Unreviewed Science in the News:
Why and How Journalists Cover Preprint Research

by

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Abstract

This dissertation seeks to understand why and how journalists use preprints, or research studies that are publicly available but have not yet been peer reviewed. Scholars post preprints to provide free, rapid access to their research—a practice that increased dramatically during the urgency of COVID-19 pandemic. Although journalists have historically been discouraged from reporting on preprints, media coverage mentioning these unreviewed studies became common during the early months of the crisis.

Through an integrative, multistage mixed method approach, this dissertation investigates the degree to which the coverage of preprints seen during the pandemic represents a departure from, or extension of, journalists' established practices for reporting on peer reviewed research. It does so using a theoretical framework of post-normal science communication—defined as the novel communication practices that can emerge in contexts where scientific uncertainty is high, values are in dispute, the need for decision making is urgent, and much is at stake.

It finds that journalists have used preprints at least occasionally for years, but that COVID-19 rapidly accelerated this use. Journalists are motivated to use preprints because of their timeliness, relevance, and accessibility, but are concerned about their potential to spread misinformation. They actively seek out preprints but also discover them passively through press releases and interviews with researchers. They struggle to verify them, relying on a mix of gut instinct, triangulation with other evidence, skeptical reading, and interviews with unaffiliated scientists—a practice they describe as their "own peer review." Journalists say that it is important to communicate the unvetted nature of preprints in their coverage but do so inconsistently in practice. Instead, preprints are often described in vague terms, as "research" or "data," or referred to using only an uncontextualized hyperlink. Collectively, these results suggest that the preprint-based coverage seen during the pandemic represents a form of semi-post-normal science communication—a mix of tried and tested strategies and novel practices that have the potential to become established journalistic norms.

Keywords: journalism; preprints; Open Science; scholarly communication; COVID-19

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Table of Contents

List of Tables

List of Figures

Chapter 1.

Introduction: COVID-19 and the Rise of Preprints in Journalism

"COVID changed everything."

These three words describe so many aspects of our lives: How we work, travel, socialize, grieve. How we think about immunity, risk, uncertainty, vulnerability. Who we trust for information. How we make decisions about our health and safety. What it means to connect, build relationships, be a part of a community.

But when Jim Handman uttered these words in an interview for *University Affairs* (Owens, 2022, para. 3) he had something different in mind. In the urgency of the pandemic, he had noticed a new practice emerging in science journalism: reporting on unreviewed research studies, or "preprints."

Preprints have long been used in scholarly communication, chiefly because they allow researchers to share their results more rapidly than is possible through peer reviewed journal publishing (Puebla et al., 2022). But while preprints are increasingly embraced by scholars, their use has long been discouraged in journalism—largely because of fears that findings may not hold up in the long term (Froke et al., 2020; Haelle, 2019). Without the safeguards of peer review, preprints leave journalists tasked with the challenging task of discerning trustworthy, credible science from potentially misleading, flawed, or even fraudulent claims.

At the time, Handman was the executive director of the Science Media Centre of Canada (SMCC), which provides resources for journalists in hopes of supporting "media coverage of science that is more informed, more accurate and more incisive."[1] Until recently, it operated under a strict "no preprint" policy, meaning studies had to be peer reviewed and published to be included in the roundup of new papers SMCC shares with

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[1] http://sciencemediacentre.ca/site/about-us/

journalists each week. But the need for timely evidence about COVID-19, along with the surge in preprint use among scholars during the pandemic, caused SMCC to reconsider. It started to circulate COVID-19-related preprints, joining other journalism organizations around the world who began sharing preprint-related resources during the pandemic (Broer, 2020; Broer & Pröschel, 2022; Haelle, 2020; Ordway et al., 2020). "[W]e couldn't wait for peer review," Handman explained, "People needed this knowledge as fast as possible" (quoted in Owens, 2022).

Handman's comments represent just a small part of the discourse around journalists' use of preprints that emerged during the pandemic. Yet his words encapsulate a common theme that recurs throughout this discourse: that preprints represent a "new normal" in journalism (Heathers, quoted in Piper, 2020, para. 35)—a rupture from established practice made only to address a public health emergency.

This dissertation evaluates the accuracy of this claim and presents some of the first insights into a part of journalism that has remained all but invisible within the scholarly literature until recently. Journalists' use of preprints is not only understudied and undertheorized, but also increasingly important, given the growing use of preprints in scholarly communication (Puebla et al., 2022), the broad public attention they received during the pandemic (Fraser et al., 2021; Majumder & Mandl, 2020; Waltman et al., 2021), and their potential to provide rapid, potentially life-saving insights during other crisis situations (Johansson et al., 2018). Preprints also raise wider questions about how journalists navigate scientific uncertainty, vet and frame information of unknown credibility, balance risks and benefits when reporting on research, and understand ongoing evolutions in the scholarly communication system.

1.1.   Research Objectives

This mixed method dissertation provides insight into these and other questions through three studies that characterize journalists' motivations and practices for reporting on preprints during, and in the lead up to, the pandemic. My overarching objective is to understand whether the media coverage of preprints seen during the first two years of

COVID-19 was truly 'post-normal' (Brüggemann et al., 2020)—i.e., a fundamental challenge to, rather than an extension of, journalists' norms and practices for covering research. I pursue this objective by addressing the following research questions:

- RQ1: Why do journalists use preprints?
- RQ2: How do they (a) find, (b) verify, and (c) communicate about them?
- RQ3: Do these motivations and practices depart from journalists' 'normal' practices for reporting on research?
- RQ4: How has the pandemic affected journalists' use of preprints?

These specific questions are addressed primarily through three studies, but their collective contribution is necessary to achieve the research objective. As such, I use a mixed-method narrative integration approach and a shared theoretical lens to weave together the results of the three studies, compare them to findings of previous scholarship examining journalists' use of research, and contextualize them within ongoing evolutions in scholarly communication and journalism. In doing so, this dissertation responds to calls for insight into how preprints are (mis)communicated to the public (Caulfield et al., 2021) and for "meta-research to better understand how scientific information and misinformation moves from scientists to the public and interacts with public action and public policy" (Glymour et al., 2023, p. 3). It contributes to our understanding of how journalists navigate changes in the media landscape and scholarly communication system, how emergent reporting practices can become established norms, and how theoretical distinctions between legacy and peripheral media outlets (fail to) hold up in practice as journalism continues to adapt and evolve. Taken together, the results can be used to inform the development of professional guidelines for reporting emerging science and provide a foundation for further research examining the intersections of scholarly communication and journalism.

1.2. Dissertation Overview

I provide a broad overview of this dissertation below and in Table 1.1, including the research questions, specific contributions, and publications that relate to each chapter. Chapter 1 (this chapter) offers a brief introduction to the topic of preprints in journalism,

describes the research questions and objectives, and provides an overview of the structure of the dissertation. Chapter 2 discusses the recent evolutions in scholarly communication and journalism that must be kept in mind when considering journalists' use of preprints during the pandemic, including the rise of the Open Access (OA) and Open Science (OS) movements, the increasing time and resource pressures that are changing how and by whom science journalism is produced, and the role of COVID-19 in accelerating the use of preprints within, and potentially, beyond the scholarly community. Chapter 3 describes the theoretical framework I use to explore the degree to which journalists' use of preprints represents a departure from their typical practices for reporting on research (i.e., RQ3). In reviewing relevant literature documenting why and how journalists use peer reviewed research, this chapter also provides a benchmark of 'normal' science journalism against which the results of the dissertation can be compared. Chapter 4 describes the iterative, mixed method methodology used in this dissertation, with a focus on how qualitative and quantitative aspects of the research were integrated through the study design, theoretical framework, data collection, and interpretation of results. Chapters 5-7 present the three empirical studies that, collectively, address the research questions. Specifically, Chapter 5 describes a qualitative analysis of 19 interviews with journalists about their motivations for using preprints (RQ1) and the practices they use to find, verify, and communicate about them (RQ2). Chapter 6 applies quantitative content analysis to more than 450 media stories mentioning COVID-19-related preprints to provide additional insight into RQ2c—how journalists communicate about preprints— corroborating the self-reported findings presented in Chapter 5. Chapter 7 sheds light on how the onset of COVID-19 affected journalists' use of preprints (RQ4) by examining coverage of preprints among 94 media outlets in the lead up to, and during, the pandemic. In Chapter 8, I bring the findings of the three studies together through a woven narrative, comparing journalists' motivations and practices for using preprints during the pandemic to their 'normal' motivations and practices to use research (RQ3). Finally, Chapter 9 discusses the scholarly and practical significance of the results and considers the many questions about journalists' use of preprints that remain unanswered, paving the way for future research exploring the changing relationship between journalism and scholarly communication.

Table 1.1.   **Organization of the Dissertation**

Chapter	RQs	Contributions	Publication Reference
Ch 1	-	General Introduction, Research Objectives and Questions	-
Ch 2	-	Context: Evolutions in Journalism and Scholarly Communication	Fleerackers et al. (2023a)
Ch 3	RQ3	Theoretical Framework for Understanding 'Normal' and 'Post-normal' Practices for Reporting on Research	-
Ch 4	-	Methodology	-
Ch 5	RQ1, RQ2	Qualitative Thematic Analysis Examining the Motivations and Practices Journalists Use to Cover Preprints	Fleerackers et al. (2022a)
Ch 6	RQ2c	Quantitative Content Analysis of How Media Coverage Framed COVID-19-related Research	Fleerackers et al. (2022b)
Ch 7	RQ4	Quantitative Statistical Analysis of Changes in the Share of Media Coverage that Mentioned Preprints During COVID-19	Fleerackers et al. (in press)
Ch 8	RQ3	Narrative Integration of Findings	-
Ch 9	-	Practical and Scholarly Contributions, Directions for Future Research	-

Chapter 2.

Context: Evolutions in Scholarly Communication and Journalism

2.1. Abstract

In this chapter I provide context for the rest of the dissertation by presenting an overview of recent evolutions in scholarly communication and journalism that are essential for understanding the media coverage of preprints seen during the COVID-19 pandemic. First, I describe the Open Access (OA) and Open Science (OS) movements and situate researchers' growing use of preprints as part of a decades-long push for greater transparency in science. Next, I explain how science journalists can contribute to OS by providing critical, contextualized coverage of research that non-academic publics can understand and use. I then describe the recent changes in the digital media ecosystem that hamper journalists from delivering on this potential, including shrinking budgets, increasing time pressures, and a corresponding decline in the number of dedicated science journalists employed in legacy media outlets. Next, I introduce preprints as a unique form of openly available research and describe some of the main benefits, risks, and controversies associated with using them, both in scholarly communication and journalism. Finally, I discuss how the COVID-19 pandemic accelerated scholars' use of preprints and how this may have influenced journalists, outlining unanswered questions that I address in this dissertation.

2.2. Introduction

The preprint-based journalism seen during the COVID-19 pandemic did not emerge from nowhere but must instead be understood in the context of ongoing evolutions in scholarly communication and journalism. For scholarly communication, the rise of preprint media coverage builds on a decades-long push for greater transparency in science and more equitable access to research, which has taken place through the Open Access (OA) movement and, more recently, the Open Science (OS) movement (Pinfield et al., 2021). For journalism, these changes include shrinking budgets and resources (particularly in science journalism) in many countries; growing pressures to meet audience and platform demands in an increasingly fast-paced news cycle, and a subsequent overreliance on public relations resources, such as press releases (Allan, 2011; Schäfer, 2017). Understanding how and why journalists use preprints requires also understanding the changing relationship between journalism and scholarly communication, including the role journalists play in mobilizing research knowledge and the tensions that can arise as a result. Finally, it would be impossible to understand changes in preprint-based journalism without considering how the COVID-19 pandemic has highlighted both the value and precarity of (science) journalism and accelerated scholars' use of OS practices—especially posting preprints. I examine these evolutions in journalism and scholarly communication in this chapter, setting the stage for the rest of the dissertation.

2.3. Open Access, Open Science, and the Push for Public Knowledge

2.3.1. The Rise of Open Access and Open Science

Accounts of the OA movement's origins vary. Some have argued that its roots date back to 1991, when Paul Ginsparg started the website for sharing unreviewed "e-prints" that would later become known as the arXiv preprint server.[2] Other believe its foundations extend to the 1960s, with the launch of initiatives that would eventually

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[2] https://cshl.libguides.com/open_access/history_policy

provide free access to research, such as Educational Resources Information Center (ERIC) and the National Library of Medicine's Medline (Suber, 2009). Others dig back even further, tracing "pervasive themes of openness" in the "open-book" approach to the Bible taken by English Protestantism during the late 1600s (Willinsky, 2005, para. 1). OA could even be seen as intertwined with the origins of science itself. Sociologist Robert Merton (1942, republished in 1973) famously proposed that "communism" is a pillar of the scientific ethos, meaning that research knowledge fundamentally belongs to the entire scientific community, not the individual scientist(s) who produced it. "Secrecy is the antithesis of this norm," he wrote, "full and open communication its enactment" (p. 274). While Merton was not writing about OA, the argument that sharing knowledge is a core aspect of science recurs within the discourse around openness (Suber, 2012). As Willinsky (2006) wrote, "To find new ways of increasing access is to extend an invitation and to acknowledge a right, for *scholarship exists only as it is shared and circulated*, only as it is open to new and diverging voices" (p. 53, emphasis added).

Just as the origin stories behind the "access revolution" (Suber, 2012, p. 1) vary, so do definitions of what, exactly, OA looks like in practice. However, most scholars agree that OA requires that academic publications are not only free to *access*, but also free to *use* (BOIA, 2002; Suber, 2012). As such, making a paper OA means removing both financial barriers to reading the research, but also eliminating copyright-related barriers that restrict its reuse. In removing these financial and legal barriers, advocates argue that OA can:

> …accelerate research, enrich education, share the learning of the rich with the poor and the poor with the rich, make this literature as useful as it can be, and lay the foundation for uniting humanity in a common intellectual conversation and quest for knowledge (BOIA, 2002).

Over the last two decades, an increasing number of scholars, funders, librarians, and research institutes have joined the OA movement in pursuit of this vision. Some of this growing support for OA can be linked to outrage over the "serials crisis" in the early 2000s, when the costs of academic journal and database subscriptions grew so dramatically that many university libraries were no longer able to afford them (Mering &

Hoeve, 2020). The increasing availability of digital tools, software, and distribution systems that enable free (or close-to-free) and widespread dissemination of research have likely also played a role (Grand, 2012; Suber, 2012; Willinsky, 2005). This has led to a proliferation of different flavours—or, perhaps more appropriately—*shades* of OA, which Piwowar et al. (2018) synthesize as follows (p. 5):

- Gold: Published in an open-access journal that is indexed by the DOAJ [Directory of Open Access Journals[3]].
- Green: Toll-access on the publisher page, but there is a free copy in an OA repository [e.g., a preprint server, an institutional repository].
- Hybrid: Free under an open license in a toll-access journal.
- Bronze: Free to read on the publisher page, but without an clearly identifiable license. [*sic*]
- Closed: All other articles, including those shared only on an ASN [Academic Social Network, such as ResearchGate] or in Sci-Hub [an online repository that distributes research papers for free, without regard to copyright (Himmelstein et al., 2018)].

Today, publishing OA is no longer a marginal practice in scholarly communication (Piwowar et al., 2018). Universities and funders around the world increasingly encourage or mandate researchers to publish their scholarship in openly accessible formats (Albornoz et al., 2018; Suber, 2012), including major granting agencies such as the Wellcome Trust (UK)[4], the State of São Paulo Research Support Foundation (FAPESP, Brazil),[5] the National Institutes of Health (NIH, US),[6] and the Canadian Tri-Agency.[7] In Latin America, regional initiatives such as SciELO[8] and AmeliCA[9] provide infrastructure that supports open access to research. Organizations,

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[3] https://doaj.org/

[4] https://wellcome.org/grant-funding/guidance/open-access-guidance/open-access-policy

[5] https://fapesp.br/12592/anexo-i-politica-para-acesso-aberto-as-publicacoes-resultantes-de-auxilios-e-bolsas-fapesp

[6] https://www.nih.gov/health-information/nih-clinical-research-trials-you/what-is-nih-public-access-policy

[7] https://science.gc.ca/site/science/en/interagency-research-funding/policies-and-guidelines/open-access/tri-agency-open-access-policy-publications

[8] https://scielo.org/en/about-scielo/open-access-statement/

[9]http://amelica.org/index.php/en/about/#:~:text=AmeliCA%20is%20a%20communication%20infrastructure,America%20and%20the%20Global%20South.

such as SPARC[10] and the Public Knowledge Project, advocate for increased public access to research under a shared vision of an open and equitable research system. Major publishers such as the Nature Publishing Group, BMJ Journals, and the American Medical Association have launched gold OA journals[11,12,13] and the five biggest scholarly publishers have made hybrid OA a growing part of their business (Butler, 2023). By 2017, almost 45% of the scholarly literature was available in one or more OA formats—and this proportion appears to be growing (Piwowar et al., 2018). Although some journals still do not allow researchers to publish their work OA, these journals now represent the exception more than the rule.

Building off the widespread adoption of OA, scholars have called for even greater openness within science. This has given rise to the Open Science (OS) movement, which urges scholars to move beyond simply providing free and unrestricted access to research findings (i.e., by publishing OA papers) to also provide access to the research process itself (e.g., by sharing software, code, protocols, peer review reports, or datasets used in research) (Albornoz et al., 2018; Vicente-Saez & Martinez-Fuentes, 2018). At the same time, OS seeks to bring other societal actors and ways of knowing into science, especially those that have traditionally been marginalized (UNESCO, 2021). In doing so, OS aims to "make scientific research from all fields accessible to everyone" (UNESCO, 2023, para. 1) in support of a vision of a scientific system that is more collaborative, equitable, sustainable, and beneficial—to scientists as well as the wider societies within which they work (ibid.).

Like OA, support for OS is growing, as can be seen from the proliferation of policies and mandates that encourage or enforce practices such as data sharing, preregistration, and open software (Albornoz et al., 2018). Major international bodies have taken active roles in advocating for OS. The United Nations, for example, began hosting an annual Open Science Conference in 2019 and worked with "eminent

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[10] https://sparcopen.org/who-we-are/

[11] https://www.nature.com/nature-portfolio/open-access

[12] https://bmjopen.bmj.com/

[13] https://jamanetwork.com/journals/jamanetworkopen

personalities in Open Science" to develop principles for using OS to address key Sustainable Development Goals.[14] The same year, 193 Member States tasked UNESCO with developing internationally accepted standards for practicing OS.[15] The resulting UNESCO Recommendation on Open Science presented principles and guidance "intended to influence the development of national laws and practices" (UNESCO, 2021). These guidelines were recently updated, with a greater focus on advancing equity and knowledge mobilization (UNESCO, 2023).

Despite growing support, uptake of OS practices such as sharing data, publishing protocols, and participating in open peer review has been more limited than uptake of OA publishing (Waltman et al., 2021). Some of the hesitance surrounding these practices relates to concerns that OS may enhance, rather than reduce, existing inequities in academia (Leonelli, 2022; Matsick et al., 2021; Ross-Hellauer, 2022; Ross-Hellauer et al., 2022). As scholars such as Ross-Hellauer (2022) have noted, many OS practices are expensive and labour intensive, requiring funding and infrastructure that may not be available to scholars in institutions and countries with fewer resources to support science. Others fear that publishing datasets could harm participants, especially those from marginalized backgrounds (who may be more easily identifiable than others, even when data have been de-identified) (Fox et al., 2021). Still others have highlighted how some practices may be less accessible to scholars in less privileged positions, such as students and early-career researchers (ECRs) who may face retaliation from supervisors and more senior collaborators who do not support the OS movement (Bahlai et al., 2019). Marginalized scholars may also be more at risk of reputational damage from participating in practices such as open-peer review, particularly when making critical comments of well-established researchers' work (Bahlai et al., 2019; Tennant et al., 2017). Limited uptake of some OS practices may also be the result of a lack of clear incentives, as nontraditional research outputs such as datasets and software remain undervalued in the review, promotion, and tenure (RPT) process (Alperin et al., 2020). More broadly, RPT guidelines do not incentivize public forms of scholarship (Alperin et al., 2019; Rose et

[14] https://www.un.org/en/library/OS21

[15] https://en.unesco.org/science-sustainable-future/open-science/recommendation

al., 2020). Perhaps because of these concerns and barriers, the transparent, accessible, equitable academic system envisioned by the OS movement has yet to become a reality.

2.3.2. From Open to Public: Science Journalists as Research Brokers

Although arguments about "public" access to research knowledge are often mentioned in the discourse around openness (Suber, 2012; UNESCO, 2023; Willinsky, 2006), efforts to communicate science beyond the academic sphere are not typically considered part of the OA or OS movements (Grand, 2012). Scholars such as Kevin Elliott (Elliott, 2022a; Elliott & Resnik, 2019), Alyssa Arbuckle (2021, 2019), and Anne Grand (Grand et al., 2012, 2010, 2010) have argued that this failure to consider public-facing forms of science communication is an oversight, given that "science performed in the open is open to anyone: to members of the public as much as to the scientists working on it" (Grand, 2012, p. 12). Indeed, research of the Latin American context suggests that as many as 16-35% of individuals who engage with OA publications are not affiliated with a university, suggesting that open research outputs have a significant but overlooked non-academic audience (Alperin, 2015). Health and medical studies are especially popular among these non-academic readers, many of whom are motivated to access this research out of "personal interest" (Alperin, 2015).

Yet, although making research outputs publicly available hypothetically enables anyone to access and use them, doing so does not automatically make them understandable or useful to a public audience. Academic publications are written for peer researchers and academics rather than the public and use specialized language and rhetorical features meant for communication with and within certain communities (Fahnestock, 1986). They are written according to disciplinary conventions and norms and can be difficult for 'lay' readers to comprehend. Thus, realistically, open licensing only expands meaningful access to research to academic and practitioner audiences who have the educational or professional background to read it. For much of the public to truly engage with and benefit from open outputs, it is necessary to provide not only "technical" or "material" access to research but also "conceptual access" that enables them to understand and use the findings (Kelly & Autry, 2013).

Journalists—especially health and science journalists—are ideally positioned to provide such conceptual access because they can critique, contextualize, and communicate findings from open research outputs in ways that highlight their relevance and implications for non-specialist audiences (Elliott & Resnik, 2019). That is, journalists can act as "brokers" of research knowledge (Gesualdo et al., 2020; Pentzold & Fechner, 2021; Yanovitzky & Weber, 2019), who have the potential to facilitate broader engagement with open research outputs by: 1) fostering public *awareness* of the OS and OA movements, 2) rendering open outputs (conceptually) *accessible* to non-academic audiences, 3) *engaging* a wider public with debates around openness that are taking place within academia, 4) *linking* those debates to broader social issues or policies with public relevance, and 5) *mobilizing* open research findings to hold those in power to account when policies or decisions do not align with the available evidence. Similarly, although health and science journalists fulfill some traditional journalistic roles—such as *watchdog* (i.e., holding powerful scientific or pharmaceutical institutions to account) and *agenda setter* (i.e., driving attention to new trends, issues, and findings in research)—they also play additional roles such as the *civic educator,* using their skills to teach audiences about the nature of scientific research and its limits and risks (Fahy & Nisbet, 2011). These roles position science journalists to align the ideals of OS "with the realities of complex, specialized genres of writing to provide better, more 'open,' access to research" (Kelly & Autry, 2013, p. 1). Yet, to date, very little research has examined the role that journalists play in enabling public engagement with open research, or how publicly available research outputs influence journalists' work.

2.3.3. Evolutions and Challenges in Digital (Science) Journalism

Despite their potential to broker research knowledge, journalists' ability to do so has been hampered by ongoing changes in the digital media ecosystem that challenge their traditional roles, practices, norms, and routines (Eldridge, 2017a, 2017b; Hermida, 2019; Wahl-Jorgensen & Hanitzsch, 2019). Social media and other web 2.0 platforms now enable anyone with an internet connection to share information and potentially reach large digital audiences (Bruns, 2018). As a result, audiences increasingly get their news from actors who have long been seen as *peripheral* to journalism (Schapals, 2022),

including social media influencers, podcasts, aggregators, and other digital content providers (Newman et al., 2020; Shearer, 2018; Shearer & Matsa, 2018). As these peripheral actors take on journalism's core function—to serve society by disseminating timely, relevant information (Kovach & Rosenstiel, 2021; Schudson, 2018)— longstanding notions of who holds the power to decide what is and isn't news, and how that news is framed, are being challenged and uprooted (Hermida et al., 2022; Meraz & Papacharissi, 2013; Moody-Ramirez et al., 2016; Papacharissi & de Fatima Oliveira, 2012).

Peripheral actors have not only taken on journalistic functions and practices, they have also pioneered new modes of producing and disseminating news. Many of these emergent practices have found their way into professional newsrooms, altering traditional journalistic sourcing and reporting routines (Hermida, 2010; Wasike, 2013), role conceptions (Willnat & Weaver, 2018), ethics (Ward, 2017), audience perceptions (McGregor, 2019), and self-promotion strategies (Molyneux et al., 2018). While digital journalism still reflects many journalistic norms and values—such as a focus on recency, accuracy, and independence—it is also characterized by a new set of traits, including a high degree of interactivity, potentially global reach, and perpetually unfinished state, where content can be updated and edited post-publication to reflect new developments (Malik & Shapiro, 2017). These ongoing evolutions have created an "existential predicament" for journalism, raising uncomfortable questions about what sets journalists apart from other content producers and what role—if any—they now play in society (Hermida, 2019). As journalism reinvents itself to stay relevant in the digital age, the boundaries of the journalistic field are blurring and expanding to accommodate these novel practices and actors (Carlson & Lewis, 2015; Eldridge, 2017b; Schapals, 2022).

Alongside this ongoing renegotiation of journalism's boundaries, the sector has undergone structural changes that have fundamentally altered how news is produced and shared. Steensen and Westlund (2020) summarize these changes as follows:

- Journalism has seen a massive shift in its revenue models, with audiences replacing advertisers as key sources of funding.

- The sector has shifted its attention to user data, metrics, and analytics as a way of understanding audience preferences.
- Distribution is no longer controlled by journalists and news companies themselves, but by third party platforms and other intermediaries.
- Journalism has become more vulnerable to attacks, manipulation, dis/misinformation, with key implications for public trust.

Collectively, these changes have created a precarious situation, in which a media outlet's financial viability is tied to the changing preferences of its audience, as well as the algorithms and logics that shape distribution of news on platforms such as Twitter (now "X") and Facebook (Hermida, 2020; Hermida & Mellado, 2020). The need to attract audiences and compete with the wealth of digital content circulating on these platforms puts pressure on journalists to produce stories that adhere to traditional news values of relevance and impact but are still surprising and engaging enough to be clickable and shareable (Malik & Shapiro, 2017; Williams & Delli Carpini, 2020). At the same time, media outlets must work to distinguish themselves from so-called *pseudo-journalism* outlets that use journalistic formats and techniques to spread fraudulent or misleading information (Träsel et al., 2019) or risk losing the already tenuous trust of their audience members (Lewis, 2020a; Newman et al., 2018). At times, these two needs—to create engaging digital content and to maintain journalistic integrity—can conflict, as journalists attempt to toe the line between information and entertainment (Williams & Delli Carpini, 2020).

Of the four changes noted by Steensen and Westlund (2020), however, the move away from advertiser-driven revenue has had the most profound effect, especially for science journalism. While media outlets are experimenting with new funding models, including those based on subscriptions, crowdfunding, or foundation support (Aitamurto, 2019; Benson, 2019; Scott et al., 2019), most continue to grapple with shrinking revenues. This, in turn, has led to mass newsroom layoffs and a growing reliance on freelancers to fill the gaps left behind (Spilsbury, 2016; Walker, 2021). The few journalists who remain in the newsroom have been tasked with doing more with less—less time, resources, and editorial support (Manninen, 2017; Murcott & Williams, 2013)—and to do so on the protracted timeline that the "always-on" digital media

ecosystem demands (Hermida, 2010). As a result, journalists increasingly rely on the pitches, press releases, and other *information subsidies* (Comfort et al., 2022; Manninen, 2017) provided by public relations (PR) officers to meet their deadlines. This has created a situation in which organizations with funding to invest in PR can play an agenda-setting role, shaping what does and doesn't become news (McKinnon et al., 2019).

While these changes have impacted journalists working in every beat, specialist reporters, including health and science journalists, have been among the most affected (Schäfer, 2017). Science coverage has always comprised only a small proportion of the news (Dunwoody, 2021) and has been on the decline for decades in many parts of the world (Anderson & Dudo, 2023; Massarani et al., 2021a; Saari et al., 1998; Schäfer, 2017). These declines are only accelerating in the digital era, as budgets shrink and demands for clickable content grow. Reflecting on the state of science journalism in the US and UK, Allan (2011) summarizes the situation as follows:

> At a time when many newsrooms are under intense financial pressure to trim expenditure on specialist, investigative reporting, it is all too often the case that science news is regarded as expendable. In the eyes of some, it is a luxury increasingly difficult to justify when certain other types of news will be both cheaper to produce and more popular with audiences (p. 773).

