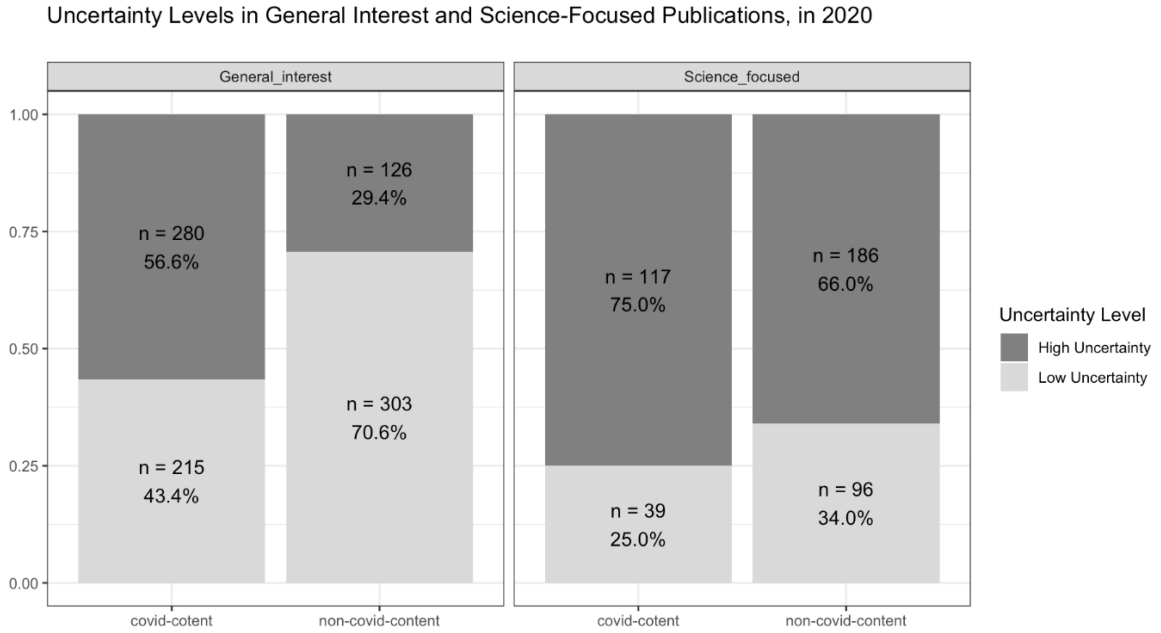

Figure 3. Scientific uncertainty in COVID-19 compared to non-COVID-19 content, in 2020, in general interest vs. science-focused media.