This decline of specialized science journalism within legacy media has created a space for novel types and formats of science journalism to emerge and thrive (Ginosar et al., 2022). These *peripheral science journalism* outlets include science blogs, science news aggregators, social media science communicators, niche science-focused publications, and other alternative producers of science news and commentary (Barel-Ben David et al., 2020; Ginosar et al., 2022; Jarreau, 2015; Koivumäki et al., 2020; Luzón, 2009). Just like legacy outlets, peripheral science journalism outlets are often driven to disseminate timely, relevant (science) news; yet the actors and goals that drive the coverage are distinct. As Ginosar et al. (2022) explain:

> This content…is not produced by professional journalists employed by journalistic outlets…Rather, the content is produced and disseminated by individuals (either journalists or scientists) and groups (established or emerging associations) whose primary motivation is a social one: to share

science news with the general public and enhance public engagement with science" (p. 16)

One peripheral outlet that has gained traction in recent years is *The Conversation* (TC) (Guenther & Joubert, 2021; Hermida et al., 2022; Young & Hermida, 2020). With editions in 11 countries and regions, this *research amplifier* platform (Osman & Cunningham, 2020) pairs experts with professional journalist editors to produce independent "news and views, from the academic and research community, delivered direct to the public."[16] These research-based stories can then be republished—or "amplified"—for free by other media outlets under a Creative Commons license, filling in the gaps left behind by cuts to specialized science sections. Similar academic-led journalism initiatives have cropped up in other countries and contexts, providing scholars with novel pathways to engage a wider public with their research (Barel-Ben David et al., 2020; Ginosar et al., 2022).

For their part, legacy media outlets in countries such as Germany and the US have responded to the growing financial pressures by significantly cutting down their science coverage and, often, laying off any specialized science reporters or editors on staff (Schäfer, 2011, 2017). As a result, the few science journalists that remain employed in legacy newsrooms grapple with growing workloads and increased time pressures, with almost half of participants in one global survey reporting that their work life had worsened in recent years (Massarani et al., 2021a). These remaining specialized science journalists employed in legacy media must work harder to "sell" science stories to their editors and audiences (e.g., by hyping new findings), potentially compromising the integrity of their reporting (Allan, 2011). They inhabit a marginal position in the newsroom, with rather "low status" compared to colleagues in other beats (Schäfer, 2011, p. 403).

As a result of these declines in specialized science reporting, the few science stories that get coverage in traditional, legacy journalism outlets are increasingly produced by unspecialized, generalist staff reporters or freelancers (Dunwoody, 2021).

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[16] https://theconversation.com/ca/who-we-are

These two groups face distinct challenges and have adopted different strategies for producing science news. Generalists typically do not have a background in, or experience with, science and often lack the specialized knowledge needed to parse dense academic texts and navigate statistics and numbers (Nguyen et al., 2021). Generalist staff journalists are also often tasked with covering breaking news stories about major scientific discoveries, which tend to be short, matter of fact, written on a very tight deadline, and focused on study findings (S. Everts, personal communication, February 14, 2023). To meet these deadlines, many rely heavily on information subsidies produced through the *science PR* efforts of research institutions and academic journals (Comfort et al., 2022; McKinnon et al., 2019; Vogler & Schäfer, 2020). This reliance on this "increasingly well-organized and slick science publicity machine" (Murcott and Williams, 2013, p. 153) is evident in the quantity of science media coverage that research receives, as studies accompanied by a press release receive more coverage than those without (Lemke et al., 2023; MacLaughlin et al., 2018; Orduña-Malea & Costas, 2023). It also influences the quality of the coverage, as science stories inspired by PR efforts often bear strong resemblance to the press releases on which they are based (Sumner et al., 2014, 2016, 2021). Scholars have argued that this reliance on science PR shifts the power from journalists to scientific institutions and journals, with dangerous implications for the autonomy of journalists and the publics they serve (Allan, 2011; Murcott & Williams, 2013).

Unlike staff reporters, freelance journalists are seldom hired for breaking news. As a result, they often have more time and leeway to dive into a study's methods, implications, or larger content and produce the kind of long-form, in-depth storytelling that Dunwoody (2021) has argued is becoming more common among legacy science journalism outlets in the digital age. However, freelance journalists face the additional challenge of needing to successfully pitch their stories to their editors, which may make them more likely to seek out unusual, overlooked research that will help their pitches stand out from those of other journalists (S. Everts, personal communication, February 14, 2023). This may make them less reliant on science PR and more motivated to identify alternative sources of research, for example, to cover older studies or research from lesser-known journals. Freelance science journalists are also often even less well-

resourced than staff reporters, working with fewer social and financial supports (Anderson & Dudo, 2023). As a result, they face additional barriers in accessing research articles that are locked behind journal paywalls (Gesualdo et al., 2020), a challenge which will be discussed in greater detail in Chapter 3. Using open access research, including un-peer-reviewed preprints, is one possible way to overcome these barriers—one which, as I discuss below, received little scholarly attention before the COVID-19 pandemic.

2.4. Preprints: Controversies in Open Science and Science Journalism

2.4.1. The Rise of Preprints in Scholarly Communication

One outcome of the growing support for openness within academia is the increasing use of *preprints*—scientific manuscripts that have been posted online (usually to a preprint server) by the authors without undergoing journal peer review (Berg et al., 2016; Kirkham et al., 2020). Preprints represent an interesting form of open research, as they straddle the line between OA and other forms of OS. Although OA is often used to refer to peer reviewed journal articles, the term technically also applies to "any unreviewed preprints that [researchers] might wish to put online for comment or to alert colleagues to important research findings" (BOIA, 2002). Preprints officially fall under the Green category of OA, along with *postprints*—or research articles that have been deposited to a publicly available repository after they have been peer reviewed (Suber, 2012). Yet, preprints are distinct from other forms of OA because they provide a snapshot of research in progress—capturing the moment studies have been completed but not yet revised and published following journal peer review. In this respect, preprints are arguably more in line with the goals of OS; they provide a view into the research process itself, with potential to reveal how studies evolve as they undergo review. At the same time, many preprints undergo only minor changes between initial posting to a server and publication in a peer reviewed journal (Brierley et al., 2022). In these cases, preprints function more like research in the other OA subtypes; they present final results, research in a more or less "finished" state.

Preprints' unvetted nature has also made them controversial in academia. On the one hand, researchers ascribe many benefits to posting them. From an access perspective, preprints provide a work-around for making research available when other forms of OA are not possible, as some journals restrict or prohibit the open publishing of the final version of an article but are open to preprints (e.g., journals published by Cell,[17] the American Heart Association,[18] and the American Association for Cancer Research[19]). Another common reason scholars use preprints is their speed (Funk et al., 2020); while publication in a peer reviewed journal can take months (in some cases even years), preprints typically come online immediately or within a few days of submission (Puebla et al., 2022). This is because preprints do not undergo journal services—including peer review, but also typesetting and proofreading—saving considerable time. That said, most servers do perform some kind of light screening process before posting preprint submissions, for example, assessing whether the manuscript is "scholarly" and free of "nefarious elements [that] might not necessarily act in the best interests of society" (Ginsparg, 2021, p. 602; see also Malički et al., 2020). These screening processes appear to be more stringent (and thus time consuming) among health and medicine-focused servers (Malički et al., 2020). Still, numerous examples have shown that these screening processes are not always effective for preventing flawed research from circulating online (e.g., Bartlett, 2023; Santos-d'Amorim et al., 2021; Scheirer, 2020).

In addition to providing greater access and speeding dissemination, researchers report using preprints to gain additional exposure, receive early feedback on findings, demonstrate productivity or progress (i.e., when applying for grants or jobs), stake a claim on a discovery, share results that are unlikely to get published in a journal, encourage opportunities for collaboration, and increase citations to their work (Chiarelli et al., 2019a, 2019b; Funk et al., 2020). Some even use preprints for ethical reasons because they "do not want to participate in the publishing game and in the publishing system" (Vianello, 2021, p. 3). In these cases, the "pre" in "preprint" is misleading, as the

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[17] https://www.cell.com/cell/authors

[18] https://www.ahajournals.org/prior-publication-policy

[19] https://aacrjournals.org/pages/editorial-policies#online

authors have no intention of ever publishing a peer reviewed version, making the preprint the final version of record. These diverse motivations and uses make it difficult to assess why some preprints are never published in a peer reviewed journal (Drzymalla et al., 2022; Otridge et al., 2022).

Despite the benefits of preprints, however, some scholars remain hesitant to use them. Key concerns include fears that doing so could contribute to information overload, undermine the value of academic journals, lead to getting "scooped" by other researchers, generate harmful comments or feedback, cause reputational damage, or jeopardize a manuscript's chances of acceptance at a peer reviewed journal (Chiarelli et al., 2019b; Funk et al., 2020; Maggio & Fleerackers, 2022). Yet, by far the most common arguments against using preprints centre on their unvetted nature. Equating the lack of peer review to a lack quality assurance, scholars worry that posting preprints will result in the circulation of flawed or problematic research that could, in turn, garner media attention, spread misinformation, and, ultimately, cause societal harm (Chiarelli et al., 2019b; Funk et al., 2020). This risk is often perceived to be greater in research areas with direct implications for public wellbeing, such as health and medicine (Bonnechère, 2020; Chung, 2020; Maslove, 2018).

Perhaps as a result, preprints have a different "standing"—or social reputation—in different disciplinary communities (Neylon et al., 2017), with some viewing them as rough drafts that should not be cited and others treating them like established and credible research outputs. Disciplines also differ in their willingness to use preprints (Chiarelli et al., 2019b). For example, physics, math, and computer science (where research poses few risks to the public) have long histories of wide-spread preprint use, whereas health, medicine, and other life sciences continue to lag behind (Berg et al., 2016; Puebla et al., 2022). The differences in preprint uptake are reflected in researchers' own publication activities but also in the timeline of when discipline-specific preprint servers were launched. As mentioned above, arXiv—the server housing preprints for physical, mathematical, and computer sciences—has been in operation for more than 30 years

(Ginsparg, 2021)[20]. In contrast, the life sciences-focused server bioRxiv was launched in 2013 (Kaiser, 2013) and the health and medicine-focused server medRxiv only came online in 2019 (Kaiser, 2019). Preprints in these fields have been given an additional push through initiatives such as ASAPbio (Accelerating Science and Publication in Biology), which seeks to "promote the productive use of preprints for research dissemination and transparent peer review and feedback on all research outputs,"[21] and the Public Library of Science's (PLOS) "Direct Transfer Service," which enables researchers submitting a manuscript to one of its journals to simultaneously submit it as a preprint to bioRxiv or medRxiv.[22] Although more and more health and medicine preprints are posted each year, their use remains limited (Puebla et al., 2022). Like OS more broadly, uptake of preprints has been slowly building for years, setting the stage for the widespread surge in use that would take place during the COVID-19 pandemic.

2.4.2. Journalists' Use of Preprints Before the COVID-19 Pandemic

Despite longstanding fears that preprints will receive premature and misleading media coverage (Chiarelli et al., 2019b; Funk et al., 2020), almost nothing was known about whether, why, or how journalists reported on these unvetted studies before the onset of the COVID-19 pandemic. The handful of papers that did discuss this issue drew primarily on anecdotal evidence or examined preprint media coverage tangentially, rather than as a focus of the research. What *can* be inferred from the pre-pandemic literature is that journalists' use of preprints is likely strongly connected to their perceptions and beliefs about peer review, which I discuss in more detail in Chapter 3. Journalistic discourses surrounding peer review tend to mirror those found in academic debates (Ampollini & Bucchi, 2020), portraying peer review as a "guarantee of good science" and the "cornerstone of maintaining the quality" of research (Ampollini & Bucchi, 2020, p. 466). As such, many journalists may be weary of OS initiatives that challenge traditional notions of peer review, such as preprints. Moreover, science journalists rely

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[20] https://info.arxiv.org/about/index.html

[21] https://asapbio.org/about-us

[22] https://journals.plos.org/plosone/s/preprints

heavily on interviews with experts to verify and communicate about new studies. Dunwoody (2021) has argued that this reliance enables experts to "easily sell the argument that journalists must respect the scientific process and, for example, must wait for peer review to take place before embarking on a wider dissemination of research results" (p. 20). Despite a lack of evidence that peer review effectively prevents flawed research from getting published (Jefferson et al., 2002, 2007), many science journalists "assume that peer review assures quality control of the science" (Conrad, 1999, p. 286; see also Forsyth et al., 2012) and professional journalism organizations have been known to discourage the use of unreviewed science (Fox, 2018; Froke et al., 2020). This is particularly true for controversial topics that are newsworthy—that is, on those issues that have the potential to generate the most misinformation or confusion among the public.[23]

Many of these controversial, newsworthy research topics are found in the life sciences, especially health and medicine-related fields. These research areas are unique because they receive among the highest levels of press release promotion (Lemke et al., 2023; Orduña-Malea & Costas, 2023) and correspondingly high levels of media coverage (Banshal et al., 2019; Ginosar et al., 2022; Joubert et al., 2022). Yet, as discussed above, these areas also have historically low levels of preprint use (Puebla et al., 2022), perhaps because of the greater potential to cause societal harm should flawed findings garner public attention (Bonnechère, 2020; Chung, 2020; Maslove, 2018). UK's Science Media Centre Director Fiona Fox (2018) emphasized these potential risks in an open letter on her blog titled "the preprint dilemma: good for science, bad for the public?" In it, she urged scholars, academic publishers, and science communicators to consider the wider impacts of preprint use, particularly within the controversial, newsworthy research areas on which the SMC focuses:

> …more and more people are telling us that preprint is now coming to new subject areas including biology, medicine and climate change. As many people have pointed out, preprint has been around in subjects like physics and maths for many years now and the sky has not fallen in. Very true. But studies in physics and maths don't tend to make the front pages of the *Sun* and *Daily Mail*, don't tend to influence personal behaviour or decisions

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[23] https://www.sciencemediacentre.org/about-us/

about new technologies and are therefore not the core focus of the Science Media Centre.

Many of Fox's concerns—and those of the scholars who would come after her—centered on the ways in which preprints can disrupt the system of "checks and balances" that she saw as essential for supporting accurate, trustworthy science media coverage. This system, which is still largely in place today, relies heavily on the peer review process as a quality control mechanism (as discussed above) and the journal embargo system as a source of story ideas. Embargoes offer journalists early access to new research studies on the condition that they hold off on any coverage until a particular date. While their use is controversial (Altman, 1996a, 1996b; Oransky, 2013), Fox (2018) argued that embargoes provide journalists the time needed to more thoroughly vet and communicate research—time they would otherwise not have in a "24-hour rolling news" cycle that privileges newness and originality over accuracy and rigour. In a world with preprints as news sources, Fox (2018) feared that embargoes would no longer be possible—and that the resulting damage would be irreparable. "The critical point is this," she wrote, "once these findings have been reported in one or two national newspapers they cannot be unreported."

Fox's letter was quickly followed by two opinion pieces in *Nature*, in which SMC senior press manager Tom Sheldon (2018a, 2018b) amplified Fox's concerns to more than 3 million online monthly readers (Nature, 2012). This pivotal moment brought fears about preprint coverage into the mainstream scholarly discourse, but also sparked some of the first arguments in defense of preprint-based news coverage. In a series of comments responding to Sheldon's (2018a) article, scholars and OS advocates highlighted the limitations of relying on peer review as a quality control mechanism (Tennant et al., 2018), arguing that media coverage of preprints and peer reviewed articles posed similar risks to public wellbeing (Sarabipour, 2018). Underpinning the responses to Sheldon's piece was a belief that "the tension between supporting preprints and good journalism is a false dichotomy" (Sarabipour, 2018); that the benefits of preprints for science outweighed any potential risks for the public (Sarabipour, 2018; Sarabipour et al., 2018); and that, rather than suppressing preprint-based journalism,

24

scholars and journalists could work together to support accurate and engaging science media coverage (J. Fraser & Polka, 2018; Sarabipour et al., 2018). The preprint stakeholders interviewed by Chiarelli et al. (2019a, 2019b) echoed this argument, stating that, "the onus is on journalists and researchers to behave responsibly and professionally, acting where appropriate to corroborate the findings of a preprint before this is shared via mass media or to report it with caveats" (Chiarelli et al., 2019a, p. 20).

Despite growing fears and opportunities about journalists' use of preprints, evidence into whether, or how often, such use takes place was all but nonexistent before the pandemic. Sheldon (2018a) noted that journalists had started "trawling" preprint servers for potential story ideas, suggesting that at least some journalists were reading these unreviewed studies. Similarly, Sarabipour (2018) noted that "Responsible journalists already report on preprints with the help of real-time commentary from scientists on Twitter and elsewhere," citing a story in *The Atlantic* by journalist Ed Yong (2016) that featured tweets about a bioRxiv preprint by Sender et al. (2016) as an example. Years later, Molldrem et al. (2021) added to these anecdotal accounts by describing the widespread media coverage of a problematic preprint study about cold fusion that had been posted to arXiv in 2013.

A study by Fraser and colleagues (2020), conducted using preprint data collected before the pandemic, appears to be the only study that empirically examined journalists' use of preprints outside of a COVID-19 context. The study found that bioRxiv preprints received far less coverage in mainstream media than their peer reviewed counterparts, as well as in comparison to a control group of peer reviewed articles that were never preprinted. This finding was in stark contrast to the attention preprints received in other online spaces, such as tweets or blog posts, where preprint coverage was comparable to that of both types of peer reviewed articles. The authors proposed that "although bioRxiv preprints are widely shared in informal social networks by colleagues and peers, they are currently less well accepted in formal public outlets, where peer-reviewed articles remain the preferred source" (N. Fraser, Momeni, et al., 2020, p. 632). However, as preprint-based media coverage was not the focus of Fraser et al.'s (2020) study, the authors did not include information about the quantity or media coverage, the kinds of media outlets

providing the coverage, or whether the findings extended to preprints from other servers. Robust empirical evidence describing journalists' engagement with preprints would remain limited until 2020, when the COVID-19 pandemic spurred dramatic increases in their use—both within academia and journalism.

2.5. COVID-19: A Catalyst and Challenge for Open Science and Science Journalism

2.5.1. The Pandemic Push for Preprint Research

On Dec 12, 2019, the first cases of a strange pneumonia-like illness were reported in Wuhan, China.[24] Patients complained of typical symptoms such as shortness of breath and fever but did not respond well to standard treatments. By January 3, more than 40 cases had been reported, and by January 12, the first patient was pronounced dead. Two months, 4,290 deaths, and over 100,000 cases later, the World Health Organization (WHO) declared the virus that had become known as COVID-19 a deadly pandemic. Lockdowns, mask mandates, vaccination campaigns, and countless other sanctions ensued, changing the lives of billions around the world. By June 2023, almost 7 million had died due to COVID-19.[25]

The emergence of COVID-19 not only changed lives, it also changed the pace, practice, and dissemination of research for many scientists. Within weeks of the first reported cases, addressing the evolving public health crisis became the single defining focus of researchers around the world. Funders and scientists pivoted, funneling resources, time, and money towards COVID-19-related science, often at the expense of research on other topics (Riccaboni & Verginer, 2022). A major push towards OS practices ensued, with the Wellcome Trust issuing a statement calling on "researchers, journals and funders to ensure that research findings and data relevant to this outbreak are shared rapidly and openly to inform the public health response and help save lives."[26]

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[24] https://www.cdc.gov/museum/timeline/covid19.html

[25] https://web.archive.org/web/20230614173244/https://covid19.who.int/?mapFilter=deaths

[26] https://wellcome.org/press-release/sharing-research-data-and-findings-relevant-novel-coronavirus-ncov-outbreak

More than 150 research institutions, funders, research councils, foundations, and publishers signed the statement, committing to work towards five goals—all of which involved practicing greater openness:

- all peer-reviewed research publications relevant to the outbreak are made immediately open access, or freely available at least for the duration of the outbreak
- research findings relevant to the outbreak are shared immediately with the WHO upon journal submission, by the journal and with author knowledge
- research findings are made available via preprint servers before journal publication, or via platforms that make papers openly accessible before peer review, with clear statements regarding the availability of underlying data
- researchers share interim and final research data relating to the outbreak, together with protocols and standards used to collect the data, as rapidly and widely as possible—including with public health and research communities and the WHO
- authors are clear that data or preprints shared ahead of submission will not pre-empt its publication in these journals

Importantly, not all these commitments became realities. Publishing research data, for example, seems to have remained relatively uncommon, with little uptake beyond the sharing of SARS-CoV-2 genome sequences early in the pandemic (Waltman et al., 2021). However, other forms of OS became widespread (Kadakia et al., 2021; Mulligan, 2022), as scientists, funders, journals, and research institutions adapted their practices to support more rapid, accessible, and collaborative research about the virus (Rijs & Fenter, 2020). Journals removed paywalls to COVID-19-related literature (albeit temporarily) (Clark, 2023) and sped up their review processes, sometimes by several weeks (Horbach, 2020). As a result, almost 90% of COVID-19 literature was available OA by April 2021 (Waltman et al., 2021). OS—or at least OA—gained widespread support that it had never seen before, with even the most hesitant actors acknowledging the value of making research publicly accessible (Grove, 2020).

Perhaps the most dramatic change in OS practices that took place during the pandemic was the surge in preprint use, especially among the health and medical scientists who had so long been resistant to them (Else, 2020; N. Fraser et al., 2021; Horbach, 2020; Waltman et al., 2021; Watson, 2022). In one survey, almost 90% of

COVID-19 researchers reported posting their work to a preprint server, either before submitting to a journal or simultaneously (Waltman et al., 2021). Another found that about two-thirds of scientists surveyed in 2020 and 2021 saw preprints as a "valued source of communication," while only 43% had felt this way before the pandemic (Mulligan, 2022). By the end of April 2020, preprints represented more than a third of the available COVID-19 literature—although this proportion fell to about 25% by the end of October (N. Fraser et al., 2021). The health and medicine-focused preprint server, medRxiv, quickly became the most active source of COVID-19 preprints, despite being only a few months old and having seen relatively little uptake prior to the pandemic (N. Fraser et al., 2021; Vergoulis et al., 2021). While preprints still represented a minority of the COVID-19-related research, preprint servers punched above their weight, posting an "order of magnitude" more research than many peer reviewed journals (Yin et al., 2021, p. 2). COVID-19-related preprints represented more than 60% of preprints posted to medRxiv during almost every month for the first year and a half of the pandemic (Waltman et al., 2021). The widespread use of preprints during COVID-19 represented a marked departure from the norm, with more preprints posted faster than during previous crises, such as Ebola and Zika (Brierley, 2021; Johansson et al., 2018).

Overall, evidence suggests that COVID-19-related preprints that were published held up relatively well to the scrutiny of peer review (Bai et al., 2023; Janda et al., 2022; Kodvanj et al., 2022; Nelson et al., 2022; Zeraatkar et al., 2022). Most COVID-19-related preprints were eventually published—usually more quickly than those on other topics (Kodvanj et al., 2022) and often in very "high quality" journals (Llor et al., 2022). At the same time, many COVID-19-related preprints were never published at all (Drzymalla et al., 2022; Otridge et al., 2022)—and it is unclear why. Pandemic-focused preprints were also less like journal articles and more like preliminary drafts than those on other topics; they were shorter, with fewer references, smaller sample sizes, and a greater reliance on observational data (Brierley et al., 2022; Candal-Pedreira et al., 2022). Perhaps as a result, COVID-19-related preprints were more likely to have undergone major changes to their conclusions between initial posting and publication in a peer reviewed journal (Brierley et al., 2022). The urgency of the pandemic not only sped uptake of preprints; it

also appears to have encouraged scholars to use them to show science in-progress—opening access to research in an evolving, preliminary, and imperfect state.

While the rapid dissemination of research via preprints likely helped societies respond to the pandemic, it also came with drawbacks. Dozens of COVID-19-related preprints were eventually withdrawn, although this number was far smaller than the number of retracted peer reviewed studies about the virus (Santos-d'Amorim et al., 2021). A small number of problematic preprints received high levels of attention—not only from scholars (Santos-d'Amorim et al., 2021) but also from journalists (see Majumder & Mandl, 2020; Massarani & Neves, 2022; van Schalkwyk et al., 2020 for overviews of these cases). These flawed findings added to a rising tide of pandemic-related myths, conspiracy theories, and confusion (Atef et al., 2020; Bridgman et al., 2021; Garneau & Zossou, 2021; Posetti et al., 2020) that the WHO director-general would eventually describe as the COVID-19 "infodemic."[27] This proliferation of pandemic misinformation reinvigorated longstanding debates about the potential for preprints to mislead and harm the public (Caulfield et al., 2021; M. Oliveira et al., 2023). That is, the COVID-19 crisis acted as both a catalyst for the use of preprints among scientists and a reminder of the societal risks of doing so.

2.5.2. COVID-19 as a Challenge and Opportunity for Science Journalism

Just as COVID-19 underscored both the benefits and drawbacks of preprints, it simultaneously highlighted the value and precarity of science journalism (Desai et al., 2021; Newman et al., 2020; Olsen et al., 2020; Perreault & Perreault, 2021; Waisbord, 2023). As the pandemic began to dominate headlines, science journalists became "a crucial positive force in guiding the public through Covid-19 data and science" (Nguyen et al., 2021, p. 6), synthesizing complex statistical information, visualizing case counts and mortality rates, and providing accessible, evidence-based predictions about the virus's spread (Desai et al., 2021; Pentzold et al., 2021). Many became adept at communicating scientific uncertainties and illuminating consensus among experts

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[27] https://www.who.int/director-general/speeches/detail/director-general-s-remarks-at-the-media-briefing-on-2019-novel-coronavirus---8-february-2020

(Pentzold et al., 2021), which, as will be discussed in Chapter 3, is a departure from pre-pandemic journalism norms. Both legacy and peripheral journalists invested intensive efforts to fact-check the flood of scientific and pseudoscientific claims circulating online (Brennen et al., 2020; Luengo & García-Marín, 2020)—another "welcome step" for a profession that has long been criticized for uncritically accepting scientists' perspectives and opinions (Dunwoody, 2020, p. 473, see also Dunwoody, 2021; Murcott & Williams, 2013).

Fuelled by a renewed sense of responsibility to keep people safe (Perreault & Perreault, 2021), both peripheral and legacy media outlets published *news you can use*-style stories that provided practical insights for navigating the crisis (Blanchett et al., 2022; Hermida et al., 2022). Readership for these public service-oriented stories surged (Hermida et al., 2022), as did engagement with science news in general (Casero-Ripolles, 2020; Dambanemuya et al., 2021). Public trust in pandemic-related journalism also grew (Casero-Ripolles, 2020; Newman et al., 2020), along with trust in science itself (Jensen et al., 2021). COVID-19 reporting won prestigious national and international journalism awards ("Ed Yong of The Atlantic," 2022; National Newspaper Awards, 2021), making science an essential beat in countries where it had long been seen as "expendable"—at least temporarily.

At the same time, the COVID-19 pandemic laid bare the consequences of the decades-long decline of science journalism, as journalists struggled to report on a crisis that was not only highly technical but also rapidly evolving (Perreault & Perreault, 2021; Waisbord, 2023; Westlund & Hermida, 2021). Layoffs, cutbacks, and closures skyrocketed, with one study finding that as many as 60 US newsrooms had been forced to close by March 2021 (Harris, 2021). The proportion of journalists reporting on health-related issues surged from 4% to 74% during the pandemic (Selva & Feinstein, 2020), pushing generalist reporters who had long been "allergic to numbers" to report on complex data and statistics for the first time (Pamela Duncan, quoted in Nguyen et al., 2021, p. 4). The few remaining specialized health, science, and data journalists employed in legacy media moved from marginal positions in the newsroom to central ones, adopting the practices of generalist, breaking news reporters to meet demands for timely

coverage (Sebbah et al., 2022). Many faced barriers in accessing high-quality evidence about the virus and turned to alternative sources of information (Massarani et al., 2021b; Sebbah et al., 2022). Others grappled with online harassment, risks to their personal safety, or death threats in reporting on what was becoming an increasingly controversial topic (Atef et al., 2020; Buchanan, 2022). Health and science journalists soon began to struggle under the growing demands on their time and expertise (Massarani et al., 2021b; Nguyen et al., 2021), with many reporting high levels of psychological distress, including anxiety, depression, burnout, and even post-traumatic stress (Posetti et al., 2020; Selva & Feinstein, 2020).

These pressures appear to have had negative consequences for the quality of science media coverage itself. In countries such as Germany, coverage of COVID-19 was dominated by "strategically communicating actors" with political expertise, rather than scientists (Leidecker-Sandmann et al., 2022, p. 29). A similar trend was seen globally, with political actors representing about half of the sources featured in pandemic coverage, but health professionals (e.g., doctors, medical experts) comprising less than 20% (Mellado et al., 2021). Pandemic coverage became extremely divisive in some countries (Melek & Iseri, 2021), with levels of polarization and politicization exceeding those found in coverage of other highly controversial science issues (Hart et al., 2020). Journalists' efforts to debunk COVID-19-related misinformation were hampered by the uncertain and constantly evolving nature of the available scientific evidence (Ball, 2020; Dunwoody, 2020; Scheufele et al., 2020), lack of access to high-quality data (Cancela-Kieffer, 2021; Westlund & Hermida, 2021), and misleading commentary from high-profile scientists speaking well outside of their areas of expertise (Hu, 2020; Makri, 2021). That is, COVID-19 highlighted the fallibility of expert commentary and evidence-based 'facts' as information sources, disrupting long-standing journalistic norms and practices for establishing "truth" (Waisbord, 2018).

2.5.3. Journalists' Use of Preprints During COVID-19

These two factors—the surge of preprints within science and the disruption of journalistic norms that took place during the pandemic—contributed to exactly the type

of widespread media coverage of controversial preprints that had long been feared. With a lack of relevant, peer reviewed evidence available, COVID-19-related preprints soon became a key source of information for journalists (N. Fraser et al., 2021; Majumder & Mandl, 2020). While much of the resulting media coverage was helpful or benign, flawed and controversial preprints also made headlines (Scheirer, 2020). Concerns about misinformation—similar to those discussed back in 2018—resurfaced, with scholars arguing that "conversations surrounding individual non-peer-reviewed preprints has made it difficult to extract meaningful signals about reliable, cumulative scientific evidence from the noise of sometimes short-lived findings [*sic*]" (Brossard & Scheufele, 2022, p. 614) and warning that "uncontrolled and potentially misleading information will reach the general public, directly or via the media, leading to incorrect, sometimes fatal, responses to the pandemic" (Chirico et al., 2020, p. 300).

As I began working on this dissertation in May 2020, evidence to substantiate these fears was only just beginning to emerge. Our first study (Paper 2 of this dissertation) built on one of the few relevant papers that was available at the time. Published in 2021 (N. Fraser et al., 2021) but originally posted as a preprint in 2020 (N. Fraser, Brierley, et al., 2020), the study found that more than a quarter of COVID-19-related preprints posted to bioRxiv and medRxiv during the first months of the pandemic were mentioned in at least one media story, while only about 1% of those on other topics received media coverage. The authors concluded that the coverage of COVID-19 preprints was a "marked change in journalistic practice" indicative of a wider "cultural shift" in journalism (N. Fraser, Brierley, et al., 2020, p. 14).

While provocative, Fraser et al.'s (2020) conclusion may have been premature, as the authors did not compare preprint coverage during the crisis to coverage from before the pandemic. More broadly, the study left many questions unanswered: Why do journalists use preprints? How do they report on them? Is media coverage of preprints truly novel? How, if at all, did the pandemic change things? I set out to address these questions in this dissertation, presenting some of the first empirical evidence into how and why journalists use preprints and the extent to which the preprint-based coverage seen during COVID-19 can be seen as a true "cultural shift" in journalism. Yet,

addressing this overarching research objective requires first understanding the established journalistic "culture" for reporting on research. I turn to these 'normal' science journalism practices in the following chapter, providing a baseline against which to compare the findings of the three studies that follow.

2.6. Contribution Statement

I participated during all stages of the development of the portions of this chapter that were adapted from Fleerackers et al. (2023a) and provided an overall contribution greater than that of any co-author. Specifically, I contributed to obtaining the funding (along with Juan Pablo Alperin, Stephen Pinfield, Germana Barata, and Isabella Peters). I also developed the concept for the paper, performed the literature review, and wrote the first draft with assistance from Natascha Chtena. All authors contributed to revising the draft and providing suggestions for additional papers not included in the initial literature review.

Chapter 3.

Theoretical Framework: Normal and Post-Normal Journalism Practices for Communicating Research

3.1. Abstract

This chapter provides a theoretical and empirical foundation for understanding whether journalists' use of preprints during the COVID-19 pandemic has been a challenge to, or an extension of, existing journalism norms. It proposes that COVID-19-related preprints are a form of *post-normal science (PNS),* characterized by high levels of scientific uncertainty and controversy, value-laden disputes, and an urgent need for political decision-making. As PNS contexts are known to produce novel communication norms and routines, it is expected that the practices journalists use to cover preprints differ from those used for peer reviewed research. As a first step towards identifying these divergent practices, the chapter synthesizes existing literature that has examined journalists' practices for finding, selecting, verifying, and communicating research in 'normal' communication contexts, as well as the motivational and contextual factors that influence these practices. The findings suggest that journalists use research for a combination of practical and strategic reasons—ranging from improving the accuracy of their reporting to establishing credibility—but that their use is hindered by conceptual and financial access barriers, as well as time and resource constraints. Journalists rely on a mix of active and passive strategies to find research, with a high reliance on press releases and expert sources. Decisions about which studies to cover are closely tied to perceptions of prestige and credibility, with research published in top-tier journals receiving the bulk of the coverage—often with minimal vetting. Overall, verifying research appears to be a challenge for journalists, many of whom rely on heuristic cues and the peer review process rather than rigorous investigation. Finally, journalists tend to frame research findings as confirmed facts, communicating uncertainty selectively to enhance the news value of their coverage.

Keywords: science journalism, news production, research, verification, uncertainty

3.2. Introduction

This chapter provides a theoretical and empirical foundation for understanding journalists' motivations, constraints, and practices for reporting on preprints during the COVID-19 pandemic and the implications for the post-pandemic future. To do so, it draws on an analytical framework for understanding *post-normal science communication* (PNSC)—the novel practices that can emerge when communicating about science issues characterized by high levels of scientific uncertainty and controversy; associated with value-laden disputes; and requiring an urgent need for political decision-making (Brüggemann et al., 2020). This framework involves five analytical steps, which I complete in this dissertation in the following ways, albeit in a slightly different order:

1. *Classify* the situation to assess whether it has post-normal characteristics (this chapter).
2. *Examine* how actors (i.e., journalists) have reacted to the situation (i.e., their use of PNSC practices; detailed in Chapters 5–7 and summarized in Chapter 8).
3. *Compare* this reaction to journalists' practices in 'normal' communication contexts (this chapter and Chapter 8).
4. *Explain* what might be causing any divergences from the norm (Chapter 8).
5. *Consider* implications for the future of journalism and society (Chapter 9).

3.3. Classifying the Situation: Preprint-Based Journalism as Post-Normal Science Communication

Funtowicz and Ravetz—the scholars who originally coined the term 'post-normal science' (PNS) (1993, 2003)—have described COVID-19 science as the penultimate PNS context (2020). They argued that the defining features outlined in the PNS mantra— "facts uncertain, values in dispute, stakes high and decisions urgent" (p. 1)—may as well "have been designed around the COVID-19 experience" (p. 2). Funtowicz and Ravetz (2020) went further, proposing that COVID-19's post-normal qualities are so all-encompassing that the pandemic might be better understood as an "age" of PNS. That is, they saw the onset of the pandemic as requiring an expansion of their original definition

of PNS—which focused on specific post-normal science *topics*—to instead reflect a broader "condition in society" (Funtowicz & Ravetz, 2020, p. 1).

In line with this expanded definition of PNS, I propose in this dissertation that preprints—especially those related to COVID-19—can also be considered a form of PNS that is likely to encourage journalists to develop PNSC practices. In part, this is due to the heightened level of scientific uncertainty preprints present because of their unvetted and potentially changeable nature (Caulfield et al., 2021; Ho et al., 2021; Ratcliff et al., 2023). A preprint's conclusions can sometimes differ radically between the version that is initially posted to a server and the one that is eventually published in a peer reviewed journal (Brierley et al., 2022)—although this seems to be true for only a minority of preprints (Janda et al., 2022; Malički et al., 2022; Zeraatkar et al., 2022). Many preprints are never published at all, especially those relevant to COVID-19 (Llor et al., 2022; Otridge et al., 2022). While preprints can remain unpublished for other reasons (Vianello, 2021), it is possible that at least some fail to pass quality checks during peer review. This potential for findings to change, or never be published at all, may be why servers such as medRxiv and bioRxiv have issued warnings that preprint findings should not "be reported in the press as conclusive."[28] In addition to being highly uncertain, preprints about COVID-19 align with the PNS mantra because of the high-stakes, controversial, and politically relevant nature of their subject matter and the "condition in society" during which they have been posted and reported (Funtowicz & Ravetz, 2020). Preprint use has also traditionally been discouraged in journalism (Froke et al., 2020; Sheldon, 2018a, 2018b), which has left journalists with a lack of established best practices for reporting on them. This, in turn, may further encourage the development of novel (i.e., PNSC) practices, norms, and routines. The late Sharon Dunwoody (2021) recently made a similar proposal, arguing that science journalists usually follow established journalistic norms but that "In the face of accidents and crises…speed and urgency can *cause these longstanding norms* to fray" (p. 20, emphasis added). She provided examples of journalists' use of preprints during the pandemic to support her argument.

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[28] https://connect.medrxiv.org/relate/content/181

3.4. Establishing the Baseline: 'Normal' Practices for Reporting on Research

Tackling Step 3 of Bruggeman et al.'s (2020) framework (comparing PNSC practices to those that would normally be expected of journalists) requires first establishing a baseline. That is, to assess whether the preprint-based journalism seen during the pandemic was 'post-normal,' we must first understand what 'normal' research-based journalism looks like (Brüggemann, 2017).

I provide such a baseline in this chapter by reviewing literature that has examined journalists' established practices, routines, and strategies for reporting on (peer reviewed) research. To structure this review, I apply an analytical framework developed by Domingo et al. (2008) to analyze these established journalism practices through each stage of the news production cycle. I return to this framework in Chapter 8 to assess whether or to what degree the practices for reporting on preprints that I explore in the dissertation depart from these established norms. In both cases, I focus on only the first three stages proposed by Domingo et al. (2008), as these are most relevant to the practices of journalists (i.e., rather than editors or audience members)[29] and to my research objectives:

1. *Access/observation:* finding research (peer reviewed studies vs preprints) to cover.
2. *Selecting/filtering:* deciding which research to cover and vetting its quality.
3. *Processing/editing*: communicating and framing the findings of research.

Like Westlund and Lewis (2018), I believe that Domingo et al.'s (2008) framework can strengthen journalism scholarship by encouraging a more "systematic approach that ensures clarity and coherence" (p. 271). In addition, the framework encourages researchers to move beyond examining specific journalistic practices to also consider the motivational and constraining factors that contribute to establishing those

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[29] Stage 4: *Distribution* refers to the publication, promotion, and circulation of news stories and is traditionally controlled by editors or publishers. Stage 5: *Interpretation* refers to how audiences respond to news (i.e., their attitudes, behaviors, etc.).

practices as professional norms. Examining these factors is essential for understanding what might be causing any divergences from existing norms with respect to journalists' use of pandemic preprints—the fourth step of Brüggeman et al.'s (2020) framework. I thus integrate Domingo et al.'s (2018) framework with Brüggemann et al.'s (2020) to create the backbone of this dissertation (see Figure 3.1). In this conceptualization, I label practices for reporting on peer reviewed research as 'normal' and those for reporting on preprints as 'post-normal'—not because this distinction is necessarily accurate but because there is theoretical grounding for such a distinction to emerge in a PNS context like the pandemic. I use the framework to examine whether, or to what extent, these theoretical assumptions hold true in practice.

Figure 3.1. Analytical Frame for Examining Journalists' Use of Preprints (Adapted From Brüggemann et al., 2020; Domingo et al., 2008)
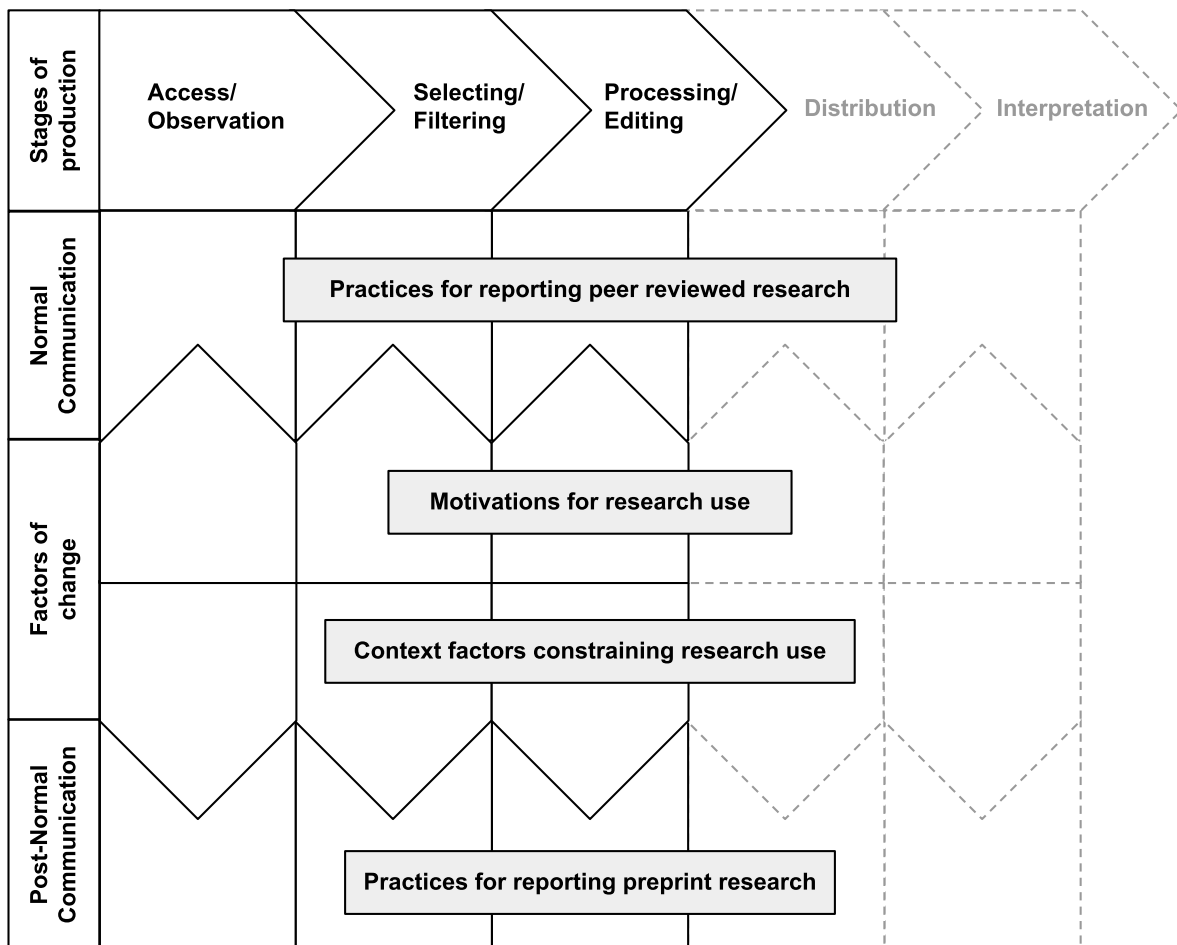
3.5. Motivations: Why Journalists Use Research

3.5.1. Pragmatic Motivations

Few studies have explicitly asked journalists about their motivations to use academic research. One notable exception is a survey of 1,118 US-based journalists, 52% of whom frequently drew on research articles (Wihbey, 2017). The vast majority of those surveyed reported that research was "very helpful" for strengthening accuracy and providing context in stories; most also felt it helped them to counter misleading claims, improve framing, and spark ideas for future stories (Wihbey, 2017). Additional insights can be gleaned from a phone interview study of 395 Danish journalists who had written a story mentioning a researcher (Albæk, 2011). When asked why they contacted the researcher, journalists said they did so to obtain their interpretation of something (51%); get background knowledge about the topic they were covering (21%); or ask for a comment on another researcher's work (6%). Another 15% said that they had contacted the researcher because they had "become aware of the researcher's results" (Albæk, 2011, p. 343), without specifying what they hoped to obtain from the interview. Albæk (2011) noted that conversations with experts appeared to help participants identify and develop story frames, concluding that journalists "maintain dynamic, 'sparring' relationships with experts brought in to provide information, depth, and perspective" (p. 344). Schultz (2023) surveyed US health and science journalists and found that scholarly articles and journals were their most common sources of story ideas, with 80% of participants claiming they cited research in over half their articles. Finally, Gesualdo et al. (2020) found that health and science journalists were motivated to include research in their stories because they felt that "clear communication of research-derived knowledge [was] central to their role" (p. 135) but didn't specify why this was central. Journalists in this study also called on unaffiliated experts with the goal of having them corroborate or critique study claims—a verification practice that I discuss in greater detail below.

3.5.2. Strategic Motivations

The findings above paint a pragmatic picture of journalists' use of academic research—one in which studies are used to inspire, inform, or strengthen news stories. However, another strand of research suggests that journalists are motivated to include research in their coverage for a more performative purpose. Because there is no formal training required in journalism, journalists' social authority rests largely on their ability to provide "fact-based news" that audiences perceive as reliable (Broersma, 2010; Ekström & Westlund, 2019). As a result, journalists lean heavily on what Tuchman (1972) calls "strategic rituals"—routine procedures that allow them to craft stories that appear objective, accurate, and unbiased and thus protect journalists from outside criticism. The rituals journalists use to appear objective have changed throughout history (Muñoz-Torres, 2012), at least in American journalism, where the objectivity norm has been particularly influential (Schudson, 2001). In the 1920s, this norm was conceptualized as the pursuit of fact-based news through "scrupulous adherence to scientific ideals" (Schudson, 2001, p. 163); objectivity was more concerned with *how* journalism was produced rather than *what* it produced (Lippmann, 1920). Over time, however, objectivity evolved into a style of reporting characterized by a focus on straight facts (presented without commentary or opinion), the inclusion of competing perspectives; and the use of cool, unemotional language (Schudson, 2001; Tuchman, 1972). Seen through the lens of Domingo et al.'s (2008) framework, modern objectivity is less about rigour during the selecting and filtering stage and more about strategic processing and editing.

The selection, citation, and attribution of expert sources is one ritual for performing objectivity (Carlson, 2009, 2020). Attributing claims or statements to trusted sources allows journalists to signal that the information they present is credible and that they, themselves, are authoritative enough to access these elite sources (Carlson & Franklin, 2010). In health and science news, including statements from established experts legitimizes journalists' news frames (Albæk, 2011; Hansen, 1994) and enables them to maintain a veneer of objectivity even while making subjective or critical claims (Conrad, 1999; Hansen, 2020; Nelkin, 1995). As is discussed in more detail below, attributing a claim to an outside expert also effectively "transfers the burden from the

journalist to the source" (Carlson, 2009, p. 528), allowing journalists to retain their "truthfulness" even if a claim is later disputed (Tuchman, 1972).

In digital journalism, hyperlinks to credible content, such as research articles, can play a similar role (Carlson & Franklin, 2010), signaling that the information presented is trustworthy, objective, and verified (Stroobant & Raeymaeckers, 2019). Very little research has explicitly examined whether strategic rituals motivate journalists to link to peer reviewed research in their stories, but studies suggest that hyperlinks are often used as indicators of authority and quality in digital communication (see De Maeyer, 2013, for a review). In addition, journalists may be motivated to include hyperlinks to credible sources, such as research articles, to appear more transparent (Karlsson & Clerwall, 2018), another strategic ritual "that journalism has enlisted as a way to increase its power and standing within society" (Allen, 2008, p. 325).

3.6. Constraints: Factors Limiting Journalists' Use of Research

3.6.1. Conceptual Barriers

As I have discussed elsewhere (Fleerackers et al., 2023a; Fleerackers & Nguyen, in press), research knowledge is often conceptually inaccessible, a major barrier constraining journalists' work. Most research articles are jargon-laden and highly technical (Baram-Tsabari et al., 2020; Ordway, 2022). As such, understanding, vetting, and using the knowledge they contain typically requires specialized training that many health and science journalists do not possess (Keshvari et al., 2018; Viswanath et al., 2008), particularly those in the Global South (Nguyen & Tran, 2019). This conceptual challenge is likely exacerbated by the ongoing decline of science journalism around the world, which, as discussed in Chapter 2, has left newsrooms lacking reporters with the specialized skills needed to cover research effectively (Brumfiel, 2009; Saari et al., 1998; Schäfer, 2017). Adding to this are generally low levels of numeracy and statistical knowledge among journalists (Harrison, 2016; Nguyen, 2018). Although specialist reporters appear to be better equipped to report on statistical data (Cushion & Lewis, 2018), "the ability to work with numbers is still not only an intellectual luxury but

sometimes a cursed subject in the news industry" (Nguyen, 2018, p. 5). Journalists'
aversion to numbers has been particularly problematic during the COVID-19 pandemic,
as journalists across multiple beats were tasked with covering a science story that was not
only statistically complex but also constantly evolving (Nguyen et al., 2021).

3.6.2. Financial Barriers

In addition to these conceptual barriers, research is also often financially
inaccessible because of academic journal paywalls (Piwowar et al., 2018). While
journalists have developed strategies for overcoming paywalls—such as obtaining copies
of articles direct from authors (De Dobbelaer et al., 2018), reporting on Open Access
research (Schultz, 2021, 2023), using academic databases (Boss et al., 2022), or relying
on abstracts or free summaries (Bray, 2019a)—access costs remain a barrier (Boss et al.,
2022; Gesualdo et al., 2020; Hinnant et al., 2017; Ordway, 2022; Schultz, 2023). This
barrier may be particularly problematic for journalists in the Global South, who are
generally less well-resourced than those in the Global North (Nguyen & Tran, 2019), as
well as for journalists with less advanced information literacy skills, who tend to "assume
all information is freely available online" (Boss et al., 2022, p. 14).

3.6.3. Time and Resource Constraints

Adding to conceptual and financial barriers, health and science journalists' use of
research is also constrained by the deadline-driven nature of news production (Gesualdo
et al., 2020; Hertzum, 2022; Keshvari et al., 2018; Rosen et al., 2016). As discussed in
Chapter 2, science has long been seen as an "expendable" beat in many parts of the world
(Allan, 2011) and is consequently allotted few resources and little page space. As a result,
health and science journalists have learned to access, select, and edit content with as few
resources and as little time as possible (Anderson & Dudo, 2023; Murcott & Williams,
2013). This pressure to produce a high volume of coverage on a protracted timeline is at
odds with the complex, highly technical nature of research and the potential for small
changes in wording to alter scientific meaning (Fleerackers & Nguyen, in press). To
overcome this challenge, journalists lean heavily on press materials, such as fact sheets

and press releases with ready-made quotes, which can be used to cover research with minimal first-hand reporting work (Leask et al., 2010; McKinnon et al., 2019; Murcott & Williams, 2013). The rapid pace of journalists' work can also conflict with academic timelines (Dijkstra et al., 2015; Moorhead et al., 2023); while a science journalist might research, write, and publish a story in a day or less, scientific research can take years. Even after completing a study, researchers must typically wait months for their article to undergo peer review and, hopefully, be published in a journal (Horbach, 2020; Huisman & Smits, 2017). Although the peer review process sped up significantly during the early months of the pandemic, this shift seems to have been only temporary (Kousha & Thelwall, 2020). Moreover, even under these expedited conditions, peer review of COVID-19-related research took about two months on average (Horbach, 2020)—a considerable delay given the urgency of the crisis.

The impacts of these time and resource constraints are not evenly distributed among journalists. In particular, women and journalists working in Africa and Europe appear to be more affected than others, as their workloads have seen the highest increase in recent years (Massarani et al., 2021a). Time pressures also appear to be greater for generalist reporters who are tasked with covering research-related stories, as these journalists often lack the training, knowledge, and specialized networks needed to efficiently report on complex health and science issues (Leask et al., 2010; McKinnon et al., 2018). Freelancers may also face greater challenges than staff reporters, as they have less support from editors, colleagues, or organizations but simultaneously need to invest more time and energy in developing and maintaining their professional reputation (Anderson & Dudo, 2023). Similarly, it is likely that digital journalists are more vulnerable than others, as they often juggle multiple tasks at once: monitoring social media, moderating comment sections, editing colleagues' stories, and sourcing images— all while producing an average of 7.5 stories a day (Manninen, 2017; Murcott & Williams, 2013). Finally, the routines of science and health journalists working in the Global South appear to be more constrained in terms of time and resources; many also lose considerable time 'selling' stories to editors who do not see science coverage as a priority (Jones, 2012; Nguyen & Tran, 2019).

3.7. 'Normal' Science Journalism: Established Practices for Reporting on Research

3.7.1. Accessing/Observing: How Journalists Find Research

Health and science journalists rely on a combination of passive and active methods to identify research articles for their stories (Gesualdo et al., 2020; Leask et al., 2010). Passive methods include public relations (PR) services—such as newsletters, research alert services, and wire services—which summarize and repackage research papers into press releases and other PR materials (Leask et al., 2010; Murcott & Williams, 2013; Rosen et al., 2016). Common sources of science PR include universities (Peters, 2012) and academic journals (Franzen, 2012), which are motivated to promote their research to maintain their status and funding (Weingart, 2022). Independent initiatives, such as the UK's Science Media Centre (Fox, 2012) can play a similar role as PR services, as they repackage and share new research studies with journalists with the goal of promoting science (Haran, 2012). Individual scientists may also reach out to journalists directly in hopes of garnering coverage for their research (Moorhead et al., 2023), or publish their own science stories through research amplifier platforms such as *The Conversation,* which may, in turn, be used by journalists as inspiration or fodder for future content (Fleerackers et al., 2022c; Zardo et al., 2018). In addition, some journalists report finding research articles via experts they are interviewing for other stories (Wihbey, 2017).

Active strategies journalists use to find research papers often rely on secondary sources. About half of journalists in Wihbey's (2017) study reported finding new research by following hyperlinks in online news stories (see also Rosen et al., 2016). Journalists may also use social media to identify research—either by following relevant subject experts (Deprez & Van Leuven, 2018) or by monitoring online conversations for interesting topics that later inspire searches for relevant academic papers (De Dobbelaer et al., 2018). In addition to these indirect strategies, some journalists report searching for research using scholarly tools such as Google Scholar or PubMed (Schultz, 2023; Wihbey, 2017); subscription databases such as LexisNexis (Boss et al., 2022); or finding

research via academic journals (Amend & Secko, 2012; Hansen, 1994; Viswanath et al., 2008). However, as discussed above, high costs of accessing research articles may discourage journalists from using these tools. Finally, journalists may also seek out new research to cover by attending conferences; however, in these cases, professional journalism resources recommend treating the research with "extra care because often only partial results are released and they haven't been subjected to full peer review" (Froke et al., 2020, p. 4), much like preprints.

3.7.2. Selecting/Filtering: How Journalists Decide What Research to Cover

Journalistic decisions of which research to cover can be best understood as the outcome of two distinct but related practices: selection and verification.

Research Selection

Much scholarship has examined the factors which influence selection routines in health and science journalism (see Amend & Secko, 2012, for a review). These studies suggest that health and science journalists rely on similar news values as other journalists, choosing story topics that are timely, novel, relevant to their communities, interesting, controversial, and involve a human-interest angle (Badenschier & Wormer, 2012; Dunwoody, 2021; Leask et al., 2010; Rosen et al., 2016). Although these values relate to *story* selection rather than *research* selection, they likely influence the types of studies that get covered. For example, the news value of timeliness may encourage journalists to select studies that present research at the cutting edge of discovery, reporting on emerging and often controversial "frontier science" rather than on replicated and well-established "textbook science" (Albæk, 2011; Claassen, 2019; Dunwoody, 1999). Indeed, a study of biomedical media coverage found that initial research studies received far more coverage than follow-up studies, even though more than half of these early studies were later invalidated (Dumas-Mallet et al., 2018). Similarly, values of relevance and human interest may help explain why health-related research tends to receive more coverage than research on other topics (Dunwoody, 2021; Joubert et al., 2022; MacLaughlin et al., 2018; Schäfer, 2017; Suleski & Ibaraki, 2010).

Journalists also decide what research to cover based on their own interests (Hansen, 1994; Rosen et al., 2016), those of their editors (Dunwoody, 2021; Murcott & Williams, 2013), and, to a lesser extent, those of their audience members (Amend & Secko, 2012; Hansen, 1994). The need to satisfy editors' interests can create tensions, as some editors do not have the same level of knowledge in research as journalists specialized in health or science and thus rely more on traditional news values, such as controversy or surprise, when selecting stories (Dunwoody, 2021). In addition, because journalists are more wary of covering research funded by industry or conducted by the government, they may preferentially select studies that were publicly funded and/or conducted by academics (Gesualdo et al., 2020). Organizational mandates may also play a role. Journalists working for media outlets with a "current news science beat" model—focused on reporting breaking science news—may cast a wide net when selecting studies (Lublinski, 2011). In contrast, journalists at outlets with a "creative science beat"—focused on providing novel perspectives on science news—may be more selective, only reporting on studies if they can find a new angle to do so (Lublinski, 2011).

Finally, journalists' need to maintain the trust of their audience can also encourage them to select research studies they perceive as presenting findings that are relatively certain (Lehmkuhl & Peters, 2016). In theory, this would require the journalist assessing the methodological rigour of the study, but—as discussed in the section on verification below—such assessments are rare in practice. Instead, many journalists rely on more subjective perceptions of the credibility or "elite" status of the research to determine whether it is worth covering (cf. Carlson & Franklin, 2010). This typically translates to bias towards studies published in prestigious journals, such as *Science* and *Nature* (Dumas-Mallet et al., 2017; Hansen, 1994; MacLaughlin et al., 2018; Moorhead et al., 2021; Olvera-Lobo & Lopez, 2015; Schäfer, 2011; St Lewis, 2011). These journals also often have more resources available to invest in science PR than less "elite" publications, exacerbating the tendency to select from these sources (De Dobbelaer et al., 2018; Maggio et al., 2019; Schäfer, 2017). Some journalists also report considering the journal's Impact Factor when selecting studies (Rosen et al., 2016), further encouraging the tendency to cover research from top journals and discouraging coverage of locally relevant research published in the Global South (Nguyen & Tran, 2019). However, some

professional journalism resources recommend considering slightly lower-tier, specialized journals, because they can provide content that might be overlooked by other journalists but also because "their peer reviewers probably put studies through their paces better" (Oransky, 2022, p. 24). That is, although research from lower-tier journals may not be as useful for signaling credibility, these studies may be more rigorously vetted—which, as I discuss in further detail below, is another key factor shaping research selection practices.