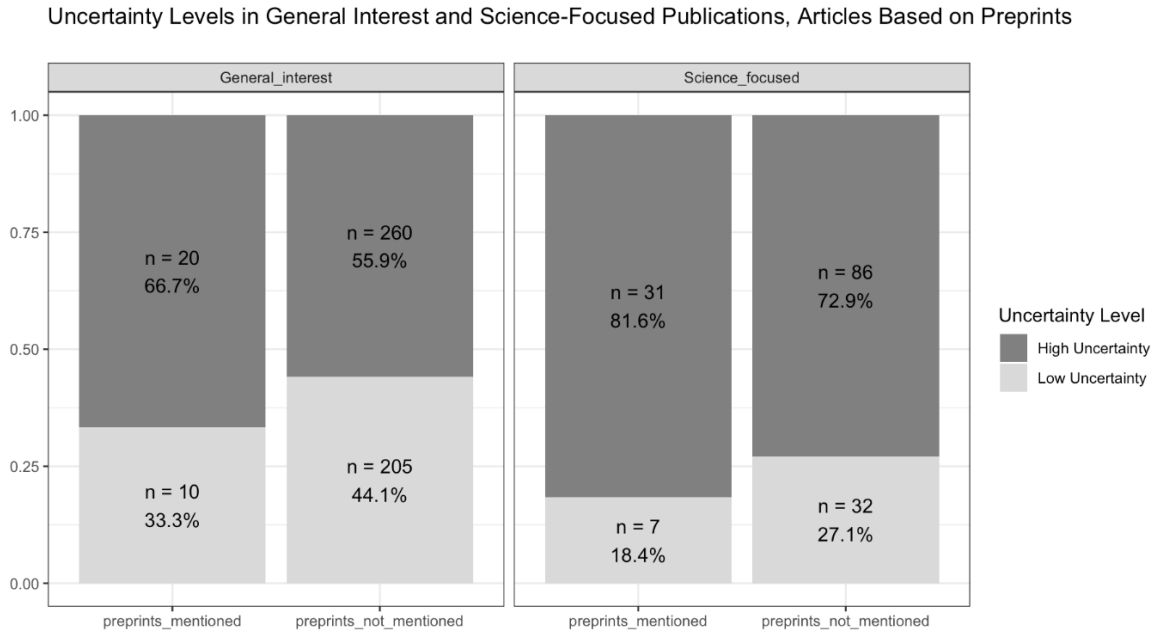

Figure 4. Scientific uncertainty in COVID-19 articles based on preprints, in general vs. science-focused media.

The results reveal a higher awareness of scientific uncertainty with more consistent commitment from science-focused publications. It also showed a subject-specific inclusion of scientific uncertainty from general interest media triggered by the discussions around coronavirus.

5 ▪ Discussion

Uncertainty is an essential feature of the scientific process. It accepts that one can never have complete knowledge over complex systems, it allows for revisions, and highlights areas where further research is needed [Provenzi & Barello, 2020]. However, journalists who cover science often omit scientific uncertainty or misrepresent it [Lehmkuhl & Peters, 2016; Ratcliff, 2021; Mesmer et al., 2024; Bradshaw, 2024]. In this study, we analysed online articles that appeared in science-focused and general interest media to evaluate how scientific uncertainty is conveyed. We included materials from several time intervals to understand whether and how major events involving science could influence journalism practices, at least temporarily. Specifically, we explored whether one such an event, namely the COVID-19 pandemic, could accelerate the adoption of more nuanced reporting, which acknowledges scientific uncertainty.

Our study made notable methodological contributions. We compared how general interest and science-focused media convey scientific uncertainty, considering three timeframes: the onset of the COVID-19 pandemic, pre-pandemic, and the declared end of the pandemic. Articles were processed automatically using a dictionary constructed by joining together sets of words previously associated with scientific uncertainty in science communication. These included markers for admissions of lack of knowledge and strong speculation [Zerva et al., 2017], hedging, modal verbs, and others [Dral et al., 2011; Kreye et al., 2022].

Consistent with previous research [Ruhrmann et al., 2015; Guenther & Ruhrmann, 2016], our findings suggest that while scientific uncertainty could be downplayed in some instances, some outlets might be becoming increasingly aware of its importance. We noticed that in 2020, both general interest and science-focused media included more linguistic markers consistent with scientific uncertainty compared to pre-pandemic levels. By the declared end of this pandemic in 2023, science-focused outlets maintained higher scientific uncertainty scores than those observed before the pandemic. In contrast, general interest media reverted to levels close to those found before the health crisis. While this issue warrants further study, it may be that science-focused publications started to acknowledge to a higher degree the importance of conveying scientific uncertainty, which prompted them to update their writing practices, while at the same time cultivating an audience that became increasingly equipped to understand the complexities of science. At the same time, general interest media, which cater to broader audiences, may have bounced back to pre-pandemic writing practices, favouring more straightforward narratives.

Our analysis also indicates that science-focused publications were more attuned to the suggestions made by previous researchers who tackled scientific uncertainty [Lehmkuhl & Peters, 2016], as well as to professional guidelines [Hart et al., 2019; Helmuth, 2020; Mulcahey, 2020], which typically recommend journalists be transparent about the uncertainties surrounding the scientific process. While more research is needed, it appears that for science-focused publications, this pandemic may have had longer-lasting effects. Studies conducted before the pandemic indicate that journalists who were more connected with the scientific community had a better understanding of the scientific method and were more likely to draw from a broader range of scientific sources, all of which contribute to more nuanced coverage [Catalán-Matamoros & Peñafiel-Saiz, 2019].

When it comes to scientific uncertainty in COVID-19-related vs. non-COVID-19-related materials, we noticed differences between the two types of media, with general interest

media exhibiting high levels of scientific uncertainty primarily when covering the COVID-19 pandemic, treating it as an exception rather than a standard practice. In contrast, science-focused publications demonstrated a more consistent approach to communicating scientific uncertainty, applying it to both COVID-19-related and non-COVID-19-related journalistic materials, which may suggest a deeper and more stable understanding of the nature of science, as well as a stronger tendency to convey nuances to their audiences. By integrating scientific uncertainty across diverse topics, science-focused outlets appear to demonstrate a stronger commitment to representing the complexities of science. The potential shift between the two types of publications could be attributed to their differing roles and target audiences: general interest media prioritise accessibility for a broad readership, while science-focused publications serve an audience that seeks detailed and accurate portrayals of scientific developments.