Research Verification

Journalists' selection-related criteria must be understood alongside their verification practices: the strategies they use to check that the research they plan to report on represents "justified, true" knowledge (Lisboa & Benetti, 2015). Although verification has famously been called the essence of journalism (Kovach & Rosenstiel, 2021), journalists' heavy workloads often cause them to vet truth claims selectively rather than comprehensively (Diekerhof & Bakker, 2012; Shapiro et al., 2013). Some studies suggest that controversial stories involving unfamiliar sources receive more verification, presumably because they pose greater risks to journalists' credibility (Barnoy & Reich, 2019). In addition, small, easily verifiable claims are almost always vetted because they require few resources, whereas "larger but greyer assertion[s]" often go unchecked (Shapiro et al., 2013, p. 669). In this sense, verification, like source selection, can be considered a strategic ritual (Shapiro et al., 2013; Tuchman, 1972)—performed, at least in part, to protect the reputation of the journalist and their organization.

Scientific findings tend to fall in the "larger but greyer" category, which may discourage journalists from vetting them (Fleerackers & Nguyen, in press). As discussed, studies are often paywalled and complex, which can create what Van Witsen (2018) calls an "information and resource asymmetry" (p. 8) between scientists—who in general have access to studies and the time and expertise to understand them—and journalists—who often have neither. As a result, many journalists rely on PR resources and abstracts (Bray, 2019a), which are not always complete enough to allow for critical, comprehensive verification.

Moreover, the iterative, self-correcting nature of science can make verifying research challenging, as what is considered 'true' and 'justified' at one point in time will often be considered 'misinformation' when more evidence emerges (Krause et al., 2022). This epistemic challenge is problematic for a profession focused on providing true facts (Lisboa & Benetti, 2015) on a deadline. This tension between providing "true" accounts of reality and acknowledging the iterative, provisional nature of scientific knowledge has been a major obstacle for many journalists covering the COVID-19 pandemic. As one journalist reflected:

> [The pandemic taught me] That search for scientific knowledge is a continuum, a collection of findings and observations and not a definitive answer that happens on a given day. And that we need to make this clear to our audiences. This is one way we fight mistrust in scientists and scientific knowledge (Ordway, 2022, para. 63).

These challenges may help to explain why journalists *describe* research verification as an essential part of their work (Amend & Secko, 2012; Gesualdo et al., 2020) but seldom attempt to verify statistics and numbers in practice (Crettaz von Roten, 2018; A. Van Witsen & Takahashi, 2021). Instead, many rely on credibility heuristics, such as the perceived trustworthiness of the research, to determine which findings to trust and which to verify (Hertzum, 2022). In general, these perceptions tend to be based on the perceived credibility of the *source* of the information more than the credibility of the information itself, with one study finding that journalists use this "auto-pilot" mode of judging trustworthiness in as many as two-thirds of their verification decisions (Barnoy & Reich, 2022).

In health and science journalism, the 'autopilot' mode of verification tends to entail relying on credibility heuristics such as familiarity or perceived trustworthiness of the researcher, the reputation of their institution, and the prestige of the journal they publish in, rather than evaluating the quality of the research itself (Conrad, 1999; Lawson, 2023; A. Van Witsen & Takahashi, 2021). In line with journalists' research selection strategies, studies published in "elite peer-reviewed journals" (Conrad, 1999, p. 286) appear to be vetted much less rigorously than other studies, if they are vetted at all (Hansen, 1994; Olvera-Lobo & Lopez, 2015). The perceived trustworthiness of these

journals is linked to journalists' perceptions of the scientific peer review process, assuming that "peer review assures quality control of the science" (Conrad, 1999, p. 286). That is, at least in the case of top journals, many health and science journalists choose to put their trust in the external, scientist-driven verification of peer review rather than independently vetting truth claims (Forsyth et al., 2012; Oransky, 2022; St Lewis, 2011). This outsourcing of verification is potentially problematic, because in practice peer review is not as reliable and consistent a quality control mechanism as it is often portrayed to be (Crettaz von Roten, 2018). It is unclear to what extent science journalists are aware of the limitations of peer review, nor how this informs their verification practices—a gap which Study 1 of this dissertation (Chapter 5) begins to address.

Although heuristic-based strategies are by far the norm for verifying peer reviewed research, a minority of journalists do appear to critically verify the numbers and statistics they report on (Lawson, 2021; A. Van Witsen & Takahashi, 2021). Interestingly, one Israeli study found that academic sources undergo more cross-verification than other types of sources (Godler & Reich, 2017). This finding has not yet been replicated but aligns with a meta-synthesis of science and health journalism scholarship, which found that quality-related considerations "such as whether the research was sound" play an important role in health and science reporting (Amend & Secko, 2012, p. 262). However, a study of Swiss, German, and Austrian science journalists suggests that these assessments of 'soundness' are highly context dependent. Specifically, journalists were more likely to thoroughly assess uncertainties associated with a given research finding when it was used as the focal point of the story, rather than supporting evidence (Lehmkuhl & Peters, 2016). They seldom investigated deeply when the finding aligned with a predefined story frame, was perceived to be societally irrelevant, or was likely to be covered by other, competing media outlets (Lehmkuhl & Peters, 2016).

Strategies journalists use to vet the quality of research include comparing numbers, measurements, and statistics to those available from other sources (A. Van Witsen & Takahashi, 2021) and, more commonly, asking one or more unaffiliated experts to corroborate study claims (Conrad, 1999; Gesualdo et al., 2020; Leask et al.,

2010; Lehmkuhl & Peters, 2016). Journalists often include these comments and critiques from experts in the story itself, both to: a) provide more 'objective' and 'balanced' coverage of the issue (i.e., by showing multiple, conflicting perspectives on the findings), and b) protect themselves from potential failures of verification via the peer review system (Dunwoody, 1999). As such, journalists' reliance on interviews with experts allows them to vet complex findings, maintain a veneer of objectivity, and shift responsibility for any incorrect information onto the expert quoted in the story. While this approach has practical and strategic advantages, scholars and practitioners have urged journalists to abandon this "uncritical" deference to scientific expertise (Figdor, 2017; Murcott, 2009), move away from "science cheerleading" (Blum, 2021), more rigorously verify the statistics they report on (Crettaz von Roten, 2018), and, ultimately, share responsibility with scientists for the accuracy of science news (Figdor, 2017; West & Bergstrom, 2021).

3.7.3. Editing/Processing: How Journalists Communicate Research

Existing literature examining editorial practices for communicating about (peer reviewed) research have primarily focused on two areas: (1) practices for referencing a particular study and (2) approaches to framing the (certainty) of the findings.

Referencing Research

The literature examining how journalists reference research in their stories is rather limited. De Dobbelaer et al. (2018) found that journalists often use "general terms" to describe the research they cover, referring to "scientific studies" rather than naming specific researchers or institutions—particularly when the credibility of those institutions is in question. This is corroborated by our study of opioid research coverage, which found that only about a third of news stories mentioned any bibliographic details about the research they cited (i.e., author names, journal titles, or institutional affiliations) (Matthias et al., 2020). Instead, as in De Dobbelaer et al. (2018), stories often described research in broad, nondescript terms or simply hyperlinked to studies without providing contextualizing information. Our more recent research suggests that these strategies for referencing research can vary across media outlets, with some outlets providing

bibliographic information such as author names or institutional affiliations more than 90% of the time and others doing so in as few as 11% of cases (Fleerackers et al., 2022d). Although we did not systematically track the proportion of references that did not provide bibliographic details, we noted during the content analysis that this was a common practice. Importantly, it is likely that the level of information provided for a particular research reference depends on the role of the research in the story, as journalists portray research differently depending on whether it is core to their narrative or supporting source for a larger story (Lehmkuhl & Peters, 2016). More information about the research tends to be included in the former case than in the latter.

Framing Research

With respect to framing research findings, three broad approaches recur in the literature: downplaying scientific uncertainty, hyping scientific uncertainty, and providing balanced coverage (Guenther et al., 2015). Frames that downplay uncertainty limit references to study limitations, focus on results rather than methods, and omit background information, while those that hype uncertainty tend to highlight controversy and emphasize study weaknesses (those that provide balanced coverage land somewhere in the middle) (Guenther et al., 2015). Journalists may also communicate scientific uncertainty through linguistic strategies (e.g., using words like 'could' or 'may') or by presenting conflicting views about the research, typically by quoting experts (Dunwoody, 1999; Lehmkuhl & Peters, 2016; A. Van Witsen, 2020). As with verification, this approach places responsibility for any invalid or controversial critiques on the source, rather than the journalist. Studies have found that journalists hype scientific uncertainty in certain cases, often by framing the research as controversial or by shedding doubt on an important finding that was previously thought to be well-established (Antilla, 2005; Lehmkuhl & Peters, 2016; Nisbet et al., 2003; Stecula & Merkley, 2019). This use of uncertainty may be strategic, a way of bringing tension to an otherwise dull, 'unsellable' science story (Lehmkuhl & Peters, 2016; Nelkin, 1995). As Peters, writing in Dunwoody et al. (2018), suggests, "the news value of some published stories derived from the uncertainty itself" (p. 3).

In most cases, however, downplaying scientific uncertainty appears to be journalists' preferred strategy for framing research findings (Bray, 2019; Dumas-Mallet et al., 2018; Guenther et al., 2015, 2019; Matthias et al., 2020; Zehr, 2000). This tendency may partially be explained by journalists' desire to simplify research so that it is more understandable to an audience (McKinnon et al., 2019). It may also stem from their need to attract audience attention, as "journalism cannot hope to garner public attention if the journalist has to start out with a caveat" (Lehmkuhl & Peters, 2016, p. 910). Indeed, many journalists fear that their audience would doubt the science too much if limitations are fully expressed (Maier et al., 2016), which may in turn cause audiences to doubt the credibility of the journalist or the media outlet (Lehmkuhl & Peters, 2016). That is, portraying science as sound and certain could be seen as yet another strategic ritual for maintaining (or regaining) journalism's authority.

Beyond framing research as certain, we know very little about how journalists use scientific findings to establish their own legitimacy. However, it is likely that some of the same heuristic cues that journalists use to select and verify research—such as journal reputation and whether the research has been peer reviewed—would feature in their framing of the research. This is supported by one small survey study, in which 45% of US health and science journalists reported always specifying whether the research they covered was peer reviewed and 40% reported always stating whether it had been published in a journal (Schultz, 2023). I begin to explore the extent to which these self-reported claims hold true in practice in Study 2 (Chapter 6) and discuss the degree to which they apply to journalists in other countries in the Discussion (Chapter 8).

3.8. Conclusion

Reflecting on the COVID-19 pandemic, Funtowicz and Ravetz (2020) prophesized that "we are now truly in a Post-Normal age. Science (and Society) will never be the same again" (p. 3). It is likely that this new, post-normal context has similarly disrupted journalists' well-established practices for reporting on research, yet the extent and nature of these changes remain largely unknown. In this chapter, I have argued that the potential for disruption is particularly high in the case of preprints, whose

unvetted and uncertain nature challenges journalists' desire to present accurate, fact-based news and maintain credibility in the eyes of their audience. As journalists have traditionally been discouraged from using preprints, there is also a lack of established norms or best practices for reporting on them, creating a context in which novel practices are likely to emerge.

As a first step towards identifying these 'post-normal' science journalism practices, I have synthesized existing research examining journalists' motivations and strategies for finding, selecting, verifying, and communicating research in 'normal' communication contexts. The findings suggest that journalists use research for both practical and strategic reasons—ranging from improving the accuracy of their reporting to establishing their own credibility—but that this use is hindered by conceptual and financial access barriers, as well as time and resource constraints. They use a mix of active and passive strategies to find research, with a high reliance on press releases and expert sources. Decisions about which studies to cover are closely tied to perceptions of prestige and credibility, with research published in top-tier journals receiving the bulk of the coverage—often with minimal vetting. Overall, verifying research is a challenge, with many journalists relying on heuristic cues and the peer review process rather than rigorous investigation. Finally, journalists tend to frame research findings as confirmed facts, seldom communicating uncertainty unless it enhances the news value of their story.

Collectively, this synthesis of existing practices sets the stage for the rest of this dissertation, but also addresses decades-old calls for "a closer look at science journalists' working routines, at their criteria of selecting and presenting news" (Schäfer, 2011, p. 407; Hansen, 2008), providing a foundation for future research at the intersection of journalism and science communication.

Chapter 4.

Methodology: An Integrative, Multistage Mixed Method Approach to Examining Preprint-Based Journalism

4.1. Abstract

In this chapter, I provide an overview of the mixed method methodology I used to examine why (RQ1) and how (RQ2) journalists use preprints, how the introduction of COVID-19 affected this use (RQ4), and whether the coverage of preprints seen during the pandemic represented a departure from, or extension of, established journalistic norms for reporting on research (RQ3). I begin with a description of the pragmatic interpretive framework that underpins my methodology, then introduce the integrative, multistage mixed method approach applied across the three studies. I discuss how qualitative and quantitative aspects of the research were integrated with one another at multiple levels, including study design, theoretical framework, data collection, and interpretation of results. In doing so, I also clarify key concepts that are relevant to this research—*journalism, media outlets, media stories, journalists, research,* and *media coverage of research*—and justify how they have been defined and operationalized in the three studies. I conclude with a reflection on the experiences, assumptions, and values that have informed the design, analysis, and interpretation of this research.

Keywords: mixed method research; pragmatic interpretive framework; post-normal science communication; reflexivity; methodology

4.2. Introduction

This chapter presents the overarching methodology I employ in this dissertation. I discuss the pragmatic interpretive framework that guided the research and justify its applicability to research projects, such as this one, that seek to contribute practically relevant insights. I then describe my multistage mixed method framework and how it enabled me to use insights gained from each study to inform the data collection, analysis,

and interpretation of those that followed. Next, I discuss how qualitative elements were integrated with quantitative ones through multiple aspects of the research process, including study design, theoretical framework, data collection, and interpretation of results. Finally, I reflect on how both the research process and results have been shaped by my own experiences and values as a researcher, as well as by the volatile pandemic context in which the three studies took place.

4.3. Pragmatic Interpretive Framework

The methodology of this dissertation is guided by a pragmatic interpretive framework, which prioritizes the methods and theories that the researcher deems most practical or effective for answering their research questions. It is informed by the ontological belief that reality is what "works" or is most useful for achieving the goals of the research and the epistemological assumption that there are many ways in which a researcher can come to know this reality (Creswell et al., 2011; Creswell & Poth, 2017). These ways of knowing can rely on both inductive, subjective evidence and deductive, objective evidence, which, as described below, makes research involving both qualitative and quantitative approaches a natural fit (Creswell & Poth, 2017). A pragmatic approach is also well-suited to the context in which I conducted this research, as, at the time I started this dissertation, journalists and editors lacked clear guidelines for vetting or communicating preprints, although many were using them in their COVID-19-related coverage (Fraser et al., 2021). As such, one goal of research has been to answer questions that journalists were asking during the early stages of the pandemic and guide organizations in establishing guidelines for covering preprints effectively. I was also continually evolving as a scholar throughout the dissertation and adapted my approach to reflect changes in my methodological, theoretical, and empirical understandings of journalism, preprints, scientific uncertainty, and science communication. I reflect on the nature of this evolution in more detail in Section 4.6.

4.4. Mixed Method Integration Approach

Informed by this pragmatic interpretive framework, I applied a mixed method approach to answer the research questions. Mixed method research intentionally integrates or combines qualitative and quantitative methods of inquiry to maximize the strengths of each (Creswell et al., 2011; Newell & Gagnon, 2013). Such integration can occur at one or multiple stages of a research project. This dissertation employs a *multistage mixed method framework,* in which data were collected, analyzed, and published over multiple phases, and insights from each phase were used to inform the subsequent ones (Creswell et al., 2011; Fetters et al., 2013).

This approach was appropriate for this dissertation because mixed method designs are well suited to answering research questions that require "real-life contextual understandings" (Creswell et al., 2011, p. 4) and for developing more comprehensive insights not only into the *what* of complex phenomena but also the *how* and *why* (Creswell & Poth, 2017). In this dissertation, I aim to identify *how* and *why* journalists use preprints (Chapter 5/Study 1), but also *what* the resulting media coverage of preprints looks like in practice (Chapter 6/Study 2 and Chapter 7/Study 3), and consider the larger context in which this coverage takes place by situating my findings within recent evolutions in Open Access, Open Science, and (science) journalism (Chapter 2); examining the role of the pandemic in accelerating preprint-based journalism (Chapter 7/Study 3); and reflecting on how the journalistic practices I identify depart from, or extend, well-established norms for reporting on (peer reviewed) research (Chapter 8).

4.5. Integration at Multiple Points of Interface

This dissertation integrates insights from qualitative and quantitative approaches at multiple "point[s] of interface" (Creswell et al., 2011, p. 6), including study design, data collection, theoretical framework, and interpretation of the results. I describe these four levels of integration in detail below.

4.5.1. Emergent and Iterative Study Design

The overarching design of this dissertation is best described as *emergent*, as I did not determine the methods for each study in advance but instead developed and refined them throughout the research process (Creswell et al., 2011; Fetters et al., 2013). Specifically, the research questions, data sources, and analytical approaches for each study were informed by the results of those that came before, as well as the discussions I had with journalists and scholars following each study's publication. For this reason, it is important to note that the three studies that comprise this dissertation were conducted and published in a different order than they are presented in the following pages. In practice, "Study 2" came first, then "Study 1," and finally "Study 3." I chose to present them in a different order as it aligned more naturally with the stages of news production laid out by Domingo et al. (2008), as described in Chapter 3.

I found this emergent and iterative study design to be valuable as it allowed me to fill in gaps identified in each paper, address challenges or questions expressed by journalists and scholars in response to the findings, and answer questions that arose as more evidence about preprints, journalism, and COVID-19 became available. For example, I decided to examine how journalists find and verify preprint research (the focus of Study 1) because of conversations with journalists who reported on Study 2. In an interview about the research for a *Science Magazine* story (O'Grady, 2021), freelance journalist Cathleen O'Grady noted that framing a preprint as preliminary or unverified may be less important than rigorously verifying it—a practice that typically appears behind the scenes and would be difficult to capture through content analysis we used in the study. This comment, and similar conversations during other interviews and conference presentations, inspired me to re-examine a series of interviews we had conducted with health and science journalists for another research project (Moorhead et al., 2023) to understand the 'hidden' practices and motivations that may have shaped the framing practices we observed in Study 2.

Similarly, I decided it was important to examine the extent of media coverage of preprints in the lead up to the pandemic (i.e., Study 3) because there seemed to be no

consensus among interviewees in Study 1 on whether journalists' use of preprints had started long before COVID-19 or whether it was a "new normal." The design and goals of Study 3 were also shaped by media coverage of Fraser et al.'s (2021) widely circulated study, which often framed the results as evidence that the COVID-19 crisis had motivated journalists to report on preprints for the first time (e.g., Kwon, 2021; Owens, 2022). However, this framing was not supported by the study itself, as Fraser et al. (2021) did not examine preprint media coverage before 2020. This dominant frame, especially in light of conflicting accounts, inspired the quantitative approach used for the final study to gather empirical evidence on whether the preprint-based media coverage seen during the pandemic was truly 'post-normal' or simply a continuation of a longer-term trend. Key aspects of the design of each study are summarized in Table 4.1 and elaborated in the methods sections of Chapters 5–7.

Table 4.1.   Overview of Design for Studies 1-3

Study	Objective and RQ	Theoretical Concepts	Data Source(s)	Method(s) of Analysis
1	Understand *why* and *how* journalists find, verify, and communicate about preprints (RQ1, RQ2a-c)	Post-normal science communication (Brüggemann et al., 2020)	Semi-structured interviews with 19 journalists who reported on research for seven diverse media outlets in Spring 2021, gathered using a custom-built script (Enkhbayar et al., 2022)	Codebook thematic analysis (Braun & Clarke, 2012, 2022)
2	Document *what* this coverage of preprints looks like in practice (i.e., how journalists communicate about preprints) (RQ2c)	Emphasis framing (Chong & Druckman, 2007; Entman, 1993) Hyperlink framing (Coddington, 2012; Karlsson & Sjøvaag, 2018) Core vs peripheral journalism (Carlson & Lewis, 2015; Ginosar et al., 2022)	521 mentions of 100 COVID-19-related preprints in stories published by 15 media outlets, gathered using Altmetric's Mainstream Media category	Deductive quantitative content analysis with intercoder reliability (Krippendorff, 2004; Lacy et al., 2015) Descriptive statistical analysis and logistic regression
3	Assess how the COVID-19 pandemic affected journalists' use of (RQ4)	Core vs peripheral journalism (Carlson & Lewis, 2015; Ginosar et al., 2022)	Mentions of 11,538 preprints from four servers and 397,446 Web of Science outputs across 94 media outlets, gathered using Altmetric's Mainstream Media category	Deductive quantitative content analysis with double coding (Hermida & Young, 2019; Krippendorff, 2004) Descriptive statistical and linear regression

4.5.2. Theoretical Integration Through Post-Normal Science Communication

Because mixed method research projects integrate multiple methods, they are often interdisciplinary and collaborative (Creswell et al., 2011). Interdisciplinary collaborations have been found to be especially useful when tackling complex problems that cannot be addressed though a single disciplinary perspective, have implications beyond the academy, and are linked to novel technologies (Briggle & Christians, 2017; Buyalskaya et al., 2021; Newell & Gagnon, 2013). All these characteristics apply to journalists' use of preprints, which, as discussed in Chapter 2, is a topic that connects to recent evolutions in both scholarly communication and journalism; raises important questions about public understanding of science; and has only been possible because of new digital technologies that enabled free, unfettered access to research. To explore this complex topic, this dissertation thus brought together interdisciplinary teams of scholars, who collectively contributed a breadth and depth of expertise in journalism, science communication, health communication, scholarly communication, and statistics to answer the research questions (Creswell et al., 2011). In line with best practices for interdisciplinary research, perspectives, methods, and theories from each discipline were considered and integrated throughout the research process (Newell & Gagnon, 2013).

The interdisciplinarity of the research teams was particularly helpful in achieving "the integration of a variety of theoretical perspectives" (Creswell et al., 2011, p. 4) that is often seen in mixed method research. Specifically, we applied different theoretical concepts and frameworks across the three studies, incorporating the disciplinary lens(es) that we believed would "work" best for addressing the research question(s) (Creswell & Poth, 2017). At the same time, a mixed method project is unlikely to succeed without a single "conceptual orientation"(Creswell et al., 2011, p. 4) that provides coherence across the various studies or research phases. As such, in this dissertation the varied theories and concepts used in the three studies are integrated through a shared lens of post-normal science communication (Brüggemann et al., 2020), and structured across three specific phases of news production (Domingo et al., 2008), as described in Chapter 3. In addition, each study applied a common understanding of several core concepts—*Journalism,*

Media Outlets, Media Stories, Journalists, Research, and *Media Coverage of Research—*
which I describe below.

Conceptualization of "Journalism"

For decades, journalism scholars have focused their attention on examining and
comparing the practices, activities, and outputs of a small number of elite media outlets,
notably the *New York Times (NYT), Guardian, Washington Post, Le Monde, Times,* and
British Broadcasting Corporation (BBC) (Hanusch & Vos, 2020; Lewis, 2020b).
Focusing on these elite outlets has had several obvious advantages. First, these outlets are
often highly trusted (Sanders, 2023; Watson, 2023) and have large, global audiences
(Majid, 2023), making them more 'impactful' than smaller, less well-known outlets.
They also tend to set an example for other news organizations, as the stories they cover
often get covered by competing outlets later the same day (Golan, 2006). Such "inter-
media agenda setting" (Golan, 2006) means that scholars can gain a relatively broad
understanding of what is happening in journalism by examining just a few outlets, an
efficient data collection approach (Nisbet et al., 2003). In addition, the elite outlets that
are most frequently studied overwhelmingly represent so-called "legacy" journalism,
meaning that they are staffed by professional journalists and guided by traditional
journalistic values, ethics, norms, and goals (Maares & Hanusch, 2022). Such legacy
outlets have been conceptualized as comprising the "core" of the journalistic field and are
often contrasted with the growing number of bloggers, news aggregators, alternative
media outlets, and other "peripheral actors" who produce news but have not traditionally
been considered journalism (Eldridge, 2017b; Maares & Hanusch, 2022). Focusing on the
outlets that comprise journalism's core arguably enables scholars to focus on journalism
in its purest form, as an institution distinct from the many other types of media and
communication that exist today. It is one way of answering the increasingly complex
question of what counts as "journalism" (Bromley, 2019; Eldridge, 2017a; Hermida,
2019; Wahl-Jorgensen & Hanitzsch, 2019) and is thus a worthy object of inquiry for
journalism scholars.

Focusing on a narrow subset of media outlets is problematic for several reasons.
First, the bias towards elite media means that we have extensive knowledge about how

61

journalism works within a small number of organizations but know very little about journalism in other spaces. This is particularly striking in the case of *NYT*, which was included in almost a quarter of comparative journalism studies that examined specific organizations between 2000 and 2015 (Hanusch & Vos, 2020). In addition, as Carlson (2015) writes, "Journalism is not a solid, stable thing to point to, but a constantly shifting denotation applied differently depending on context" (p. 2). While journalism's core function—to serve society by disseminating timely, relevant information (Kovach & Rosenstiel, 2021)—has remained surprisingly stable over time, how media outlets deliver on that function has evolved and fragmented (Schapals, 2022). Media outlets of all kinds—including peripheral and legacy media—are rapidly adapting their practices, norms, platforms, formats, and business models to stay relevant and financially viable in a volatile digital media ecosystem (García-Avilés, 2021). In the midst of these fast-changing innovations, evolutions, and reinventions, understanding contemporary journalism requires taking a broader view that also considers nontraditional journalistic formats, practices, and actors (Belair-Gagnon et al., 2019; Schapals, 2022). A broader view pushes us beyond the core-periphery dichotomy (Deuze & Witschge, 2018) in recognition that peripheral actors often share qualities with those at the core (Coddington, 2020; Schapals, 2022; Schapals et al., 2019). Moreover, younger audiences increasingly prefer to receive news from social media influencers and other digital content creators (Newman et al., 2023), making research examining only legacy outlets less relevant. News aggregators, such as Google News, are also heavily used (Newman et al., 2020) but rarely receive scholarly attention (Coddington, 2019). Finally, scholars have argued that innovations of journalism's peripheral actors often shape the norms, practices, and routines that eventually come to define its core (Maares & Hanusch, 2022). Examining these marginal actors could thus provide insight into emergent practices that will later become established in journalism more broadly. This is particularly relevant in the context of post-normal journalism, whose practices tend to "evolve at the fringes of traditional journalism" rather than its core (Brüggemann, 2017, p. 10).

Therefore, to understand the degree to which journalists' practices and motivations for reporting on preprints during the COVID-19 pandemic differ from those seen in 'normal' communication contexts, the studies that comprise this dissertation

employ a broad definition of journalism—which includes both 'peripheral' and 'legacy' actors—and investigate (rather than presume) the degree to which the practices of each depart from journalistic norms (Deuze & Witschge, 2018; Schapals, 2022). In doing so, the research follows Eldridge II's (2019) recommendation and conceptualizes journalism "as something constructed by those who identify themselves as belonging to the field, and those who embrace its contributions" (p. 13) rather than as an institution with sharply defined edges. On a practical level, this means that journalists and media outlets were included in our research based on how they presented themselves (i.e., as journalists, news sites) (cf. Maares & Hanusch, 2022), rather than normative or theoretical judgements about what should and shouldn't be considered journalism (Deuze, 2005).

Conceptualization of "Media Outlets," "Media Stories," and "Journalists"

Following this broad conceptualization of journalism, in this dissertation, I use the term 'media outlets' to refer to both legacy and peripheral outlets, 'media stories' to refer to the content published by these outlets, and 'journalists' to refer to the individuals who write or curate these stories. Although I take an inclusive view of media outlets and journalists, I acknowledge that completely abandoning distinctions between the core and periphery is likely unwise (Eldridge II, 2019), especially given that some studies *have* identified important differences in the practices of the two types of actors (Cheruiyot et al., 2019; Cheruiyot & Ferrer-Conill, 2018; Ginosar et al., 2022). In light of this, and to test Brüggemann's (2017) assertion that post-normal journalism is more likely to emerge at the periphery of the field, we examined the degree to which the outlets and journalists we studied represented legacy or peripheral media (and in Study 3, "non-journalism"). This allowed us to explore whether post-normal practices for reporting on preprints are indeed more likely among peripheral media, as well as whether differences in journalistic practice follow along theoretically derived lines. It also enabled us to consider a more diverse sample of outlets and journalists than is typically seen in journalism scholarship and respond to calls for research that treats peripheral actors as "legitimate" contributors to the field (Schapals, 2022, p. 12). In doing so, this dissertation contributes to a growing body of theoretical scholarship that explores the blurring and expansion of journalism's boundaries (Carlson & Lewis, 2015; Eldridge, 2017b) and considers what this means for

how scholars study journalism (Maares & Hanusch, 2022; Schapals, 2022). It responds to Schapals' (2022) call for a more critical examination of core-peripheral distinctions that:

> …consider[s] what journalism is becoming in relation to established, normative definitions we have held close for many years…[and] allows for an examination not only of journalism's past, but also of its complex, multifaceted present and future (p. 7).

Conceptualization of "Research" and "Media Coverage of Research"

Just as the boundaries of what is and isn't journalism are blurring, the rise of OS has contributed to a situation in which what counts as "research" is expanding. As discussed in Chapter 2, the OS movement advocates for making all aspects of the research process publicly available, including traditional, peer reviewed journal articles and books but also nontraditional outputs that show research in progress, such as preprints, protocols, codebooks, datasets, and software (UNESCO, 2023). While these nontraditional research outputs are still seen as less valuable than traditional publications, some universities now consider them when making tenure and promotion decisions (Alperin et al., 2022). Although many forms of academic research have the potential to support journalists' work (Fleerackers et al., 2023a; 2023b), I focus only on two of them in this dissertation: peer reviewed journal articles and preprints. These two types of research are comparable in that they are both publicly available, complete scholarly manuscripts (i.e., including an introduction, literature review, methods, results, discussion, and/or conclusion) (Berg et al., 2016). As discussed in Chapter 2, they are distinct because preprints have not yet been peer reviewed or published in a journal. Moreover, while nontraditional forms of research such as datasets seldom receive media coverage (Khan et al., 2021; Loosen et al., 2020; Zamith, 2019), journalists draw heavily on journal articles (Lehmkuhl & Promies, 2020; Schultz, 2023). That is, journal articles represent the default source of research in 'normal' journalism, making them an ideal comparison for understanding the degree to which journalists' use of preprints during the pandemic can be considered "post-normal." As such, this dissertation defines "media coverage of research" as media stories that mention preprints or journal articles, either through in-text descriptions or hyperlinks (cf. Fleerackers et al., 2022d).

Implications of Conceptualizations of Core Concepts

In line with the conceptualizations described above, the media outlets (and corresponding media stories) and journalists included in the three studies were selected because of their frequent use of research (i.e., preprints and journal articles)—the practice most relevant to this dissertation. In practice, this sampling approach meant that many of the journalists and media outlets did not focus on health or science specifically. For example, in Study 1 we interviewed many health and science journalists but also a lifestyle editor, a freelancer who covered design and culture, a staff journalist who reported primarily on politics, and a freelance journalist who specialized in in-depth features but did not have a specific topical focus. Similarly, several of the media outlets we included in Studies 2 and 3 were not focused on health or science but on other topics, such as business, lifestyle, and general news. What united these journalists and outlets, and made them appropriate for addressing our research aims, was not their specialization but rather their frequent use of research: COVID-19-related preprints in the case of Study 2, and peer reviewed research indexed in the Web of Science in Study 3.

Our decision to examine a diversity of journalists and outlets has several strengths. First, it aligns with recent recommendations to view "non-professional journalists' (or 'amateur journalists') contribution to journalism and society according to the practices they employ and the products they provide" (Ginosar et al., 2022, p. 2). In addition, scholars have found that studies of "science and the media" have focused almost exclusively on the practices of specialized health and science outlets and journalists, leaving much unknown about the wider coverage of research in our diverse and rapidly evolving media ecosystem (Hansen, 2008). This oversight is problematic, as journalists use research to report on a range of beats, including general news, business, economics, and politics (Boss et al., 2022; Ordway, 2022). Similarly, media outlets focused on a variety of topics publish content that mentions research, including general news, local-interest, culture, politics, business, and entertainment (Alperin et al., 2023; Hansen, 2008; Matthias et al., 2020; Ortega, 2020b, 2021). Our practice-focused sampling approach enabled us to help fill this gap and build a broader, more representative understanding of where and how preprints are used in contemporary journalism. In addition, as I have

argued elsewhere, non-science-focused information sources may engage a more diverse audience than those specialized in science (Fleerackers et al., 2022c), because only a narrow subset of the population actively seeks out science news (Funk et al., 2017). Choosing to examine coverage of preprints among non-science outlets thus allowed us to provide insights that have relevance beyond the "narrow public" that is often the focus of science communication research (Dawson, 2018, p. 784). Finally, our inclusive approach gave us an opportunity to explore whether specialized health and science journalists are better equipped to cover preprints than those working in other beats, as has been suggested by other scholars (Nguyen et al., 2021; Wormer, 2018).

Alongside these strengths, however, our broad conceptualization of media coverage of research comes with limitations, as "the ways in which communication researchers define what qualifies as 'science coverage' impinges directly on what they find" (Hansen, 2008, p. 108). In our case, our findings were undoubtedly influenced by the decision to select journalists and outlets which *frequently* covered research, rather than those who reported on it only occasionally. Recent research suggests that health and science journalists who often cite research are better informed about preprints, at least in the US (Schultz, 2023). Their practices and perspectives may also be more likely to have been shaped by the researchers they interview, a process of 'scientization' that can occur among journalists who frequently interact with scientists (MacGregor et al., 2020). As such, it is possible that the practices of the journalists we studied depart from those of less frequent research users. The same is true for the media outlets whose content we analyzed. For example, those that often feature research-based stories may have established editorial guidelines for vetting and framing research, while other outlets may not. Their journalists may be more experienced in navigating scholarly literature, further contributing to the limitations discussed above and likely shaping the type and frequency of preprint communication practices we identified in Studies 2–3. Finally, because these outlets were selected based on their practices rather than audience size or geographic scope, they may not capture the way in which most people come across research in the media nor represent the most influential outlets in the global media ecosystem (although several elite outlets with large followings, such as *NYT* and *The Guardian*, were included in all three studies). Due to biases of our sampling approach (discussed below), they were

66

also overwhelmingly based in the Global North, which means our results may not generalize to media outlets in the Global South.

4.5.3. Data Integration Through Altmetric Research Mentions

This dissertation used a *connecting* approach to integrate qualitative and quantitative data from the three studies, meaning that study samples were gathered using a single data source and sampling frame (Fetters et al., 2013). Specifically, to identify journalists and media outlets who frequently report on research, we used data from Altmetric, a company that tracks "mentions" of research in a wide range of digital sources, including policy documents, social media, blogs, and Mainstream Media (MSM) (Altmetric, 2023). Altmetrics identifies these mentions using a combination of *link matching* (i.e., identifying URLs that link to research) and *text mining* (i.e., searching online texts for descriptions of research-related metadata, such as journal titles, publication dates, or author names) (Altmetric, 2020b). Researchers can tailor their search to identify mentions of specific research outputs (e.g., a collection of 100 COVID-19-related preprints, as we did in Study 2), published by specific journals or preprint servers (e.g., the four preprint servers examined in Study 3), over a specific timeframe (e.g., 2014-2021, as in Study 3). Within these source categories, researchers can also filter for specific outlets, such as particular Twitter users or, in our case, media outlets. The resulting data can then be downloaded as a CSV file and analyzed to better understand where, how, and by whom research outputs are mentioned by these diverse digital sources.

Altmetric data are frequently used in studies of "altmetrics," which seek to understand wider engagement with research by tracing the circulation of scholarly outputs across the web (Priem, 2014; Sugimoto et al., 2017). While the study of social media metrics has emerged as its own sub-discipline, with data from Altmetric as its most widely used source (Ortega, 2020a), the use of Altmetric among journalism scholars remains surprisingly rare, limited to only a handful of studies—many of which were led by researchers in my research group (e.g., Maggio et al., 2019; Matthias et al., 2020; Moorhead et al., 2021). Instead, most studies of science journalism identify science-

related media coverage by querying the websites of specific media outlets or searching news databases (e.g., LexisNexis, Factiva) using topical keywords (Dumas-Mallet et al., 2017; Hart et al., 2020; Lai & Lane, 2009; Nisbet et al., 2003). While this approach allows researchers to examine themes, frames, and practices related to coverage of science *issues*, it does not enable them to examine how, when, or whether journalists communicate about scientific *research studies* specifically. As discussed above, this likely overlooks a large number of stories that report on research without using the target keywords (Hansen, 2008). For example, our previous research has revealed that many media stories do not refer to research studies using searchable keywords but instead mention them using uncontextualized hyperlinks (Fleerackers et al., 2022d; Matthias et al., 2020). As Study 2 of this dissertation demonstrates, this practice also occurred in many stories that mentioned COVID-19-related preprints during the early months of the pandemic (Fleerackers et al., 2022b). As such, analyzing only those stories that mentioned preprints using keywords such as "preprint," "medRxiv," or "bioRxiv" (cf. Massarani & Neves, 2022) would have left a large number of stories overlooked.

While Altmetric has several clear strengths as a data source, it must be used with awareness of several important limitations (Ortega, 2019, 2020a, 2020a, 2021). First, despite its name, Almetric's "Mainstream Media" (MSM) category not only includes mainstream media outlets but also blogs, news aggregators, content farms, niche publications, and other peripheral media, as well as outlets that arguably should not be considered journalism at all, such as university websites and press release distribution services (Lehmkuhl & Promies, 2020; Robinson-Garcia et al., 2019). Second, media outlets are continually added and removed from the list of MSM that Altmetric tracks, and little information is available about how or why these outlets are included (Altmetric, 2020a). This can make longitudinal analyses of media coverage, such as the one presented in Study 3, problematic unless care is taken in selecting a sample of outlets that remained in Altmetric's list of tracked outlets over the course of the study timeframe (as we have done). Third, while Altmetric's precision appears to be quite high, its recall is variable, meaning that its ability to successfully identify all mentions of research in a given media story varies across outlets (Fleerackers et al., 2022d). More broadly, Altmetric tends to be less reliable when identifying mentions of research in stories

written in languages other than English (Ortega, 2020b, 2021). For these reasons, working with a fixed set of English-language media outlets—rather than the entire collection of MSM outlets—is recommended (Fleerackers et al., 2022d).

This is the approach we took in the three studies that comprise this dissertation. In Study 1, we identified journalists who had recently covered research (including both preprints and peer reviewed articles) for at least one of seven media outlets. These included general interest outlets (the *Guardian, NYT*) and health or science-focused outlets (*IFLScience, MedPage Today, News Medical, Popular Science, Wired*) (Enkhbayar et al., 2022), as these types of outlets have been found to cover more research than others (Ortega, 2021). In Study 2, we focused on the 15 media outlets that published the most stories mentioning 100 COVID-19-related preprints during the early months of the pandemic. Again, this sample comprised both general news and specialized outlets, some of which would be considered legacy and some peripheral. Finally, Study 3 examined coverage of preprints over 7.5 years using a sample of 94 media outlets with a history of publishing a high volume of stories mentioning (peer reviewed) research. We coded this list of outlets using a codebook adapted from Hermida and Young (2019), finding that it included a rich mix of peripheral, legacy, and non-journalism outlets specializing in a range of topics (Fleerackers & Fagan, 2022). While the sample used in each study was unique, several media outlets appeared in all three (e.g., *NYT, The Guardian, Wired, News Medical,* and *MedPage Today*). Including these outlets across the three studies allowed us to assess the degree to which our qualitative and quantitative challenged or confirmed one another, i.e., to examine the "fit" of the data integration (Fetters et al., 2013). At the same time, including additional outlets enabled us to examine a larger and more diverse sample, increasing the generalizability of our results.

4.5.4. Integration of Results Through a Woven Narrative

I present a narrative integration of the findings of the three studies in Chapter 8, providing the final "point of interface" in this mixed method dissertation. Drawing on the theoretical framework described in Chapter 3, I apply a *weaving approach* to narrative integration to present a concept-by-concept overview of the qualitative and quantitative

results (Fetters et al., 2013). In this case, the concepts include the constraining and motivating factors that shape journalists' use of preprints, the practices they use to cover them in each of the first three stages of news production in Domingo et al. (2008), and the role of the COVID-19 pandemic in shaping this coverage. Throughout the chapter, I assess the "fit" of data integration by examining the degree to which findings from each study confirm, expand on, or conflict with one another (Fetters et al., 2013). I also compare them to results from other studies of preprint-based journalism which emerged during the writing of this dissertation. Finally, I compare the integrated results to findings of previous research examining journalists' use of research in 'normal' communication contexts (i.e., those synthesized in Chapter 3). Collectively, this comparative integration enables me to provide a more holistic understanding of why and how journalists use preprints (RQ1–2), how the pandemic has affected this use (RQ4), and whether preprint-based journalism can be considered 'post-normal' (Brüggemann et al., 2020) (RQ3) than would be possible through a single quantitative or qualitative study.

4.6. Reflexivity Statement

Axiologically, researchers working under a pragmatic interpretive framework believe that knowledge reflects not only participants' but also researchers' perspectives, requiring a reflection on the values and assumptions that may have shaped the collection and analysis of the data (Creswell & Poth, 2017). Reflecting on my own values, I recognize that my choice of research questions and methodology were informed by my professional background as a freelance journalist, editor, and publicist, which continues to attract me to research that can provide practically relevant insights for journalists and other communication professionals. I am also drawn to research projects with practical implications, such as this one, because of my commitment to public scholarship. Fundamentally, I believe that scholars have a responsibility to consider how their research could benefit the societies within which they are embedded and should work to maximize those potential benefits (e.g., by pursuing socially relevant research, communicating results publicly, ensuring publications are freely accessible). This belief has at times been challenging to negotiate in completing this dissertation. For example, it has motivated me to preprint two of the studies (Fleerackers et al., 2022e; Fleerackers et

al., 2023c) and, in some cases, share those preprints on social media and with journalists who I believed would be interested in using the findings. As some of these journalists noted, there was a certain irony to this decision, given that my research has at times been critical of journalists' preprint coverage. In addition, I recognize that I am hopeful for a future in which both Open Science (including preprints) and science journalism can flourish. I have made this bias explicit by noting my experiences posting preprints and contributing to journalism in the qualitative study in this dissertation (Study 1) but not in the two other studies (Studies 2–3), as such reflections are uncommon in quantitative work. In writing all three papers, however, I have reflected on my personal biases and attempted to avoid framing our findings in an overly positive light.

In addition, this dissertation was conducted over the first three years of a deadly pandemic, a volatile time during which science and science communication were both rapidly changing. As what we knew about COVID-19, preprints, and journalism evolved, so did my perceptions and value judgements of journalists' use of these unreviewed studies. These perceptions and judgements continued to change as I completed my doctoral coursework and readings and developed a deeper understanding of preprints, peer review, Open Science, and journalism. This can be seen in Study 2 of this dissertation (the first study I conducted), in which we described preprints as scientifically uncertain because of their unreviewed nature. While I have made similar arguments in my other work (Ratcliff et al., 2023), my view of preprint uncertainty has become more nuanced. Specifically, after reading more about the biases, inequities, and inefficiencies of peer review (Balietti et al., 2016; Horbach & Halffman, 2018; Publons, 2018), the lack of evidence into its effectiveness as a quality control mechanism (Jefferson et al., 2002, 2007), and the many retractions of COVID-19-related journal articles that have occurred during the pandemic (Abritis et al., 2021; Santos-d'Amorim et al., 2021), I am no longer convinced that undergoing peer review *necessarily* makes scientific evidence more certain. Instead, I recognize that there is some risk that preprint findings may not hold up during peer review, but that this risk appears to be relatively small, including for COVID-19-related preprints (Brierley et al., 2022; Nelson et al., 2022; Nicholson et al., 2022; Zeraatkar et al., 2022). As such, it is no longer clear to me whether the risk of disseminating flawed or fraudulent findings is greater for preprints than peer reviewed

71

studies (Santos-d'Amorim et al., 2021). However, I do suspect that many journalists *perceive* preprints to be less certain than journal articles because of a historical reliance on peer review as an external form of verification (Forsyth et al., 2012; Oransky, 2022; St Lewis, 2011), as discussed in Chapter 3. This makes preprints an ideal case for examining larger questions at the intersection of journalism and scholarly communication, as I discuss in Chapter 9.

4.7. Conclusion

This dissertation employs a rigorous mixed method approach guided by a pragmatic interpretive framework to understand the degree to which journalists' use of preprints during the pandemic represents post-normal science communication. It does so through one qualitative and two quantitative studies that are integrated at multiple points of interface, including study design, theoretical framework, data collection, and interpretation of results. These studies were conducted in an iterative fashion, allowing the research questions, methods, and findings of later studies to build on those of the studies that came before. While the three studies make use of different theories and disciplinary perspectives, they are united in a shared understanding of several core concepts. Rather than applying the narrow definitions of terms such as *journalist, media outlet*, or *research,* the research takes an inclusive view of these contentious terms to allow for a more holistic understanding of how preprints are communicated in a rapidly evolving digital media ecosystem. This inclusive approach is made possible by the dissertation's final integrative element: an innovative data source for tracking mentions of research in diverse digital media, providing a broad view of the diverse journalists and outlets who report on preprints.

Chapter 5.

Science in Motion: A Qualitative Analysis of Journalists' Use and Perception of Preprints

5.1. Abstract

This qualitative study explores why and how journalists use preprints—unreviewed research papers—in their reporting. Through thematic analysis of interviews conducted with 19 health and science journalists in the second year of the COVID-19 pandemic, it applies a theoretical framework that conceptualizes COVID-19 preprint research as a form of post-normal science, characterized by high scientific uncertainty and societal relevance, urgent need for political decision-making, and value-related policy considerations. Findings suggest that journalists approach the decision to cover preprints as a careful calculation, in which the potential public benefits and the ease of access preprints provided were weighed against risks of spreading misinformation. Journalists described viewing unreviewed studies with extra skepticism and relied on diverse strategies to find, vet, and report on them. Some of these strategies represent standard science journalism, while others, such as labeling unreviewed studies as preprints, mark a departure from the norm. However, journalists also reported barriers to covering preprints, as many felt they lacked the expertise or the time required to fully understand or vet the research. The findings suggest that coverage of preprints is likely to continue post-pandemic, with important implications for scientists, journalists, and the publics who read their work.

This chapter presents the content of the paper published by Fleerackers et al. (2022a): *Fleerackers, A., Moorhead, L. L., Maggio, L. A., Fagan, K., & Alperin, J. P. (2022). Science in motion: A qualitative analysis of journalists' use and perception of preprints. PLOS ONE, 17(11), e0277769. https://doi.org/10.1371/journal.pone.0277769*

5.2. Introduction

COVID-19 has changed many aspects of how health research is communicated. Among these changes has been a surge, both within and beyond the scholarly community, in the use of *preprints*, research papers posted online before formal peer review (Berg et al., 2016). Preprints are useful for rapid information sharing in outbreak contexts (Johansson et al., 2018), as they allow researchers, by circumventing the often lengthy peer review process, to share findings and build on one another's work more quickly than would otherwise be possible (Penfold & Polka, 2020). Yet, their use in the health and biomedical sciences has historically lagged behind uptake in other fields (Puebla et al., 2022). This hesitance may be due to the potential danger that unverified findings could receive premature media coverage (Funk et al., 2020) and, ultimately, mislead audiences. This fear may also explain why journalistic preprint coverage has often been discouraged within and outside of journalism (Froke et al., 2020; Sheldon, 2018a, 2018b).

The urgency of addressing the pandemic, however, seems to have outweighed this risk for many journalists and researchers, including those covering or in health and biomedical fields. As early as January 2020, scientists across the disciplinary spectrum began posting preprints in numbers not seen before (Brierley, 2021; Horbach, 2020; Sevryugina & Dicks, 2021), and COVID-19-related preprints soon surpassed those on other subjects in terms of uploads, views, downloads, comments, and citations (N. Fraser et al., 2021). Yet, it was not only the scholarly community that increased its use of preprints to meet pandemic demands. In the absence of relevant peer reviewed research, media coverage of COVID-19 preprints saw a parallel surge (N. Fraser et al., 2021), with some journalists reporting on them for the first time (Makri, 2021). This surge was not restricted to the domain of specialized health and science reporting but instead engaged a wide range of media outlets, including major generalist outlets, such as the *New York Times* and the *Guardian* (Fleerackers et al., 2022b; Massarani & Neves, 2022). On the one hand, this broad uptake may have benefited audiences, as many of the most highly covered preprints provided insights into key public health issues such as disease transmission, intervention, and treatment (N. Fraser et al., 2021). However, some of the

longstanding fears associated with premature media coverage have also played out, with several flawed or biased preprints gaining considerable media attention (see Majumder & Mandl, 2020; van Schalkwyk et al., 2020 for a description of these cases).

In light of this problematic media coverage, scholars have called for more research examining the reasons behind journalists' deviation from professional norms when covering preprints and, more broadly, for "Further consideration…about the place of preprints and how to counter their possible harm on public discourse" (Caulfield et al., 2021, p. 411). This study addresses these calls through an exploration of the use of preprints in health and science news from the perspective of journalists. In particular, it seeks to understand journalists' motivations to cover preprints and the degree to which they have adopted novel reporting practices to mitigate the potential risks of doing so—a topic which scholars have only begun to address (Massarani et al., 2021b). We conducted semi-structured interviews, which we analyzed using a theoretical framework of *post-normal science communication* (Brüggemann et al., 2020), to examine whether the way in which journalists find, verify, and communicate preprint research represents a departure from 'normal' science journalism and, if so, whether this departure is likely to persist post-pandemic.

5.3. COVID-19 as a Post-Normal Science (Communication) Context

We conceptualize journalists' preprint use during the pandemic as a response to *post-normal science* (PNS) (Funtowicz & Ravetz, 1993, 2003), defined by four features, all of which apply to the COVID-19 context: i) high levels of scientific uncertainty, ii) science policy considerations that involve values (not just evidence), iii) high relevance to society, and iv) an urgent need for political decision-making. Such contexts challenge the norms of science, pushing researchers to consider and engage with an "extended peer community" that includes policy makers, journalists, and members of the public. Journalists and other science communicators must also adapt their norms and practices in PNS contexts; as Brüggemann and colleagues write, "These post-normal situations, combined with the changing media environment and a polarized society, shape and

challenge the professional roles and norms that underlie their communication practices."(Brüggemann et al., 2020, p. 3)

Scholars have documented several practices that science journalists "normally" use to find, verify, and communicate research, summarized in Table 5.1. These studies suggest that journalists apply a mix of passive and active strategies to find research studies; rely on triangulation, quality assessments, and the opinions of outside experts to verify them; use quotes from scientists to add context to their coverage; and strive to communicate research simply and objectively.

Scholarship on PNS journalism is more limited and has focused primarily on communication practices rather than on how journalists find or verify research. This body of literature (summarized in Table 5.1) proposes that journalists should strive to bring reflexivity into their reporting, communicate tensions or uncertainties, and highlight (or even advocate for) potential solutions rather than simply reporting on problems. It also suggests that journalists should contextualize new research, describe the process of science, and actively engage audiences in dialogue. However, the scholarship on PNS journalism described above is largely prescriptive rather than descriptive, outlining how journalists should communicate about PNS and not how they actually do so. It has also focused primarily on climate science, a limitation given that the communication norms that emerge from PNS situations may differ across contexts (Brüggemann et al., 2020). This research contributes to filling both of these gaps by extending the PNS framework to a novel context (COVID-19 preprints) and by documenting journalists' practices for covering this post-normal research.

Table 5.1.   Normal and Post-Normal Science Journalism Practices Described in Previous Research

Normal science		Post-normal science
Find research	*Passive methods:* receiving press releases, pitches, PR materials, news alerts (Gesualdo et al., 2020; Leask et al., 2010; Van Witsen & Takahashi, 2021) *Active methods*: accessing research through academic search tools, social media, specific journals, or contact with researchers (Amend & Secko, 2012; Gesualdo et al., 2020; Viswanath et al., 2008)	*Accurately portray "tensions and dissensions"* within science by incorporating perspectives from researchers and stakeholders on all sides of the issue; describing expert concerns; communicating scientific uncertainties (Brossard et al., 2019; Brüggemann, 2017) *Engage audiences* by encouraging public comments/ feedback, making data and information directly available, acting as a "dialogue" or "knowledge broker" (Brossard et al., 2019; Brüggemann, 2017; Nisbet & Fahy, 2015) *Interpret science* by putting research into context, describing the process of science (not just results); widening perspectives on polarized debates; highlighting policy implications; considering long-term outcomes (Brüggemann, 2017; Brüggemann et al., 2020, 2021; Nisbet & Fahy, 2015) *Strive for reflexivity;* call objectivity into question; incorporate subjective feelings/views; be transparent about values; frame differing perspectives as context-specific rather than competing (Brüggemann, 2017; Brüggemann et al., 2020, 2021) *Advocate* for common goods and/or social transformations (Brüggemann et al., 2020, 2021) Critically discuss *solutions,* rather than simply reporting what is wrong (Brüggemann et al., 2021)
Verify research	Assess *quality-related factors,* such as "whether the research was sound, whether the source was reputable" (Amend & Secko, 2012, p. 262) Corroborate or critique study claims through *commentary from unaffiliated experts* (Gesualdo et al., 2020; Van Witsen & Takahashi, 2021) *Triangulate* statistics and findings by comparing them with those of other credible sources (Van Witsen & Takahashi, 2021)	
Communicate research	*Use expert quotes* from study authors and unaffiliated researchers to set context, legitimize research, establish a sense of balance, articulate societal implications (Conrad, 1999) *Translate or simplify science* to make it more understandable to lay audiences (Brüggemann et al., 2020; McKinnon et al., 2019) *Strive for objectivity* in all reporting (Brüggemann et al., 2020; Kovach & Rosenstiel, 2021)	

5.4.   Research Questions and Objectives

The practices, roles, and norms that emerge during PNS situations can either complement or replace existing ones (Brüggemann et al., 2020). This can be seen in the solutions scholars and journalists have proposed to mitigate the potential risks associated with preprint media coverage, which include consulting unaffiliated experts (Ordway et al., 2020), assessing study quality with a critical eye (Khamsi, 2020), and "emphasizing the preliminary nature of conclusions" (Caulfield et al., 2021, p. 411). Rigorous fact checking, working closely with study authors, and using independent sources to validate research findings have also been identified as important protective measures (J. Fraser & Polka, 2018; Sarabipour, 2018; Tennant et al., 2018), as has building awareness among journalists and their audiences about the nature of preprints (Penfold & Polka, 2020). Although many of these recommended practices, such as fact checking or consulting unaffiliated experts, are simply "basic science journalism principles" (Sarabipour et al., 2018, p. 2), others, such as labeling papers as unreviewed or helping audiences understand the process of scholarly publishing, mark a departure from traditional journalistic practice. That is, the proposed solutions for reporting on preprints represent a combination of 'normal' and 'post-normal' activities.

Perhaps because some of these activities are post-normal, their uptake among journalists has been uneven. Studies find that media stories mentioning COVID-19-related preprints early in the pandemic inconsistently described these studies as preliminary, unreviewed, in need of verification, or a "preprint" (Fleerackers et al., 2022b; T. Oliveira et al., 2021; Van Schalkwyk & Dudek, 2022a). Those stories that *did* make the preprint status of the research clear tended to offer only a brief explanation (or none at all) of what the term *preprint* means or how it relates to the larger academic publishing system (Massarani & Neves, 2022; Van Schalkwyk & Dudek, 2022a). However, while these results shed some light on what audiences may encounter in preprint news coverage, they fail to capture what might be going on behind the scenes. That is, it remains unknown whether and how journalists apply other, less visible recommended practices for covering preprints, such as critical evaluation, consultation

with outside experts, or use of outside sources to verify results. It is also unclear whether journalists' coverage of COVID-19 preprints during the pandemic is an artifact of the crisis or evidence of a larger shift in journalism practice. This research aims to help fill these gaps by addressing the following research questions:

RQ1. What benefits and risks do journalists consider in deciding whether to cover preprints?

RQ2. What practices do journalists use to find, verify, and communicate the preprints they cover?

RQ3. How has the COVID-19 pandemic affected journalists' use of preprints?

5.5. Materials and Methods

We conducted a qualitative interview study informed by a constructivist paradigm using qualitative description (Bradshaw et al., 2017). Qualitative description was selected for its utility as an appropriate methodology when interviewing those who directly experienced the phenomenon of study and when the researchers seek to understand "why, how, and what questions about human behavior, motives, views, and barriers"(Neergaard et al., 2009). This study is part of a larger research project examining the journalist-scientist relationship; only sections of interviews directly related to preprints or peer review were analyzed. The Simon Fraser University Research Ethics Board (# 30000244) and the San Francisco State Institutional Review Board (#2021175) exempted the project from further review. All participants provided written consent to participate in this research. The authors engaged in this research have backgrounds in education, journalism, medicine, and scholarly communication. NA, KF, AF, and LLM have worked in journalism. All of the authors have posted preprints.

5.5.1. Sample

All interview participants (described below) worked for one of the following outlets: the *Guardian* (science section)*, HealthDay, IFL Science, MedPage Today, News Medical,* the *New York Times* (science section)*, Popular Science,* and *Wired.* These publications were selected for their focus on science and health news, as well as their

reach and popularity with readers in Canada, Europe, and the US. These outlets also represent the changing media landscape (Bakker, 2012; Hermida, 2019), as they include the science sections of traditional, legacy news organizations (i.e., the *Guardian, New York Times*) and historically print-only science magazines (*Popular Science, Wired*) as well as digital native health sites *(News Medical, MedPage Today)* and science and health blogs (*HealthDay, IFLScience*).

5.5.2. Participants

The 19 journalists who participated in this study reported on research for one or more of the previously mentioned eight outlets. We identified journalists from these publications first by collecting all the stories available through the outlet's RSS feed or, if a feed was unavailable, through the Twitter timeline of the official account that posted a link to every story. Using these two methods, we identified stories published in the corresponding sections between March 1 and April 30, 2021. We then read each story for *mentions*, or links to, research (both preprints and peer reviewed) and saved the accompanying bylines. Scripts used to identify and save stories are openly available (Enkhbayar et al., 2022).

5.5.3. Recruitment

LLM randomly ordered the sampled stories and recruited from bylined authors, top to bottom, from the ordered list; bylines appearing to be from organizations (e.g., American Heart Association News) and politicians were excluded. LLM gathered contact information from publicly available sources (e.g., outlet masthead or contact listing, personal website). KF emailed potential participants up to three times. Nineteen journalists from seven of the eight publications agreed to be interviewed (see Table 5.2 for participant characteristics). Recruitment and interviews occurred between July and November 2021.