Our results have several practical implications. The different manner in which uncertainty was conveyed at the declared end of the pandemic, with science-focused publications appearing to exhibit a long-term shift in writing practices as opposed to general interest media that prioritised accessible information, highlights the need for tailored communication strategies during similar crises, and underscores the importance of integrating scientific uncertainty into all forms of science communication, including science journalism and institutional messaging.

Although we expected to observe a higher degree of scientific uncertainty in journalistic materials that referenced preprints because their results have not yet been validated through peer review, we were not able to confirm this, possibly due to the small sample size, as few materials mentioned preprints directly. It is also possible that journalists who reported on preprints or mentioned them did not always explicitly identify them as such, choosing instead vague language such as *study* or *research* to describe them or used hyperlinks [Fleerackers, Riedlinger et al., 2022]. As these results indicate, reporting on yet unvalidated science still poses challenges. Science communicators, journalists, and policymakers could increase their effort to produce materials that explain the nature of science, and the differences between preliminary and peer review studies.

6 ▪ Conclusion

Our study explored whether major global events that expose journalists to science in progress, such as the COVID-19 pandemic, can serve as a catalyst for how media perceive scientific uncertainty, potentially prompting journalists to upgrade writing practices. We noticed that the onset of this pandemic saw an increase in scientific uncertainty scores in both types of media studied, general interest and science-focused, with specialised publications using scientific uncertainty markers more frequently. Additionally, while science-focused outlets displayed more scientific uncertainty in both COVID-19-related and non-COVID-19-related materials, general interest media used a high number of scientific uncertainty markers mostly in their coverage of the pandemic. At the declared end of the health crisis, writing practices diverged: science-focused publications still had high scientific uncertainty scores in science stories overall, not just COVID-related, while general interest media reverted to pre-pandemic levels. This suggests a more stable approach to scientific uncertainty in science-focused outlets.

Our study has several limitations. One of these stems from the method used; while dictionaries are straightforward and transparent [Rutkowska & Szyszko, 2024], being an efficient tool to assess scientific uncertainty when using a large dataset, computer-assisted methods might be less nuanced than hand-coding and might not capture all instances of scientific uncertainty [Conway, 2006; Günther & Quandt, 2016]. Another limitation arises from the fact that we considered each scientific uncertainty marker to carry the same weight for simplification purposes [Schuster & Degen, 2020; Ratcliff, 2021]. Moreover, we manually checked the tool classification efficacy with a random sample of articles (N = 25) on a small sample. Future studies might employ more robust checks and weighting. Limitations also arise from the dataset. Our study considered journalistic articles written in English and published by *The Guardian*, *Scientific American*, *National Geographic*, and *Quanta*, in which materials from the general interest media outnumbered those from science-focused outlets. Future research could explore how scientific uncertainty was conveyed across a broader sample of publications from different geographies. Another limitation stems from the process of filtering journalistic materials to only include science journalism pieces. Our method prioritised the reduction of false positives and used three mentions in total for the keywords *covid* and *coronavirus* to distinguish between journalistic materials about this health crisis and articles mentioning the pandemic in passing. Other keywords such as *virus* or *pandemic*, which were less specific, were considered less optimal. We also used the keywords *study* and *research** for filtering, although other keywords like *data* or *scientists* could have equally worked. Furthermore, we only considered, conservatively, articles mentioning preprints directly, leaving aside hyperlinks, although some publications use hyperlinks to preprint servers [Fleerackers, Riedlinger et al., 2022]. We chose this because it is not possible to determine whether audiences actually click on links and understand the concept of preprint servers. Similarly, we did not include the term *arXiv* in our dictionary of preprint-related words. Future research might address a methodology to include these concepts. Lastly, our research employed a specific context. Events distinct from the COVID-19 pandemic, a more diverse array of publications analysed [Maier et al., 2016], and potential variations in staffing and journalistic practices across different social and cultural contexts might offer additional insights [Paek & Hove, 2020; Massarani et al., 2021].

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