5.5.4. Interviews

KF conducted semi-structured interviews of journalists via Zoom. Participants were asked about their professional experience with reporting on preprint and peer reviewed research and how the pandemic had affected that experience and their views on the use of preprints. The interview guide is available online (Moorhead et al., 2022). Interviews lasted between 10 and 47 minutes, with most averaging about 35 minutes. All interviews were recorded and then transcribed by a third-party company; transcripts were de-identified prior to analysis.

5.5.5. Data analysis

Our analysis was guided by Brüggemann et al.'s framework for analyzing and understanding post-normal science communication (Brüggemann et al., 2020). This framework comprises five analytical steps, which we address as follows:

1. Classify whether the situation has post-normal characteristics (Literature Review);
2. Document how actors (e.g. journalists) are reacting to the situation (Method, Results);
3. Compare these reactions to what would be expected in a 'normal' context (Literature Review, Discussion);
4. Explain what might be causing the divergences (Discussion); and
5. Consider the societal implications of these emerging norms (Discussion).

We selected thematic analysis as our method for *documenting how actors are reacting to the situation* due to its overall flexibility and for its utility in identifying experiences, perspectives, and behaviors across a dataset (Braun & Clarke, 2012; Kiger & Varpio, 2020). Interview transcripts were de-identified, then inductively analyzed using Braun and Clarke's steps of thematic analysis (2006, 2012), which allowed us to identify, examine, and report patterns in how journalists viewed and used preprints in their work. This process began with three researchers (AF, LAM, LLM) independently undertaking a close line-by-line reading of the first 12 transcripts to familiarize

themselves with the data. Next, the authors independently identified initial codes, example quotes, and working definitions of the codes relevant to the research questions and informed by the literature on 'normal' science journalism, discussed above. All code data were shared amongst the research team during several collaborative video conference discussions. Guided by these discussions, and informed by the research questions and theoretical framework, a single researcher (AF) reviewed each author's codes, identified patterns and areas of overlap, and synthesized the most relevant and common themes into a series of tables comprising working theme labels and exemplar quotes. At this point, the team reviewed these thematic tables, added comments and suggestions, then met again to discuss the findings and whether *sufficiency* (i.e., the point at which the collected data from participants enables researchers to answer the research question) (LaDonna et al., 2021; Vasileiou et al., 2018) had been met.

The team agreed that data collection should continue, so an additional 7 interviews were conducted, transcribed, de-identified, and coded. Based on the collective transcripts, the team agreed that data and analytical sufficiency had been achieved.

5.6. Results

Based on interviews with 19 health and science journalists, ranging in duration from 10 to 47 minutes and representing seven news publications (see Table 2), we identified a variety of themes to answer our research questions. Below we report these themes in relation to the research questions they address. For a summary of themes and representative quotes see Table 3.

Table 5.2.   Characteristics of Journalists Who Participated in Interviews (n=19) About Use of Preprints

Journalist	Primary outlet	Primary outlet description	Employment status (staff or freelance)	Years in journalism
J1	IFLScience ("I fucking love science")	UK-based science blog	On staff	6
J2	Popular Science	US-based science news and feature publication	Freelance	7
J3	Popular Science	US-based science news and feature publication	Freelance	2
J4	Popular Science	US-based science news and feature publication	Freelance	6
J5	Wired	US-based science, technology and culture publication	Freelance	33
J6	Medpage Today	US-based medical news service provider	On staff	1
J7	Medpage Today	US-based medical news service provider	Freelance	25
J8	Popular Science	US-based science news and feature publication	Freelance	1-2
J9	Wired	US-based science, technology and culture publication	On staff	4
J10	IFLScience	UK-based science blog	On staff	8
J11	Popular Science	US-based science news and feature publication	On staff	25
J12	News Medical	US-based medical news service provider	On staff	6
J13	Guardian	UK-based news and media publication	Freelance	10
J14	Guardian	UK-based news and media publication	On staff	14

Journalist	Primary outlet	Primary outlet description	Employment status (staff or freelance)	Years in journalism
J15	Wired / Ars Technica	US-based science, technology and culture publication / US-based technology, science and political news publication	Freelance	8
J16	Wired	US-based science, technology and culture publication	On staff	28
J17	Popular Science	US-based science news and feature publication	On staff	7
J18	New York Times	US-based daily news publication	Freelance	9
J19	Guardian	UK-based news and media publication	On staff	3

NB. To protect journalist identities, education information is reported in aggregate only. All 19 participants had received at least one educational certificate or degree, with all but two reporting that they had a bachelor's degree or higher in a social sciences and humanities (SSH) field (n = 17). Many journalists also had training in a Science, Technology, Engineering, or Math (STEM) field (n = 6), with three journalists stating that they had attained a graduate degree in this area. Finally, eight participants reported having received professional journalism education through a certificate, bachelor's, or master's program.

Table 5.3.   Themes Identified in Interviews With Journalists (N = 19) About Their Use of Preprints

Theme	Definition	Example quotes
RQ1: What benefits and risks do journalists consider in deciding whether to cover preprints?		
A risk-benefit equation	Journalists weighed the risks of covering preprints against potential benefits for the public; audience needs were central to this calculation	The calculation is: 'Do we think that the audience needs to hear the story now or can they wait six to eight weeks… for the story to be peer reviewed?' And most of the time we think the wait is important and we tend to for the vast majority to avoid picking preprint [J1]
Accessibility (Benefit)	Preprints were valued because they were free to access. This benefit was both practical (i.e., easier for journalists) and ethical (i.e., a belief that knowledge should be free)	Preprints, it's easy, because they're freely available… Luckily, for Covid, a lot of things are Open Access. Maybe this is the future of science. It should be. But for now, we have to manage as we can [J12]
Timeliness (Benefit)	Preprints were valued because they allowed more timely access to relevant research than was possible through peer reviewed research	[As journalists,] our allegiance is to our readers, and getting accurate but timely information to readers...When people are dying, you gotta get things going a little bit. And so that's, I think, what we've seen in the last year, in this argument over preprints [J5]
Potential to misinform (Risk)	Covering preprints was seen as risky because unreviewed results could turn out to be false or flawed, contributing to misinformation	There was a study that was bad about running, how doing more running caused you to expel the virus. That was totally bunk. It was one of the things that like after a week of it making the rounds everywhere, everyone realized, 'Oh, wait. That wasn't true at all' [J2]
Difficult to verify (Risk)	Lacking the expertise, resources, or skills needed to verify preprints was described as a major challenge	Just because I have a PhD in [the field] doesn't mean that I have in most cases the right expertise to look at the paper and perfectly judge it. This is why we tend to favor covering the peer reviewed [J1]

Theme	Definition	Example quotes
RQ2: What practices do journalists use to find, verify, and communicate the preprints they cover?		
Active strategies (Finding preprints)	Journalists actively searched for new preprints, most often direct from the servers themselves	With preprints, you tend to have to just go on, like, the preprint websites and kind of just sift through it and, like, see [J11]
Passive strategies (Finding preprints)	Journalists received preprints from other sources, such as PR services and from authors themselves	[Preprint research] only comes into my life usually when I'm already sort of interviewing someone and they say, "Well, we have this piece that's out for peer review" [J11]
Extra skepticism (Verifying preprints)	Journalists felt that an added layer of skepticism was needed when verifying preprints; often linked to trust in peer review as a quality control mechanism	There's another level of skepticism that should go into reporting on preprints, because there's one less safety net, basically, that the research has gone through [J8]
Critical reading (Verifying preprints)	Journalists verified preprints by reading studies with a skeptical eye, asking critical questions of the methods, sample, analyses, and findings; these practices were described as standard in science journalism	We're using the same toolkit, our toolkit for looking at a paper and evaluating its newsworthiness. We're like, "Okay. Well, is this a good paper? Is the science good? Do the statistics make sense to us? Do the results actually answer the question that it says it answers, and what's left out?" We ask those things of formally-published— you know, if it comes out in *Science*. We ask those questions, too, because sometimes the answer is "No" and sometimes the answer is like, "Actually, this does seem dicey" [J16]
Triangulation (Verifying preprints)	Journalists verified preprints by comparing findings to information from other trusted sources, such as peer reviewed papers, experts, or other preprints	If we can find some article, in that case, we look more at similar work in the literature to back up some of the claims [J1]

Theme	Definition	Example quotes
Do your own peer review (Verifying preprints)	Journalists used outside scientists to verify preprints—to comment on methods, results, and significance in a process resembling scholarly peer review	In my opinion you can't do an unsourced preprint coverage. Like, you need to ask like 10 doctors or 10, you know, epidemiologists or 10 whatever relevant, you know, specialists there are like, "What did you think of this," and then you need to include the back-and-forth that naturally results from that to do it responsibly [J3]
Intuition (Verifying preprints)	Journalists relied on trust and intuition as a substitute for, or an addition to, other preprint verification strategies; this gut instinct was viewed critically by some journalists	I just come back to that idea that it is so much about the individual reporter's gut feeling about something. That is, I think, a little scary. Fortunately, we have a lot of good reporters working on these things, but, but, yeah, I don't think that anybody has like a framework that's agreed upon for how to approach these things [J4]
State that research is unreviewed (Communicating preprints)	Journalists felt it was important to disclose the unreviewed nature of the preprints they cited (e.g., by labeling it a preprint, stating it had not yet been peer reviewed)	…people can share these articles on social networks and everywhere like they're peer reviewed—like they're something that's already textbook knowledge, which is far from it. This is something that should also be highlighted in the article, and I try to highlight it: 'It's a preprint. It's not peer reviewed yet' [J12]
Contextualize (Communicating preprints)	Journalists stated that it was essential to add context to preprint findings, often by comparing them with information from other sources of evidence	I think contextualized properly, they're a really useful and valid source of reporting…where possible, you should try and bolster it with other information [J9]
Highlight limitations (Communicating preprints)	Journalists emphasized the importance of describing caveats, weaknesses, and limitations associated with the preprints they cited	Something that I find fantastic in a lot of medical articles that are hardly found in any other discipline is discussion on limitations, which we are trying to include more and more in our articles [J1]

Theme	Definition	Example quotes
RQ3: How has the COVID-19 pandemic affected journalists' use of preprints?		
A new normal	COVID-19 preprint coverage was viewed as a complete paradigm shift in science journalism, one likely to continue post-pandemic	…we didn't consider them as really newsworthy items before COVID. Now, we consider them... like—something that should be covered like a normal peer reviewed article, which is a complete paradigm shift, maybe, in science covering [J12]
A moderate shift	COVID-19 preprint coverage was viewed as a more temporary change in journalism practice, an exception caused by the pandemic	I think that among myself and sort of my friends/peer group you know I think we're pulling back a little bit and I doubt that arXiv is the place a lot of medical reporters are going to eagerly pull reporting from [J4]
Undecided	Journalists were unsure whether preprint news coverage would persist post-pandemic	It will be interesting to see like, what the implications of that are going forward…Are preprints going to be covered more generally even outside such an urgent context? [J3]

5.6.1. What Benefits and Risks Do Journalists Consider When Deciding to Cover Preprints (RQ1)?

Across the interviews, most journalists described the decision to cover preprints as a careful *risk-benefit analysis*. This was true both in general (i.e., when deciding whether to cover preprints at all), as well as on a case-by-case basis (i.e., when deciding whether to cover or cite a specific preprint). At the heart of this decision was a consideration of *audience needs*, where preprints were described as something that should only be reported on if the potential benefits for readers outweighed possible risks of early coverage. This sentiment is captured by statements such as, "The calculation is: 'Do we think that the audience needs to hear the story now or can they wait six to eight weeks…for the story to be peer reviewed?'" [J1].

The *timely nature* of preprint findings, in comparison to peer reviewed research, was a key benefit journalists mentioned as influencing this calculation. This was particularly true during the pandemic, as many of the journalists felt that COVID-19 research with relevance to public health should be made available as soon as possible. However, some journalists saw timeliness as a benefit that extended beyond the post-normal COVID-19 context, such as J9, who reported that, "preprints feel like science in motion and in creation...they're a place to find the kind of dynamics and flux of science." The timely nature of preprint research was also seen as valuable because it offered journalists a competitive "edge" over colleagues who relied on only peer reviewed research. Yet, timeliness also acted as a barrier, with several journalists noting that tight deadlines prevented them from verifying the results or general empirical integrity of preprints (see below), or in some cases, from covering them at all.

Accessibility was also described as a key advantage of preprints, which are freely available, while many peer reviewed papers are not. Journalists described accessibility as a personal benefit, as it allowed them to find and use research more easily, but also as a societal one: "That's knowledge that it's not, I think, ethical to be only available to rich people. Especially if it was produced in part with tax dollars, then it's unconscionable that only somebody with a lot of money can get to it" [J16]. One journalist said they appreciated that authors of preprints were typically more accessible for interviews than

authors of peer reviewed papers, presumably because they were more excited to discuss their work while the "study is fresh" [J7]. However, this was not a perspective mentioned by other participants.

Journalists considered these anticipated benefits alongside several potential risks. Chief among these was the *potential for preprints to misinform*, a risk many journalists noted had become particularly relevant during the pandemic. For example, J4 described how the conversation around COVID-19 and schools had become "extremely muddied by preprints," while J16 recalled the challenge of reporting on a vaccine-related preprint in the context of "anti-vax folks" who might misuse the evidence to promote their own agendas.

This potential to misinform was closely linked to the *challenge of verification*, which many of the journalists noted was a barrier to their use of preprints. Journalists explained that they did not possess the expertise needed to assess the reliability or accuracy of the research—a challenge shared by both journalists with advanced degrees in a Science, Technology, Engineering, or Math (STEM) fields and those without. Journalists noted that preprints could change considerably between posting to a preprint server and publication in an academic journal, that some may never be published at all, and that it was difficult to tell which would pass the scrutiny of peer review. Although journalists attempted to mitigate these risks with a number of verification strategies (outlined in the next section), the challenge of verification remained front of mind: "…we all want to believe that we can tell what a good preprint is from what a bad preprint is, and I don't always think that that is true" [J4].

Perhaps as a result of their different risk-benefit calculations, journalists varied widely in the degree to which they supported using preprint research. Some were generally apprehensive, reporting that they felt it was "best to not use them" [J15]. Others were positive, noting that "preprints are now a reality. Everybody can access it. Everybody shares them" [J12]. Still others landed somewhere in the middle, stating that coverage of preprints was acceptable but only "when handled with caution" [J19]. We discuss some of these "cautious" reporting practices in the following section.

5.6.2. What Practices do Journalists Use to Find, Verify, and Communicate the Preprints They Cover (RQ2)?

Equally varied as the risks and benefits influencing the decision to cover preprints were the strategies journalists used to find, verify, and communicate about them.

Some journalists relied on active strategies to find preprints, such as J3, who reported "us[ing] preprint repositories like arXiv and medRxiv" during the pandemic. In some cases, these active strategies were contrasted with journalists' 'normal' sourcing practices, which were often more passive (e.g., receiving press releases). Still, some journalists discovered preprints in similarly *passive ways*, such as through press releases, authors who mentioned them during interviews, or through services such as the UK's Science Media Centre,[30] which releases round ups of expert commentary on new research studies, including preprints. Although journalists sometimes welcomed these passive strategies for finding preprints, they were more often treated with skepticism, "because they can get a little bit promotional" [J7].

When it came to verification, almost all the journalists said that an additional level of scrutiny was required to vet preprints than to vet peer reviewed journal publications. This belief was closely tied to the perceived value of the peer review process, which journalists viewed as a "safety net, basically, that the research has gone through" [J8]. Interestingly, this extra level of skepticism seldom required the use of new, post-normal verification practices, but was instead described as adherence to standard science journalism best practices. As J16 summarized:

> We're using the same toolkit, our toolkit for looking at a paper and evaluating its newsworthiness. We're like, 'Okay. Well, is this a good paper? Is the science good? Do the statistics make sense to us? Do the results actually answer the question that it says it answers, and what's left out?" We ask those things of formally-published—you know, if it comes out in *Science*. We ask those questions, too, because sometimes the answer is 'No' and sometimes the answer is like, 'Actually, this does seem dicey.'

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[30] https://www.sciencemediacentre.org/

However, some journalists suggested that they took shortcuts when using non-preprint research and deadlines loomed, essentially allowing the peer review process to replace some of the best practices used to verify information. In addition, a minority of journalists did not explicitly mention treating preprints with extra caution. One such journalist ended up questioning their lack of skepticism during the interview process, reflecting:

> I've never really thought of [preprints] as a bad thing. And when you're investigating it in a way that you are, it makes me wonder whether there is a lot of manipulation of the facts going on. So hopefully your study when you report it will give me a few extra clues of what I should be watching for. [J7]

The practices journalists described using to verify preprints included *critically reading* the methods and results, *triangulating* findings with those from other, ideally peer reviewed studies, and *relying on outside expertise* in a process that resembled scholarly peer review:

> Sometimes you need help from other people, say, and you gotta take the study, email it to some experts, and say, 'Okay, I'm gonna do my own peer review with some peers, and we're gonna review it.' And it may be faster, it may not take six months, but we're gonna take a day or two and point out some good and bad things on this study. [J5]

Still, despite these multiple and varied formal strategies, intuition also played a role in journalists' verification practices—or lack thereof. As J4 explained, "I think that, sort of, it does come down to gut feeling: how much you trust the gut feeling of the people you're reading." This reliance on intuition may be linked to the time-sensitive nature of journalistic work, which, as discussed above, sometimes prevented journalists from applying best practices when vetting preprints. While some journalists were critical of colleagues and peers who relied on gut feeling, others saw intuition as an important journalistic tool that could be used to identify studies warranting additional verification. As J8 explained, if a finding "sounds a little too good to be true…it might be."

Finally, journalists applied a range of communication practices when covering preprints. Being *transparent about the unreviewed nature of the research* was chief

among these practices, either because of journalists' own beliefs or because doing so was mandated by their organization. For example, journalists made comments such as, "This is something that should also be highlighted in the article, and I try to highlight it: 'It's a preprint. It's not peer reviewed yet,'" J12). Other journalists went further, adding that any disclosure of preprint status should be accompanied by an explanation of what the term meant: "if I was going to write, 'This is not peer reviewed,' I'd then have to—would spend at least a sentence—explaining why" [J13]. This sentiment was often closely tied to beliefs about the audiences' level of scientific literacy:

> …saying whether something is or isn't peer reviewed—specifically for the kind of outlets that I write for, which is, like national media, women's magazines, that kind of thing—is that people probably don't understand, like, what the significance of that is. So, if you want to be kind of legit you just have to kind of really spell out what actually happened. [J13]

In addition to this novel journalistic practice, many journalists also emphasized the importance of applying more standard best practices for science reporting, such as *providing context* and *highlighting study limitations*. Some journalists went so far as to say that they covered preprints "in the exact same way as published papers" [J12], although this perspective was uncommon.

5.6.3. How Has the COVID-19 Pandemic Affected Journalists' Use of Preprints (RQ3)?

Most journalists reported that COVID-19 had changed their use of preprints, although there was variability in the extent of these perceived changes. Some felt that the pandemic had created "a complete paradigm shift" [J12], both in their own work and in that of their peers. These journalists reported that they were not using preprints before COVID-19, but that the pandemic context "made us all just feel like it was normal and okay to be, you know, skeptically reporting on them and, and paying them a lot of attention" [J4]. Others were more moderate in their views, reflecting that they used preprints occasionally but still "don't report on them much" [J18]. A small number of journalists said that their use of preprints had been unchanged by the pandemic, but this was not a typical perspective.

At the heart of this perceived shift were considerations of the audience's needs and of the urgency of the crisis, with journalists offering explanations such as "there was so little information on COVID...we need[ed] to stay really on top of this and cover things, just give the people the information that they need right now" [J3]. Yet, the shift was also described as being tied to a parallel shift within science itself. Specifically, journalists felt that "COVID revealed flaws in the publishing system" [J8] and that the pandemic had normalized preprint use among scholars as well. Other journalists believed that the pandemic had changed the quality of preprints themselves:

> I would say prior to COVID…when I would come across preprints or a writer would pitch me a preprint, it was a kind of, 'We've got this thing early, but it's almost definitely going to be peer reviewed, it's going to be released in "X" journal three months later'… they were journal articles in waiting, really... I don't think we were saying, 'And this might get thrown out entirely, who knows?' [J9]

Across these varied perspectives, journalists seemed to agree that preprint coverage had been a "net positive" [J8] in the context of the pandemic. However, they differed in the degree to which they believed, or hoped, this change would persist in the long term. Some had started covering preprints on topics other than COVID-19 or noted that even major legacy publications had started using them. Others reported that they were moving away from preprints, and that in "normal times, I probably wouldn't go to preprints" [J19]. Still others were unsure whether preprints would remain important within journalism outside of the urgent pandemic context.

5.7. Discussion

During COVID-19, journalists shifted their professional norms and practices to more readily include preprints. Our findings suggest this departure is likely to continue post-pandemic and expand beyond the use of preprints related to health and biomedical sciences, albeit perhaps to a lesser degree than seen during COVID-19. As part of their reporting, journalists spoke of regularly seeking scientific papers that preceded formal peer review, often using preprint servers like arXiv and medRxiv. Such scholarship appealed to them, as it was timely, cutting edge, and freely available (as opposed to

behind a paywall). This shift marked a departure from 'normal' science journalism, with journalists and their media organizations becoming increasingly open to citing unreviewed papers, though typically with definitions of preprints and caveats (e.g., findings needed to be replicated or part of an evolving story).

Within this post-normal context, journalists worked to verify preprints through a process not entirely dissimilar to peer review, though in greatly compressed timeframes. While the typical formal peer review process might take weeks or months, journalists truncated their verification process to meet publishing deadlines (e.g., hours or days). As part of this ad hoc process, journalists contacted scientists unaffiliated with the research in question and asked for a critique of the work. Journalists also spoke of triangulating findings as a form of verification, and in some respects, their efforts mirrored the best practices called for in standard, or "normal," science journalism. Yet, most journalists still expressed concerns about the use of preprints. At best, they said, preprints offered potentially life-saving information at a time of great need; at worst, they contributed to misinformation among the public. These findings mirror the results of a survey of 633 science journalists from six world regions about their work during COVID-19, which found that 67% of US and Canadian journalists and 69% of European and Russian journalists had adopted different procedures to cover preprints during the pandemic (Massarani et al., 2021b).

Journalists also reported concern that their audiences might misunderstand what preprints are, a concern they attempted to address by offering definitions and context in their articles. Again, this aligns with findings from surveys by Massarani and colleagues (Massarani et al., 2021b, 2021c). However, this effort stands in contrast to those of recent content analyses, which found that journalists inconsistently identify scholarship mentioned in news articles as preprints, often describing it as "research" or simply hyperlinking to it (Fleerackers et al., 2022b; T. Oliveira et al., 2021), and only sometimes explain what the term "preprint" means (Massarani & Neves, 2022). Further research into a potential disconnect between the professional practices journalists believe they do and the practices that actually appear in their published work is needed.

Our findings suggest that there can be value in sharing a preprint version of one's work with journalists, particularly if it regards urgent matters of public health. Preprints offer scientists a more timely and direct way to share information with the public, and journalists can augment the process by offering context and clarification to the research, as well as reach and distribution. Yet, journalists also make errors and frame research in ways at odds with scientists' goals and views (Dixon & Clarke, 2012; Dunwoody, 1999). As such, scientists need to weigh the risks and benefits of sharing research through journalists, who act as mediators between them and the public (Burns et al., 2003).

Both scientists and journalists share responsibility in accurately communicating research that has yet to complete the peer review process, especially if methodological errors or misinterpretation could have grave public consequences (Figdor, 2017; Roy & Edwards, 2022). Most journalists reported not having the expertise to verify the quality of unreviewed research and spoke of the need for scientists to help them vet each study and consider its place in a larger scientific context. Scientists could help address such issues and support journalists in finding, verifying, and accurately communicating their work by understanding the deadline constraints journalists face and avoiding jargon or hype, particularly within the methodology, findings, and limitations sections. Providing lay summaries of preprint findings could also be helpful, particularly for topics that have important public implications (Roy & Edwards, 2022). If called on by a journalist to discuss a preprint, researchers may also recommend peers who have the appropriate expertise to vet the findings. Interprofessional training programs in which journalists and scientists learn together to communicate research in a post-normal context could also help maximize benefits and mitigate risks associated with preprint-based media coverage, both during the COVID-19 pandemic and beyond.

Based on our findings, journalists would likely appreciate scientists taking on the role of educator or explainer (Fahy & Nisbet, 2011) and allowing time for both interviews and potential follow-up questions. As verifying preprints is a challenge for journalists, scientists should understand that being asked to comment on a peer's work is, to a large extent, joining the journalist's efforts in orchestrating a truncated peer review (London & Kimmelman, 2020). These scientists are being asked to play a key role in

shaping whether and how that preprint is covered; their commentary does more than simply add context or legitimize research, as it would in a 'normal' science journalism context (Conrad, 1999). As such, scientists asked to comment on preprint findings for a news story should consider the significance and implications of the research with the needs of the public in mind, noting, in particular, any risks that could be associated with the findings. Supporting this vetting process is particularly important, as other practices journalists used to cover unreviewed studies, such as describing them as "preprints," appear to have limited effects on audience perceptions (Ratcliff et al., 2023).

Scholarly publishers and preprint servers can also support this vetting process by standardizing efforts to show markers of credibility that journalists can use to assess new research (e.g., what, if any, review has taken place; who are the authors, institutions, and funders; what are the potential conflicts of interest, etc. [Soderberg et al., 2020]). As the use of preprints has become more commonplace even outside a crisis such as COVID-19, publishers, universities, and other groups with marketing and communication efforts may need to rethink their approach to promoting them, an increasingly common activity (Baker, 2020; Fox, 2020). For instance, PR efforts could include additional context, links to related evidence, and recommendations for unaffiliated researchers with expertise on a topic. In addition, journals may wish to revisit policies that encourage preprint use but simultaneously prevent researchers from discussing findings until manuscripts have been formally peer reviewed. Such policies—meant to ensure media attention focuses on the peer reviewed version rather than the preprint—may instead lead to media coverage of preprint research that is not well-vetted and is poorly contextualized.

Our findings suggest that although many journalists work behind the scenes to verify, clarify, and communicate the research they cite, these practices are not well established and vary greatly across journalists and outlets. Several journalists expressed concern about the heavy reliance on "gut instinct" in how they and their peers covered preprints. Although some mentioned that their organizations had explicit guidelines about how to report preprints, we could not find any of these online. Organizations such as the Associated Press give a nod to handling preprints in their style guides, advising "extreme care" in their use (Froke et al., 2020); however, they fall short in spelling out how to

practice such care or how to handle fallout when having reported a preprint that is later discredited or largely changed by the peer review process. While professional journalism resources are now beginning to recommend some of the post-normal practices identified in this study—such as "commissioning" one's own peer review (Oransky, 2022)—concrete guidelines for covering preprints are still far and few between. Journalism associations may seek to address this gap by joining recent efforts to further develop resources and style guides for covering preprints (Khamsi, 2020; Miller, 2021; Ordway et al., 2020). Professional training and development for journalists, either through universities or continuing education, could also provide additional support.

5.7.1. Limitations and Future Directions

Our own backgrounds, as with all qualitative description, shaped this analysis—both as a limitation and a strength. A former journalist (KF) led the interviews, which may have influenced participants' responses. We conducted research at a time of relative stability during the pandemic—the initial vaccine rollout had been completed and boosters were being administered in the US, Canada, and the UK, where most of the journalists were based. It is likely that the views in this paper would differ from those of journalists interviewed at the very beginning of the pandemic. However, the timing allows for us to link the changing practices and norms of journalists to the changing (i.e., post-normal) communication context. Still, the pandemic remained very much a concern during the time of data collection and publication, with variants of COVID-19 spreading (i.e., Delta, Omicron) and creating uncertainty.

In terms of our sample, all publications in the dataset were text-based (not multimedia), English only, science and health news-focused, and based in the Global North. Future research could expand outside these categories, especially given that journalistic preprint use appears to differ across geographic regions (Massarani et al., 2021b). Additionally, although we included niche publishing models (i.e., *HealthDay* and *News Medical*), these models remained underrepresented in our sample. *HealthDay*, for instance, specialized in producing what it called "evidence-based health content" (HealthDay, n.d.) to license to media companies (e.g., *CNBC, U.S. News & World*

Reports, WebMD), hospitals, managed care organizations, publishers, nonprofits, and government agencies. However, email requests for interviews to 8 journalists within the organization went unanswered. While we cannot know why our requests were ignored, *HealthDay* editors and reporters may have their own norms and practices that are different from those of the journalists we interviewed. With the changing media landscape and broadening definition of "journalist" (Hermida, 2019), more research is needed to understand differences and shared norms and practices of journalists at diverse types of outlets, including those at the "margins" of more traditional, legacy journalism (Bromley, 2019; Deuze & Witschge, 2018).

5.8.   Conclusions

Collectively, these findings contribute to a still emerging post-normal science communication context that will require new norms and practices for journalists, and perhaps, for the scientists whose work they cite. Our research provides insight into some of these novel journalism practices and the extent to which more established norms for how research is covered have shifted due to the COVID-19 pandemic. The findings fill a gap in our current understanding of how journalists find, vet, and communicate preprints. They build on our previous work (Fleerackers et al., 2022b), which considered journalists' empirical use of research but overlooked other, less visible practices that journalists use to communicate research. The results also act as a reminder that all science is provisional—not just preprints—and that many journalists seem to recognize and communicate this to their audiences.

This research contributes to theory building by using the theoretical framework of post-normal science communication within the emerging COVID-19 context. To a certain extent, our findings align with existing scholarship that has examined post-normal science communication in other contexts, such as climate change. For example, many of the journalists we interviewed strove to put science into context and to communicate the uncertainties associated with preprint research (Brossard et al., 2019; Brüggemann, 2017; Nisbet & Fahy, 2015). However, we also identified other journalistic practices, such as actively seeking out preprint research and orchestrating one's own peer review, that have

not been described in previous studies. Similarly, we found no evidence of journalists advocating for social transformation or engaging audiences in dialogue, both of which are practices that have been associated with post-normal science communication in previous scholarship (Brossard et al., 2019; Brüggemann et al., 2020, 2021; Nisbet & Fahy, 2015). More research is needed to better understand why journalists adopt certain communication practices in some post-normal contexts and not others, and what issues these novel practices might raise for their audiences. This is particularly important given that, as Funtowicz and Ravetz (2020) state, "we are now truly in a Post-Normal age. Science (and Society) will never be the same again" (p. 3).

5.9. Contribution Statement

I participated during all stages of the development of this paper and provided an overall contribution greater than that of any co-author. I contributed to developing the concept for the study and obtaining the funding, both with assistance from Laura Moorhead and Lauren Maggio. I also worked with Moorhead and Maggio to create the interview guide, sampling frame, and analytical approach, and provided input during data collection (led by Moorhead and Kaylee Fagan). I led the analysis and the writing of the initial draft, with assistance from Moorhead and Maggio. All authors contributed to revising the draft.

5.10. Copyright Statement

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5.11. Data Availability

News story data can be accessed via the Harvard Dataverse at https://dataverse.harvard.edu/ with the doi: 10.7910/DVN/KK6T86. Interview guides

can be accessed via the Open Science Framework at doi: <u>10.17605/OSF.IO/V98NQ</u>.
Interview transcripts cannot be shared publicly because they contain information that
could be used to identify participants.

5.12. Funding

5.13. Competing Interests

LM worked as an editor at *Wired* from 1995 to 2007. This past role has in no way
influenced the outcome or development of this work.

5.14. Acknowledgements

5.15. Disclaimer

The views expressed in this article are those of the authors and do not necessarily reflect
the official policy or position of the Uniformed Services University of the Health
Sciences, the Department of Defense, or the U.S. Government.

Chapter 6.

Communicating Scientific Uncertainty in an Age of COVID-19: An Investigation into the Use of Preprints by Digital Media Outlets

6.1. Abstract

In this article, we investigate the surge in use of COVID-19-related preprints by media outlets. Journalists are a main source of reliable public health information during crises and, until recently, journalists have been reluctant to cover preprints because of the associated scientific uncertainty. Yet, uploads of COVID-19 preprints and their uptake by online media have outstripped that of preprints about any other topic. Using an innovative approach combining altmetrics methods with content analysis, we identified a diversity of outlets covering COVID-19-related preprints during the early months of the pandemic, including specialist medical news outlets, traditional news media outlets, and aggregators. We found a ubiquity of hyperlinks as citations and a multiplicity of framing devices for highlighting the scientific uncertainty associated with COVID-19 preprints. These devices were rarely used consistently (e.g., mentioning that the study was a preprint, unreviewed, preliminary, and/or in need of verification). About half of the stories we analyzed contained framing devices emphasizing uncertainty. Outlets in our sample were much less likely to identify the research they mentioned as preprint research, compared to identifying it as simply "research." This work has significant implications for public health communication within the changing media landscape. While current best practices in public health risk communication promote identifying and promoting trustworthy sources of information, the uptake of preprint research by online media presents new challenges. At the same time, it provides new opportunities for fostering greater awareness of the scientific uncertainty associated with health research findings.

Keywords: uncertainty, digital communication, hyperlinks, framing, public health, preprints

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the chapter to be included in an author's thesis.

6.2. Introduction

The public expectation and need for credible health information in the midst of
the COVID-19 pandemic have put a renewed focus on science and its internal processes,
while simultaneously challenging traditional journalistic sourcing practices in the absence
of relevant peer reviewed research. As researchers respond by publishing research as so-
called preprints, journalistic reporting on research that has yet to be peer reviewed is
filling this gap and driving public discourse (Majumder & Mandl, 2020). While this surge
in preprint media coverage could benefit publics by connecting them with timely and
relevant public health information, it could prove problematic if the uncertainties
associated with the research are not made transparent. In this study, we address this
tension by analyzing the framing devices used by digital media outlets to emphasize the
scientific uncertainty of COVID-19-related preprints in the early stages of the pandemic.

6.3. Literature Review

6.3.1. Preprints and Scientific Uncertainty

Preprints are generally recognized by the scientific community as unvalidated and
uncertain science, and journalists have been reluctant to report on them (Froke et al.,
2020; Haelle, 2020). Yet, this reluctance eased during the early months of the COVID-19
crisis, with online media coverage of COVID-19-related preprints outstripping that of
preprints about any other topic (Fraser et al., 2020). While timely reporting of this
emerging research is important for information-seeking publics, it can also mislead if
findings are reported too early, without validation from the research community

(Kharasch, 2020). While the potential for results to be invalidated through subsequent studies is an inherent aspect of science (see Schneider, 2016), this ever-present "scientific uncertainty" (Gustafson & Rice, 2019) may be further amplified in the case of preprints. Without peer review, results that are not supported by a wider scientific community can spread; indeed, a widely circulated COVID-19 preprint linking the SARS-CoV-2 spike protein to HIV-1 glycoproteins was later withdrawn by the authors because of criticism from other scientists about methodological flaws and faulty interpretation of results (see Fraser et al., 2020 for a description of the case).

The scientific uncertainty inherent in COVID-19 preprints presents challenges when communicating research findings. Journalists may ignore uncertainty when sharing research findings, particularly when dealing with risk communication (Peters & Dunwoody, 2016). Media have historically been found to gloss over unknowns and uncertainties when covering health issues (Dan & Raupp, 2018; Hove et al., 2015; Jung Oh et al., 2012), perhaps to reduce the risk of alienating audiences with limited understanding of scientific work (Schneider, 2016; Stroobant & Raeymaeckers, 2019). Yet, communicating scientific uncertainty can be beneficial. For example, Jensen (2008) found that college students viewed both journalists and scientists as more trustworthy "when news coverage of cancer research was hedged (e.g., study limitations were reported)" and "when the hedging was attributed to the scientists responsible for the research" (p. 347).

Importantly, the choice to highlight scientific uncertainty varies by topic; media coverage of controversial research areas may exaggerate scientific uncertainties and disputes to appear "balanced" (Corbett & Durfee, 2004; Dixon & Clarke, 2012; Zehr, 2000); to add conflict to stories (Schneider, 2016); or to involve researchers debating scientific uncertainties among themselves (Dunwoody, 1999). Journalists are also guided by audience expectations and influenced by the practices of their colleagues, editors, and competitors when reporting scientific uncertainty (Guenther et al., 2015; Guenther & Ruhrmann, 2016). Media outlets' portrayal of uncertainty becomes all the more important in times of crisis, when individuals look to them for timely guidance (Austin et al., 2012). Best practices in public health risk communication are grounded in core communication

values associated with fostering public understanding of risks (Sellnow et al., 2009), which include transparency and credibility (Covello et al., 1989). To help publics navigate the risks associated with health crises like COVID-19, communicators should strive to be honest, frank, and open—clearly addressing unknowns and uncertainties— and coordinating and collaborating with trustworthy sources (Covello & Allen, 1988).

6.3.2. Framing Uncertainty through Hyperlinks

Definitions and theoretical perspectives of framing vary widely (Entman, 1993; Scheufele & Scheufele, 2010); however, analyzing *emphasis frames* (Chong & Druckman, 2007), which "select some aspects of a perceived reality and make them more salient" (Entman, 1993, p. 52), can be useful for understanding what journalistic content communicates (e.g., Guenther et al., 2019; Semetko & Valkenburg, 2000). A review of the literature by Guenther, Gaertner, and Zeitz (2020) points to the paucity of emphasis framing studies in health communication that use content analyses to investigate media reporting. We aim to help fill this gap with a timely study investigating the framing devices that emphasize the (un)certainty of preprint research in digital media stories.

According to Coddington (2012), textual references associated with hyperlinks are particularly important for framing researchers to investigate because the language associated with hyperlinks "work[s] together to frame the content and context of the hyperlink" (p. 2018). Yet, hyperlinks do more than frame. Online health media stories often use them to cite authoritative sources, such as academic research websites or government resources (Karlsson & Sjøvaag, 2018; Stroobant & Raeymaeckers, 2019). In theory, these "hyperlinks as citations" (Karlsson & Sjøvaag, 2018, p. 1) act as credibility markers (Coddington, 2012; Luzón, 2009; Stroobant & Raeymaeckers, 2019), influencing how audiences perceive and trust media messages (Borah, 2014). However, hyperlinks as citations do not always fulfill this role in online health stories. In a study of opioid-related research media coverage in the US and Canada, Matthias and colleagues (2020) found that journalists incorporate research into their published work via hyperlinks to peer reviewed articles but provide little context or information to help readers evaluate the validity of these studies and the certainty of claims. This tendency

seems to be more common in media stories that report on research in the context of some larger issue than in stories that focus on the research itself (Matthias et al., 2020).

6.3.3. Scientific Uncertainty in a Changing Media Landscape

Researchers have found that the way media stories represent scientific (un)certainty depends on the reporting context (Peters & Dunwoody, 2016). These contextual differences may only amplify as the media landscape diversifies, and as blogs, aggregators, and other "digital-native" media outlets join traditional journalistic news sources (Barthel, 2019; Berkowitz, 2009; Bruns, 2018; Hermida, 2019; Stocking, 2019). For example, Hurley and Tewksbury (2012) found that focused providers (e.g., the *New York Times*, *MSNBC*) differed from news aggregators both in terms of the frames they used and the degree of (un)certainty they incorporated into their coverage. Similarly, an analysis comparing an "independent" and a "mainstream" media outlet in New Zealand found notable differences in the frames the outlets used when communicating about the relationship between climate change and health, with the mainstream outlet favouring negative and sensationalist framing (Harrison et al., 2020).

Despite the growing popularity of digital-native news outlets (Stocking, 2019), digital news startups (Carlson & Usher, 2016), and native in-platform publishing (Bruns, 2018), these content providers have been largely overlooked in media scholarship (Hurley & Tewksbury, 2012; Lee & Chyi, 2015). When they have been studied, they have often been conceptualized as "periphery" to "core" legacy outlets—amassed into catch-all categories like "hybrid" journalism or dismissed as low-quality—rather than examined as integral, interconnected components of a diverse, ever-changing media ecosystem (Bakker, 2012; Deuze & Witschge, 2018; Witschge et al., 2019). As the boundaries between newsmakers, reporters, consumers, and distributors blur, drawing distinctions between content providers and curators has become more difficult—and, arguably—less valid (Berkowitz, 2009; Hermida, 2019; Jenkins & Deuze, 2008). For example, while so-called "periphery" outlets may rely more heavily on nontraditional practices such as republishing stories produced by other outlets or relying on publicity materials for content, these practices have increasingly been adopted by "core" outlets as

well (Bakker, 2012). Similarly, while news bloggers and aggregators can be viewed as "parasitic" competitors to mainstream news outlets, they can also complement their work by amplifying their stories and increasing their web traffic (Bruns, 2018; Lee & Chyi, 2015). Additionally, these publishers often mimic the norms and values of professional journalism. As Coddington (2019) argues, an "amalgam of standards and practices shapes aggregation as a hybrid practice that is built on professional journalism yet marginal within it" (p. 1).

In response to these ongoing transformations to the media landscape, researchers have called for "scholarship to address the dance between stability and change, to capture the diversity in the field" (Witschge et al., 2019, p. 655). This article responds to that call by exploring how a diversity of online media outlets represent—or frame—scientific (un)certainty in preprints about COVID-19. We answer three interconnected research questions:

- RQ1. What content producers and curators (outlets) in the media ecosystem are communicating about COVID-19-related preprints?
- RQ2. How are outlets using hyperlinking practices when communicating about COVID-19-related preprints?
- RQ3. How are outlets using framing devices that emphasize uncertainty when communicating about COVID-19-related preprints?

6.4. Method

6.4.1. Sample Selection and Collection

To understand how preprints on topics related to COVID-19 were reported in online media, we focused our analysis on preprints posted on medRxiv and bioRxiv—the two top-ranked preprint servers for publishing studies related to COVID-19 (Kwon, 2020). These two servers noted a rapid uptake of COVID-19-related submissions in the early months of 2020 (Fraser et al., 2020) and are among the most widely used preprint servers for biomedical research (Penfold & Polka, 2020). We relied on the dataset from Fraser and colleagues (2020) that includes all the submissions published in both of these servers between January 1 and April 30, 2020 that were available through the bioRxiv

Application Programming Interface (API[31]) on May 1, 2020. From the original set of 14,812 preprints, we used the 2,527 (17.06%) preprints that Fraser and colleagues (2020) identified as COVID-19-related through the presence of relevant terms in the preprints' title or abstract.

On June 1, 2020, we searched for these 2,527 COVID-19-related preprints in the Altmetric database by querying the Altmetric Explorer[32] with their Digital Object Identifiers (DOIs). Altmetric tracks online activity of research, including references or "mentions" in media stories, by identifying links to publications (i.e., a hyperlink or a publication identifier, such as a DOI) and by regularly scanning the text of thousands of media stories and using natural language processing techniques to identify study details such as author names, journal titles, and publication dates. This search yielded 14,717 total media mentions across 801 (31.7%) of the 2,527 COVID-19-related preprints. We noted that some outlets published multiple stories mentioning the same preprint. To avoid double counting and to understand how outlets first introduced these preprints to their readers, we kept only the first mention of each preprint by each outlet. This restricted the set to 10,572 mentions across the 801 preprints. We further limited our study to the 8,270 mentions with titles identified as being in English via the langdetect[33] Python library.

To identify which outlets in the media ecosystem were most actively communicating about COVID-19-related preprints, we restricted our sample to the 15 media outlets most prevalent in this subset of English-language mentions (after eliminating two sources: 1) *Infosurhoy* because all URLs Altmetric had collected for this source were invalid, and 2) *Google News* because URLs attributed to this source redirected to stories posted on other media outlets). Importantly, Altmetric applies a broad conception of media outlets—one that does not filter by history, audience size, or influence. As such, the 15 outlets we analyzed were not necessarily those with the greatest readership or level of public recognition, but rather the outlets incorporating the

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[31] https://api.biorxiv.org
[32] https://www.altmetric.com/explorer/
[33] https://pypi.org/project/langdetect/

greatest number of COVID-19-related preprints into their coverage during the study time period.

After the restrictions listed above, these 15 outlets accounted for 1,117 mentions. To focus our analysis on preprints that were circulated widely, we further restricted our sample to those mentions that were about the 100 most mentioned preprints in the original dataset.[34] This final dataset comprised 590 mentions in 457 stories across the 15 outlets (a media *story* can contain multiple *mentions* of different *preprints*; see Figure 6.1, below). We removed 69 mentions because of broken story URLs or because the stated preprint was not actually mentioned in the story. The remaining 521 mentions were quantitatively analyzed.

Figure 6.1. Conceptualization and Sample Size of Preprints, Mentions, and Stories
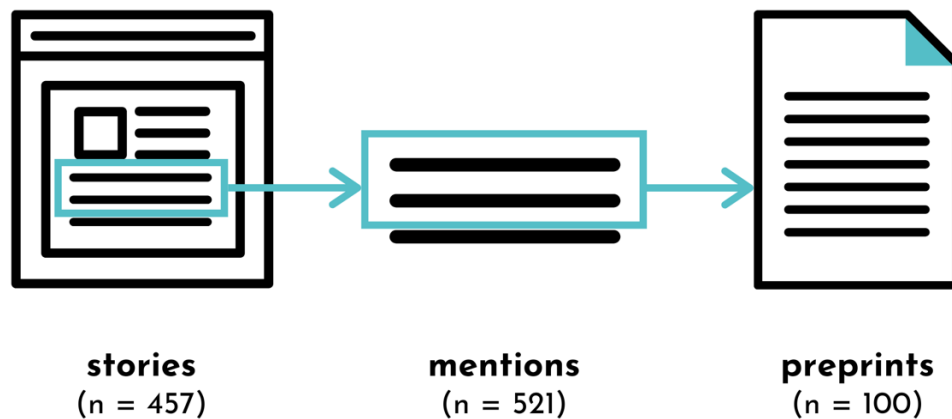
NB: In this study, we define "stories" as media articles that implicitly or explicitly refer to one or more COVID-19-related preprints and "mentions" as those parts of the story that relate to the preprint in question.

6.4.2. Codebook Development

Following Evensen and Clarke (2012), our codebook was developed deductively, drawing on both relevant scholarly literature and professional guidelines. We adapted codes from previous studies examining (un)certain or initial scientific evidence in media

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[34] Like media coverage of other scholarly research, mentions of COVID-19 preprints follow a skewed distribution, with a small number of highly influential preprints receiving the bulk of the coverage, and a long tail of other preprints that received only one or two mentions during the study period.

stories (Dumas-Mallet et al., 2018; Matthias et al., 2020) and informed by relevant work on media framing of scientific (un)certainty (Dan & Raupp, 2018; Gustafson & Rice, 2019; Hove et al., 2015; Jung Oh et al., 2012; Nisbet et al., 2003). We referenced professional journalism resources (e.g., tip sheets, blog posts, stylebooks) describing best practices for reporting on COVID-19 preprints to complement the scholarly literature (Froke et al., 2020; Helmuth, 2020; Jaklevic, 2020; Khamsi, 2020; Ordway et al., 2020).

Coding was binary (cf. Hart & Feldman, 2014), with variables of interest broken down into multiple questions to be coded as either *0 = no/false* or *1 = yes/true* (cf. Semetko & Valkenburg, 2000). Although the codebook emphasized manifest content, it allowed for implicit or latent interpretations (Evensen & Clarke, 2012), as frames may be interpreted somewhat differently by different individuals (Entman, 1993; Gamson & Modigliani, 1989; Price & Tewksbury, 1997). Coding assessed both the story overall (e.g., "Is this story a published press release?") as well as the specific mention of the preprint in question (e.g., "Does the story mention that the study is a preprint?"). Given that transparency is key for valid, reliable framing content analysis (Matthes & Kohring, 2008), the complete codebook and dataset are available online (Fleerackers et al., 2020). Brief definitions and examples of codes are available in Table 6.1, below.

Table 6.1.   Overview of Codes

Code	Description	Examples
science communication story	The primary focus of the story is to communicate the results and/or implications of the preprint.	Study of twins reveals genetic effect on COVID-19 symptoms [headline] New MIT machine learning model shows relaxing quarantine rules will spike COVID-19 cases [headline]
reposted story	The story was first published by another source.	This article by Joseph Eisenberg Professor and Chair of Epidemiology at the University of Michigan, first appeared in *The Conversation* on February 5, 2020. [attribution line] This story is auto-aggregated by a computer program and has not been created or edited by *Dailyhunt*. Publisher: *News Karnataka* [disclaimer]
press release	The story is a published press release.	Provided by Leiden University [attribution line] SALINAS, CA – Congressman Jimmy Panetta (D-Carmel Valley) joined 63 Representatives in calling on Administration officials for improved testing... [opening line]
defines preprint	The story defines preprints in some way.	...in one preprint study, meaning it is currently under peer review… Pre-prints are a way of getting research out quickly to get rapid responses, without waiting for peer-review, but they have some really important limitations.
mentions "preprint"	The story mentions that the study is a preprint.	Two new preprints about the likely prevalence of the novel coronavirus… Another preprint study of outbreaks in Japan suggests…

Code	Description	Examples
mentions work is unreviewed	The story explains that the study has not been peer reviewed.	Their results, published Friday in a study that has yet to be peer-reviewed…
		However, a recent study under review shows…
mentions work is preliminary	The story suggests that the study is preliminary.	On 20 February the researchers posted a preliminary version of the study…
		The research is still early.
mentions verification is needed	The story suggests that the study results are inconclusive (i.e., should be replicated or verified).	… clearly further scientific research is required to substantiate these claims.
		The researchers called for the "immediate validation" of the results.
indicates mention is research	The story refers to the preprint as scientific research.	A new study suggests…
		A startling paper by a team of French scientists…
includes a hyperlink to preprint	The story contains a hyperlink to the study it cites.	A small study, done in macaque monkeys, shows… [underline = hyperlink]
		A separate multi-center comparative clinical trial in China indicated…
link does not indicate it is research/ preprint	The story hyperlinks to the study but does not make it clear that it is a research study or a preprint.	Brazil has many advantages over its neighbors for an effective pandemic response: universal health coverage, a large community-based primary care delivery system…
		The infection risk is especially high among household contacts.

6.4.3. Intercoder Reliability

Following best practices for mass communication research (Lacy et al., 2015), coding was performed by one researcher (AF) and a second, independent coder who was not involved in developing the codebook (cf. Strekalova, 2015). The lead author tested the codebook by coding 69 representative stories that were not part of the main coding

(i.e., they mentioned COVID-19-related medRxiv and bioRxiv preprints amoung the top-15 outlets, but mentioned preprints that were not among the top 100 used in our final sample) and refined the codebook as needed (Lombard et al., 2002). A second coder was provided with the codebook and a demonstration of the method. The second coder then independently coded the same 69 stories. All coding was performed using Excel. Krippendorff's alpha reliability scores were calculated using Python's krippendorff library.[35] Given that this measure of intercoder reliability is conservative and that the study is exploratory, we set the minimum acceptable level of reliability at .70 (Lacy et al., 2015; Lombard et al., 2002). This level was met or exceeded for all codes, as shown in Table 6.2 (below).

Table 6.2.   Intercoder Reliability Scores

Code	Krippendorff's alpha
science communication story	.97
reposted story	.97
press release	1.00
defines preprint	.76
mentions "preprint"	.81
mentions work is unreviewed	.96
mentions work is preliminary	.88
mentions verification is needed	.91
indicates mention is research	.92
includes a hyperlink to preprint	.75
link does not indicate it is research/preprint	.75

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[35] https://pypi.org/project/krippendorff/

After intercoder testing, both coders met to discuss discrepancies, particularly regarding the codes with lower levels of agreement: *defines preprint, includes a hyperlink to preprint,* and *link does not indicate it is research/preprint*. Sources of disagreements were identified, and appropriate coding approaches were reviewed and clarified in the codebook (e.g., preprint definitions do not have to be correct to be coded as *defines preprint;* a hyperlink to a different version of a preprint than the one in our data should be coded as *includes a hyperlink to a preprint*). Finally, the main dataset (n = 521 stories, none of which were used for the intercoder reliability test) was divided for coding by the two coders. Although coding was largely performed individually, coders consulted with one another to resolve difficult cases, discussing possibilities until they reached consensus (cf. Evensen & Clarke, 2012).

6.4.4. Statistical Methods

Binary logistic regressions were performed using the Python statsmodels[36] package.

6.5. Results

In the following, we present the findings of our study alongside the three research questions.

6.5.1. What Content Producers and Curators (Outlets) in the Media Ecosystem Are Communicating About COVID-19-Related Preprints (RQ1)?

The data collection and analysis yielded a diverse set of outlets that mentioned COVID-19-related preprints most frequently in the study period (Table 6.3). These outlets included legacy media (e.g., the *Guardian, New York Times*), digital-native news outlets (e.g., *Inverse*), medical-niche publications (e.g., *Medical News, MedicalXpress, Medscape*), technology-niche publications (e.g., *Business Insider, Wired*), Web portals

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[36] https://www.statsmodels.org/

114

(e.g., *MSN, Yahoo! News*), a native in-platform publisher (*Medium*), several news aggregators (e.g., *Dailyhunt, National Interest*), and *The Conversation*, a nonprofit outlet that "sources its content exclusively from university scholars and provides journalistic editing services to its authors" (Bruns, 2018, pp. 52–53). Regardless of categorization of these outlets, all but one (*Inverse)* showed a clear tendency to either publish reposted content (i.e., stories aggregated from other media outlets or press releases) or publish original content. We loosely categorized these outlets as "aggregators," defined, for the purposes of this study, as media outlets for which at least two thirds of stories were originally published by another source (i.e., were coded as reposted stories). Although we did not include press releases in this analysis, we note that doing so does not change the categorization of any outlet. *Medical News* published the greatest proportion of stories that we categorized as science communication stories (n = 15, 65.2%), where the primary focus was to communicate the research results and/or implications of the preprint. *MedicalXpress* and *Medscape* also published a large proportion of science communication stories (30.2% and 33.3%, respectively).

Table 6.3.   Number and Type of Stories Mentioning COVID-19-Related Preprints Published by Top 15 Outlets

Outlet	Total Stories	Press Releases		Reposted Stories		Science Communication ('Scicomm') Stories	
		Number	Percent	Number	Percent	Number	Percent
Business Insider	31	0	0	6	19.4	3	9.7
Dailyhunt*	27	1	3.7	26	96.3	8	29.6
Foreign Affairs New Zealand*	25	6	24	18	72.0	5	20.0
Inverse	22	0	0	10	45.5	3	13.6
MedicalXpress*	43	10	23.3	29	67.4	13	30.2
Medium	25	0	0	0	0.0	3	12.0
Medscape	15	0	0	1	6.7	5	33.3
MSN*	36	0	0	35	97.2	7	19.4
New York Times	29	0	0	0	0.0	4	13.8
The Conversation	41	0	0	0	0.0	2	4.9
Guardian	24	0	0	0	0.0	5	20.8
Medical News	23	2	8.7	4	17.4	15	65.2
National Interest*	32	1	3.1	26	81.2	1	3.1
Wired	17	0	0	2	11.8	3	17.6
Yahoo! News*	67	6	9	61	91.0	16	23.9

NB: Media outlets categorized as aggregators are demarcated with an asterisk.

6.5.2. How Are Outlets Using Hyperlinking Practices When Communicating About COVID-19-Related Preprints (RQ2)?

As there were no notable differences in the hyperlinking practices of outlets we categorized as aggregators and those that mostly posted original content, we do not draw distinctions in the rest of our results. Similarly, our findings remained unchanged whether or not press releases were included in the analyses; because of this—and because there

were so few press releases in our sample (n =26)—we do not make comparisons with this group in the following results. The vast majority of stories mentioned a single preprint (n = 419, 91.7%) or two of the top 100 COVID-19-related preprints that comprised our sample (n = 28, 6.1%). The remaining stories mentioned between three and five preprints. We also noted that many stories mentioned preprints beyond our sample, but these were not systematically studied.

For the remaining analysis, we considered a story to include a particular practice if it was used when mentioning at least one of the preprints associated with that story. In most cases, stories included a hyperlink to a preprint (n = 417, 91.2%). Similarly, most stories indicated that what was being mentioned was research (n = 368, 80.5%), for example, by referring to the preprint as "a study" or "new research." Nearly 20% of stories hyperlinked to a preprint without any indication of what the hyperlink pointed to (n = 88).

However, these practices varied by outlet (Table 6.4). While most outlets in our sample included a hyperlink to the COVID-19 preprints in their stories, only 27 (33.3%) of *Dailyhunt*'s stories had at least one hyperlink to a preprint (all other outlets included hyperlinks in over 80% of their stories; five outlets included them in 100%). Two outlets stand out for the infrequency of references to research; *The Conversation* and the *National Interest* only mentioned research in approximately 60% of their stories. In many of these instances, the two outlets simply hyperlinked to a preprint without further indication that the hyperlink led to research (i.e., there was no mention of words such as "study" or "findings"). For example, a story from *The Conversation* titled "Predicting COVID-19: what applying a model in Kenya would look like" (Nanyingi, 2020) stated (hyperlink to preprint underlined):

> There is an urgent need for serological tests. These find antibodies in the blood—molecules made by the immune system in response to a pathogen's attack—and would <u>measure</u> how much the virus spread and how many people recovered.

While these outlets had the highest number of stories that included hyperlinks without indication of research (43.9% and 50%, respectively), two additional outlets

published over 30% of their stories with uncontextualized hyperlinks (*Foreign Affairs New Zealand* and *Medium*) and two more had over 20% of stories with such hyperlinks (*Inverse* and *MedicalXpress*).

Table 6.4.   **Number and Percent of Stories by Hyperlinking Practice And Outlet**

Outlet	Includes a hyperlink to preprint		Indicates mention is research		Link does not indicate it is research/preprint	
	Number	**Percent**	**Number**	**Percent**	**Number**	**Percent**
Business Insider	30	96.8	28	90.3	3	9.7
Dailyhunt	9	33.3	21	77.8	2	7.4
Foreign Affairs New Zealand	24	96.0	17	68.0	9	36.0
Inverse	22	100.0	17	77.3	5	22.7
MedicalXpress	39	90.7	33	76.7	11	25.6
Medium	24	96.0	19	76.0	8	32.0
Medscape	14	93.3	14	93.3	1	6.7
MSN	30	83.3	30	83.3	2	5.6
New York Times	28	96.6	26	89.7	2	6.9
The Conversation	41	100.0	25	61.0	18	43.9
The Guardian	24	100.0	22	91.7	2	8.3
The Medical News	20	87.0	22	95.7	0	0.0
The National Interest	32	100.0	20	62.5	16	50.0
Wired	17	100.0	17	100.0	0	0.0
Yahoo! News	63	94.0	57	85.1	9	13.4
Total	**417**	**91.2**	**368**	**80.5**	**88**	**19.3**

NB: Because some stories mention more than one COVID-19-related preprint, a story may be counted as both having only a hyperlink and as indicating the mention pertains to research (i.e., if a story cites two different preprints, one may be described as research and the other included with only a hyperlink).

6.5.3. How Are Outlets Using Framing Devices That Emphasize Uncertainty When Communicating About COVID-19-Related Preprints (RQ3)?

Regardless of the practices used to identify or hyperlink to a preprint posted on medRxiv and bioRxiv, just over half of all stories made use of one or more framing devices to emphasize scientific uncertainty (i.e., they mentioned that the study was a preprint, unreviewed, preliminary, and/or in need of verification; n = 263, 57.5% of stories). In nearly half of these instances, the stories included a single framing device (n = 129, 49%), whereas 92 stories (35%) included two framing devices, 35 stories (13.3%) included three devices, and the remaining seven (2.7%) had all four devices (Figure 6.2).

Figure 6.2. **Proportion of Stories Using Different Numbers of Framing Devices That Emphasize Scientific Uncertainty**
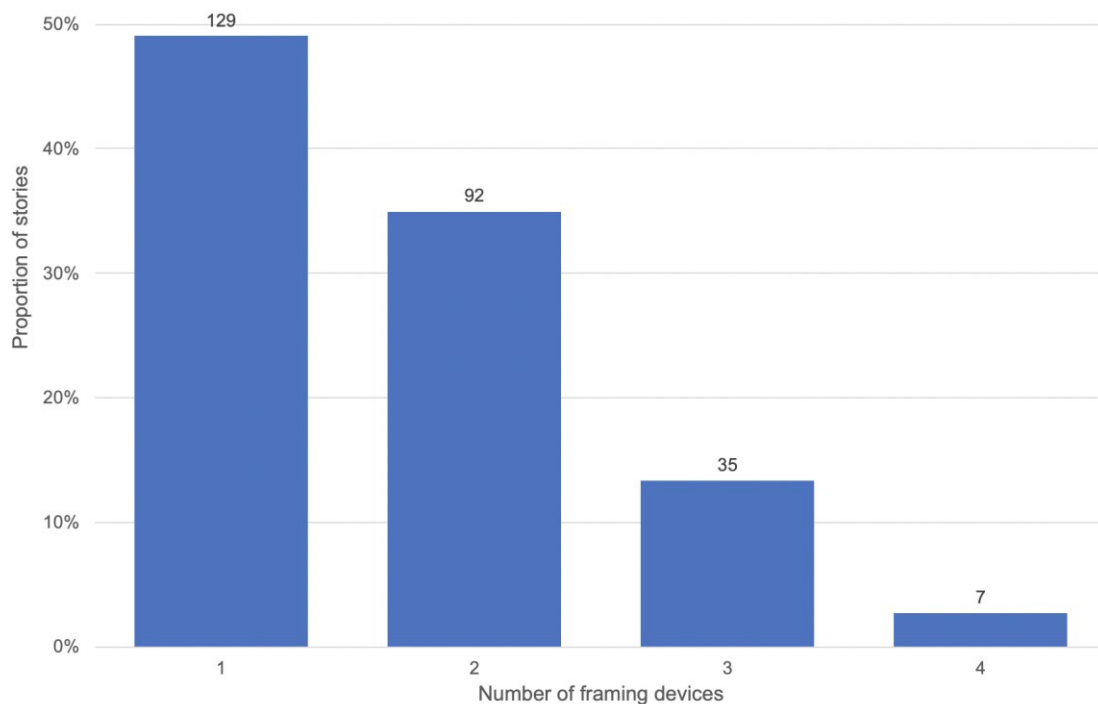
Noting that content was unreviewed was the most common uncertainty framing device, appearing in 172 (37.6%) of stories, followed in equal numbers by identifying the content as a preprint and noting that further verification was needed (n = 99, 21.7% for both devices). Indicating that the work was preliminary was the least common uncertainty framing device, appearing in only 76 (16.6%) of the stories.

The devices used to frame uncertainty about COVID-19-related preprints varied by outlet. While some outlets indicated some form of uncertainty framing in over 80% of their stories (i.e., *Medical News, Medscape, Wired*), others did so less than half the time (*The Conversation, Foreign Affairs New Zealand, Medium, New York Times*) (Table 6.5). To test the significance of these differences, we calculated a logistic regression that examined whether the probability of finding an uncertainty framing device varied depending on the publication outlet. More formally, we calculated a model in the form $P(Y = 1) = \beta_0 + (\beta_1 x_1 + \beta_2 x_2 + ... + \beta_{15} x_{15})$, where Y is a binary outcome variable coded as 1 if at least one uncertainty framing device was used and 0 otherwise, and $x_1 x_2 ... x_{15}$ are a set of predictor variables corresponding to each of the 15 outlets. A Wald Test easily rejects the null hypothesis that the outlets are equally likely to use at least one uncertainty device ($F = 39.32$, $p < .001$).

Table 6.5.   Percentage of Stories by Type of Uncertainty and Outlet

Outlet	Mentions "preprint"	Mentions work is unreviewed	Mentions work is preliminary	Mentions verification is needed	Any of four devices
Business Insider	6.5	54.8	19.4	9.7	67.7
Dailyhunt	22.2	48.1	7.4	22.2	59.3
Foreign Affairs New Zealand	24.0	28.0	12.0	16.0	44.0
Inverse	27.3	54.5	31.8	27.3	72.7
MedicalXpress	30.2	34.9	4.7	23.3	53.5
Medium	12.0	16.0	8.0	16.0	32.0
Medscape	73.3	40.0	33.3	33.3	86.7
MSN	13.9	44.4	22.2	25.0	61.1
New York Times	3.4	37.9	17.2	20.7	44.8
The Conversation	12.2	24.4	9.8	22.0	41.5
The Guardian	12.5	45.8	29.2	29.2	62.5
Medical News	65.2	39.1	13.0	21.7	82.6
National Interest	12.5	28.1	21.9	15.6	53.1
Wired	64.7	52.9	41.2	23.5	88.2
Yahoo! News	11.9	34.3	11.9	23.9	55.2

Some outlets, such as *Medical News*, *MedicalXpress,* and *Wired,* included specific definitions of preprints within their stories. We identified a variety of definitions in 46 stories (10.1%). For example, some stories highlighted the uncertain nature of preprints in their definitions, such as this one published by *Medical News* (Mandal, 2020):

> The preprint paper is a version of a scholarly or scientific paper that precedes formal peer review and publication in a peer-reviewed scholarly or scientific journal…medRxiv publishes preliminary scientific reports that are not peer-reviewed and, therefore, not be regarded as conclusive, guide clinical practice/health-related behavior, or treated as established information.

Other outlets offered a more positive spin in their preprint definitions. For example, a *Wired* story titled "Blood From Covid-19 Survivors May Point the Way to a Cure" (Rogers, 2020), defined preprints as "not peer-reviewed, but available for people to try," while *Foreign Affairs New Zealand* (2020) described them as "the 21st century way to report data almost in real time."

We identified many of these preprint definitions in stories that specifically indicated that the study mentioned was a preprint (29 of 99 stories, 29.3%). Outlets, such as the *New York Times, Medscape*, and *Wired*, had previously published stories specifically about peer review, preprints, and COVID-19, which they occasionally hyperlinked to in their COVID-19 coverage as a shortcut for defining preprints. For example:

> "The paper, which has not yet undergone peer review, appeared on **the Medrxiv preprint server**." [from *Wired* (Molteni, 2020); the bolded hyperlink leads to the story "Biology's roiling debate over publishing research early," which provides an overview of what preprints are, why they can be beneficial, as well as why they can be detrimental]

> "The study, however, was published on a **preprint server**, medRxiv, where, as Medscape readers know, researchers publish early versions of a manuscript before they are peer-reviewed." [from *Medscape* (Coffey & Oransky, 2020); hyperlink leads to the article "To maintain trust in science, lose the peer review," which explores the pitfalls of peer review and the barriers media face when covering research that is not Open Access]

"The research was posted on <u>MedRxiv</u>, a website where scientists have been posting articles **submitted for publication elsewhere that have not yet been through peer review**." [from the *New York Times* (Yan, 2020); hyperlink leads to a story on preprints, including their strengths and weaknesses, titled "Coronavirus tests science's need for speed limits"]

All outlets in our sample, particularly those focused on medical issues (*Medical News, MedicalXpress,* and *Medscape*), published stories specifically about the COVID-19-related preprints in our study (Table 6.3). We coded these stories as "science communication" if the results and/or implications of the preprint were the primary focus. We estimated the probability of whether a story would include an uncertainty framing device if the story was coded as a science communication story from the logistic model in the form $P(Y = 1) = \beta_0 + \beta_1 scicomm$, where Y is a binary outcome variable coded as 1 if at least one uncertainty framing device was used and 0 otherwise, and where *scicomm* is a predictor variable coded as 1 if the preprint was the primary focus of the story and 0 otherwise. We found that such stories were statistically more likely to include some uncertainty framing device when compared to other stories (odds ratio = 9.64, $p < $ .001). We ran a similar model using the 26 stories that were coded as press releases and found an increased likelihood that these contained an uncertainty framing device (odds ratio = 2.58, $p = $ .046). However, the significance of this effect disappears when both variables are considered in the same model ($p = $ .337), while the increased likelihood of science communication stories containing an uncertainty framing device remains statistically different from zero ($p < $ .001).

6.6. Discussion

This study aimed to identify the digital content providers that are sharing COVID-19-related preprint research and the hyperlinking and communication practices these outlets use when mentioning preprints in media stories. Because preprint research is characterized by a high level of scientific uncertainty (Berg et al., 2016; Chiarelli et al., 2019b; Fry et al., 2019), we were particularly interested in how these outlets framed this uncertainty.

To inform this study, we drew on research about scientific (un)certainty in health reporting (Hove et al., 2015; Jung Oh et al., 2012; Matthias et al., 2020) and work documenting the changing media landscape (Bakker, 2012; Bruns, 2018; Hermida, 2019; Lowrey, 2012). We found that a diverse range of legacy and digital-native content providers and curators are using the 100 most-mentioned COVID-19-related preprints in their stories, and that each media outlet had a unique approach to covering them. We loosely categorized these outlets as legacy, aggregators, medical-niche, digital-native news, technology-niche, and outlets such as *Medium* and *The Conversation*, which resist categorizations found in existing research.

We recognize that digital outlets will continue to diversify and innovate (Bruns, 2018; Lowrey, 2012; Witschge et al., 2019), but we also note trends in how the outlets identified in our study used preprints in their stories. Hyperlinking was a ubiquitous practice, with over 90% of stories we analyzed including a hyperlink to at least one preprint. Identifying those preprints and hyperlinks as pointing to research was also common. This standardization or routinization of practices points to some stability in the media landscape (Lowrey, 2012)—at least among the 15 outlets that were most active in covering COVID-19-related preprints. Existing research has similarly documented a tendency among digital communicators to hyperlink to academic sources, often to demonstrate credibility and transparency (Coddington, 2012; Karlsson & Sjøvaag, 2018; Stroobant & Raeymaeckers, 2019). However, our findings extend the literature by examining how hyperlinks to COVID-19-related preprints were used as citations by a diversity of media outlets, and how even uncertain science may be leveraged as a credibility marker—especially when described as "research" rather than as a preprint. Indeed, outlets in our sample were much less likely to identify the research they mentioned as preprints—perhaps to maintain credibility, but perhaps also to avoid alienating readers with limited knowledge of scientific methods. Although more research is needed to understand the motivations behind media outlets' use of different uncertainty framing devices, avoiding terms like "preprint" may be a strategic editorial approach adopted by media professionals who are known to pay close attention to audience preferences when making editorial decisions (Arenberg & Lowrey, 2019; McKenzie et al., 2011; Tandoc, 2015; Vu, 2014).

Some outlets (e.g., *Medscape, Wired)* framed the preprints they mentioned as uncertain in almost every story; others (e.g., *The Conversation, New York Times*) did so in less than half of the stories we analyzed. Over 40% of stories in this study did not frame the preprint as uncertain at all; of those that did, most included just a single framing device—typically a statement that the research had not been peer reviewed. This may be because peer review is a feature that obviously distinguishes preprints from other research articles (Fraser et al., 2020; Teixeira da Silva, 2020), but it may also suggest that some communicators are wary of emphasizing uncertainties that are more directly tied to the quality of the research, such as its preliminary nature or the need for verification, as these could potentially undermine credibility and trust (Frewer et al., 2003; van der Bles et al., 2020). These findings align with previous studies examining editorial framing of health issues (Dan & Raupp, 2018; Hove et al., 2015; Jung Oh et al., 2012; Matthias et al., 2020), which find that science is seldom framed as uncertain. In our study, only about half of the stories we analyzed contained framing devices emphasizing uncertainty; yet this was still far more frequent than past studies have reported, perhaps because of the nature of the topic of our study. Previous studies have largely focused on media coverage of peer reviewed health research, while our work focused specifically on preprints, which are scientifically uncertain. In the context of risk communication where transparency is deemed essential (Bourrier, 2018; Covello & Allen, 1988; Nisbet et al., 2003; Sellnow et al., 2009), some media outlets may recognize the importance of framing them as such. Indeed, although research examining media coverage of unreviewed health science is limited, available evidence from beyond the COVID-19 context suggests media outlets may frame scientific uncertainty differently when communicating during a public health crisis. These studies—which focused on media coverage of other forms of preliminary health research (e.g., findings from initial biomedical studies or medical conference proceedings)—found that only about one in five media stories mentioned the uncertain or unverified nature of the findings they communicated (Dumas-Mallet et al., 2018; Lai & Lane, 2009). While more research is needed in this area—particularly comparing media coverage of peer reviewed and unreviewed research findings, as well as the portrayal of preprints across different topics, communication contexts, and outlets—it is encouraging to consider that media may be more attentive to addressing scientific uncertainties when

such transparency has important implications for public health, such as when communicating research related to the COVID-19 pandemic.

In comparing the hyperlinking and framing practices of these diverse outlets that mention preprints frequently, this study revealed greater similarities between outlets from different categories than previous research (Harrison et al., 2020; Hurley & Tewksbury, 2012; Stroobant, 2019)—at least in their coverage of COVID-19-related preprints. For example, both *MSN* and *Dailyhunt* can be considered aggregators, but *MSN*'s communication practices had more in common with niche outlets such as *Wired* or *Medical News,* which were among the most likely to hyperlink to preprints and identify them as such. Similarly, while the *Guardian* and *New York Times* shared similar hyperlinking practices (i.e., they almost always hyperlinked to the COVID-19-related preprints they mentioned, and rarely did so without identifying them as research), the *New York Times* was less likely to include a framing device emphasizing uncertainty in their stories. In this instance, the *New York Times* had more in common with outlets like *The Conversation* or *Foreign Affairs New Zealand,* both of which used fewer uncertainty framing devices than other outlets. These similarities across "categories" could suggest, as other scholars have argued, that drawing divides between legacy or "core" journalism and alternative, "peripheral" outlets may no longer make sense; the boundaries between them appear to have become blurred (Bruns, 2018; Chadwick, 2017; Deuze & Witschge, 2018; Hermida, 2019). Future studies examining the use of uncertainty framing devices among a larger sample of media outlets could provide important insights into the degree to which such blurring is, indeed, taking place.

Within our sample, the digital-native outlets (e.g., *The Conversation, MedicalXpress*, *Yahoo! News*) published the most stories citing preprints. This may be explained in part by the resources required to cover scientific research: when contributors get "no-pay" or "low-pay" for producing original content, media outlets face fewer financial barriers to publishing it (Bakker, 2012; Coddington, 2019). The dominance of *The Conversation* in the lack of framing devices emphasizing uncertainty*,* however, is surprising, given its official terms and conditions specify that "Research, as a general principle, should not be reported before it has been subjected to a recognized process of

peer review" (*Terms and Conditions*, 2020). The urgent nature of a crisis like the COVID-19 pandemic may have prompted revisions to media policies by some outlets and provides an area for future research.

Professional journalism resources, such as tip sheets, blog posts, and stylebooks, that describe best practices for reporting on COVID-19 preprints (Froke et al., 2020; Helmuth, 2020; Jaklevic, 2020; Khamsi, 2020; Ordway et al., 2020) recommend using the uncertainty framing devices that we investigate in this paper. Interestingly, aggregators like *MedicalXpress* and *Yahoo! News* were more likely to follow these guidelines when mentioning the most reported on COVID-19-related preprints, compared with some of the more "traditional" outlets in our sample. These findings depart from research suggesting that aggregators are less likely to include uncertainty in their coverage (Hurley & Tewksbury, 2012) and more likely to provide shallow, sensational content (Coddington, 2019). While more research is needed in this area, one possible explanation is that aggregators are increasingly heterogeneous, with some licensing high-quality journalistic content. Aggregators, at least those identified in this study, may also have new content options outside traditional news media. For instance, *The Conversation*, with articles commonly republished by aggregators within the dataset, represents a relatively new form of content available for free and from researchers at a mix of academic institutions. Finally, several of the aggregators in our sample also occasionally reposted press releases, the majority of which were science communication stories and thus more likely to include at least one uncertainty framing device.

The Conversation also stands apart, as does *Medium,* for having the fewest stories hyperlinking to a highly mentioned COVID-19-related preprint without framing it as uncertain. Both outlets were relatively unlikely to identify those preprints as preprints. This may be expected in the case of *Medium,* which allows anyone to publish content with little or no editorial oversight[37], and hence is likely to feature stories by authors with limited awareness or concern of what preprints are or the scientific uncertainty surrounding them. The limited uncertainty in *The Conversation* stories is more surprising,

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[37] *Medium* offers guidelines and best practices, but does not enforce them https://medium.com/creators

given academics' typical reliance on uncertainty framing devices to communicate scientific findings (Zehr, 2000). *The Conversation*'s readership, while largely working in non-academic settings (*Our Audience*, 2020), is mostly university educated and it may be assumed that this audience is already knowledgeable about preprints. This raises issues around article sharing by outlets with readership beyond *The Conversation*'s initial or intended audience. As such, *The Conversation*'s distribution and editorial approach— what it calls "academic rigor, journalistic flair"[38]—present a tension deserving of further research.

Across the 15 outlets we analyzed, "science communication" stories—that is, stories focused on communicating the results or implications of a particular COVID-19-related preprint—were more likely to portray that preprint as uncertain compared to stories using preprints for other purposes (e.g., to cover a wider issue, to support an argument). This finding supports recent research by Matthias and colleagues (2020) which similarly found that scientific uncertainty was more likely to be conveyed in science communication rather than stories that mentioned research but focused on broader scientific or social issues. These findings are not surprising considering media preferences for novelty and significance; framing research as scientifically uncertain does not enhance a story unless the implications for the audience necessitate it (Fahnestock, 1986). This tendency may also come down to a question of word count and reader experience. Discussing the uncertainty associated with a preprint takes up valuable space—even in online publications that typically work to keep articles brief—and could disrupt the "flow" of a story (Van Leuven et al., 2018). While outlets and their editorial staff may deem an explanation of a preprint as warranted in a story focused on that research, they may be less likely to do so when a preprint is mentioned only in passing.

There are practical implications from these research findings that we wish to highlight. Media are a key source of public health information during times of crisis (Austin et al., 2012); yet many of the outlets we analyzed do not appear to follow public health risk communication best practices when it comes to the portrayal of uncertainty

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[38] https://theconversation.com/

surrounding COVID-19 preprint research—at least not consistently. We recognize that covering this unvalidated science poses challenges for public health risk communicators, as doing so requires balancing the public's need for timely, relevant information with risk communication best practices of communicating with transparency and openness regarding unknowns and uncertainties (Covello et al., 1989; Covello & Allen, 1988). Still, our findings suggest that achieving these seemingly conflicting aims is possible; *Wired* and the *New York Times* have both produced explanations about the uncertainty inherent in science, peer review, and the scientific method, and each outlet includes hyperlinks to these "meta"-science stories when mentioning preprint research. These practices could be seen as a first step toward a standardized industry practice, although they offer no guarantee that readers will click through for additional information (Yaros, 2011). Evaluating the certainty of scientific findings can be challenging for readers without a science background; however, readers can at least understand whether research is established or preliminary with the help of editorial framing devices such as those analyzed in this study. This seems especially important for global issues with such local and personal relevance as COVID-19.

These issues warrant further study and could be explored by building on the research method we employed, which is innovative in two ways. First, our approach builds on the emerging field of altmetrics (Erdt et al., 2016), which seeks new ways to capture how and when research is shared and communicated online, by analyzing the contexts within which research is mentioned. Second, while much previous research has analyzed uncertainty frames using a holistic approach (i.e., is the story uncertain?), often with nontransparent coding schemes (Matthes & Kohring, 2008), we offer our full coding scheme and break down uncertainty frames into four distinct framing devices, allowing the identification of the relative prevalence of each device overall, as well as for each outlet.

This study comes with limitations. First, we focused on the framing of uncertainty specific to COVID-19-related preprints, rather than uncertainty in these stories more generally. We see this focus as a strength, as, to our knowledge, no existing research has examined how preprints are portrayed in online media coverage. However, by restricting

the unit of analysis to the preprint mention, we might have missed some of the context surrounding the preprint that could influence how the preprint is perceived by readers (Corbett & Durfee, 2004; Tewksbury & Riles, 2018). Second, we further restricted our sample to mentions of the 100 most mentioned COVID-19-related preprints, which may not be representative of coverage of less popular preprints. Indeed, media outlets sometimes take their lead from other outlets when deciding how and whether to cover issues (Golan, 2006; Wang & Guo, 2018); seeing a preprint mentioned by multiple outlets—especially without the inclusion of an uncertainty framing device—may have encouraged the outlets in our sample to see the research as sound and verified, and portray it accordingly in their own coverage. Third, we found that a large proportion of our stories used preprints with a hyperlink, but this may be an artifact of how Altmetric tracks research mentions and could bias the data to include hyperlinked preprints over text-based mentions of preprints. While we can be certain that Altmetric's natural language processing is successful in identifying text-based mentions of preprints at least some of the time, the exact precision and recall of this approach remains unknown. We encourage scholars to complement our findings using other data sources and methodologies—as well to systematically evaluate the effectiveness of Altmetric's text-based data collection. Fourth, we restricted our sample to English-language stories from the 15 media outlets that mentioned the most COVID-19-related preprints, but these may not be the most influential or most read outlets covering the pandemic, nor representative of preprint coverage in other languages. Future research could examine whether our findings apply to international outlets, as well as those chosen based on the size and influence of their audiences or the reach of their stories. Finally, interviews with content providers and curators could advance our understanding of how they approach the communication of scientific uncertainty surrounding preprint research in their media stories and help us develop a more complete explanation of media communication of preprint research.

6.7.   Contribution Statement

I participated during all stages of the development of this paper and provided an overall contribution greater than that of any co-author. I developed the concept for the

study and contributed to obtaining the funding, with assistance from all other authors. I worked with Juan Pablo Alperin to gather the data and develop a study design. I led the content analysis, including creating and refining the coding instrument, training and supervising the student coder, performing intercoder reliability tests, and analyzing the media stories. Alperin led the statistical analyses. I led the analysis and the writing of the initial draft, with assistance from Laura Moorhead, Michelle Riedlinger, and Juan Pablo Alperin. All authors contributed to revising the draft.

6.8. Data Availability

Media mention data and the codebook used for the content analysis can be accessed via the Harvard Dataverse at https://dataverse.harvard.edu/ with the doi: 10.7910/DVN/WG9VDS.

6.9. Funding

6.10. Competing Interests

The authors have declared that no competing interests exist.

6.11. Acknowledgements

Chapter 7.

Unreviewed Science in the News: The Evolution of Preprint Media Coverage from 2014-2021

7.1. Abstract

It has been argued that preprint coverage during the COVID-19 pandemic constituted a paradigm shift in journalism norms and practices. This study examines whether and in what ways this is the case using a sample of 11,538 preprints posted on four preprint servers—bioRxiv, medRxiv, arXiv, and SSRN—that received coverage in 94 English-language media outlets between 2014–2021. We compared mentions of these preprints with mentions of a comparison sample of 397,446 peer reviewed research articles indexed in the Web of Science to identify changes in the share of media coverage that mentioned preprints before and during the pandemic. We found that preprint media coverage increased at a slow but steady rate pre-pandemic, then spiked dramatically. This increase applied only to COVID-19-related preprints, with minimal change in coverage of preprints on other topics. The rise in preprint coverage was most pronounced among health and medicine-focused media outlets, which barely covered preprints before the pandemic but mentioned more COVID-19 preprints than outlets focused on any other topic. These results suggest that the growth in coverage of preprints seen during the pandemic may imply only a temporary shift in journalistic norms, including a changing outlook on reporting preliminary, unvetted research.

7.2. Introduction

On January 10, 2020, the World Health Organization published its first set of guidelines for preventing and controlling a suspected "novel coronavirus (nCoV)" (WHO, 2020). Soon journalists found themselves plunged into an unexpected crisis, with an out-of-control, little understood infectious disease, and an influx of new scientific information to sift through and report on. Without much peer reviewed literature to go on—especially in the early stages of the pandemic—many turned to preprint servers to share urgent new information with the public (Fraser et al., 2021). The ensuing media coverage of preprints seen during the pandemic has since been described as a complete rupture from past reporting practices (e.g., Burke, 2021; Makri, 2021). Yet, empirical evidence supporting this assertion is lacking. As noted in previous research, there is currently an absence of longitudinal investigations that examine preprint coverage over time and which assess the impact of COVID-19 on journalistic practices and norms (Fleerackers et al., 2023a; Van Schalkwyk & Dudek, 2022b). This study fills this gap by examining how media coverage of preprints has evolved, both qualitatively and quantitatively, in the lead up to, and during the first year of, the COVID-19 pandemic. Using Altmetric data, it examines changes in the volume and nature of media coverage of 11,538 preprints posted between 2013 and 2021 on bioRxiv, medRxiv, arXiv, and SSRN—four of the most actively used servers used to share COVID-19-related research (Waltman et al., 2021).

7.3. Literature Review and Research Questions

7.3.1. Preprint Media Coverage Before and During the COVID-19 Pandemic

Preprints have been used extensively in physics, math, and computational science since arXiv launched in 1991. However, scientists in the biological and medical fields have been more reluctant to do so—that is, until recently (Puebla et al., 2022). The early months of the pandemic saw a sharp increase in the volume of available COVID-19-related preprints (Funk, 2023; Horbach, 2020), with preprint servers such as medRxiv and bioRxiv becoming key disseminators of pandemic research (Else, 2020; Vergoulis et

al., 2021). One study (Kousha & Thelwall, 2020) found that preprints posted to arXiv bioRxiv, medRxiv, and SSRN comprised 13.26% of the COVID-19 literature during March–April 2020, while an analysis by Fraser et al. (2021) found that preprints posted to 16 servers (including the four examined in this study) comprised almost 25% of the COVID-19-related research available from January–October 2020. Studies have predicted that the use of pandemic-related preprints continued to grow at a relatively stable rate throughout 2021 and 2022, although more research is needed to confirm these predictions (Nane et al., 2023).

COVID-19-related preprints also gained traction within news media, receiving coverage in diverse media outlets around the world (Fleerackers et al., 2022b; Massarani et al., 2021b; Massarani & Neves, 2022; Simons & Schniedermann, 2023; Van Schalkwyk & Dudek, 2022a). One study found that more than a quarter of COVID-19-related bioRxiv and medRxiv preprints were mentioned in at least one media story during the pandemic, while only about 1% of those on other topics received media coverage (Fraser et al., 2021). Some journalists reported adopting novel practices to report on these unreviewed studies, something they said they had never done before (Fleerackers et al., 2022a; Massarani et al., 2021b).

This media coverage of preprints seen during the COVID-19 pandemic has been described by some journalists as a "paradigm shift" (Fleerackers et al., 2022a). Yet, while studies conducted during the COVID-19 pandemic provide important evidence into how journalists covered preprints during the evolving health crisis, little is known about whether journalists have covered preprints on other topics or during other communication contexts. For example, Fraser et al. (2021)'s widely cited study is often described as providing evidence that "During the pandemic, journalists…paid increased attention to preprints" (Kwon, 2021, para. 8), but the authors did not compare pandemic preprint coverage to pre-pandemic levels. Instead, they provided evidence that COVID-19-related preprints received an outsized amount of media attention, *relative to those on other topics posted to bioRxiv and medRxiv during the same time period*—but not relative to preprints posted during different time periods or on different servers (Fraser et al., 2021). One recent study begins to fill this gap through an examination of coverage of preprints by

seven German newspapers from 2018–2021 (Simons & Schniedermann, 2023). The authors identified low and stable rates of coverage leading up to the pandemic, followed by a major surge in 2020 and 2021 that was driven by COVID-19-related preprints. However, it is unclear whether this trend is reflective of other media outlets (e.g., those outside of Germany) and whether there are disciplinary differences in coverage trends.

More broadly, although preprints made up a significant proportion of the COVID-19-related literature available within the first months of the pandemic, it is unclear how media coverage of preprints compares to coverage of peer reviewed research. One article found that the five COVID-19-related research articles that received the most media coverage were all peer reviewed publications; however, the analysis was descriptive and did not compare the volume of preprint coverage to that of peer reviewed papers (Kousha & Thelwall, 2020). Another small study found no significant difference in the amount of media coverage received by medRxiv preprints and peer reviewed publications about COVID-19-related therapies that were posted between February 1–May 10, 2020 (Jung et al., 2021). A study of South African media found that only 3% of stories mentioning COVID-19 research included a mention of a preprint (Van Schalkwyk & Dudek, 2022a). Besançon et al. (2021) used Altmetric to examine media coverage of COVID-19-related preprints posted to arXiv, medRxiv, and bioRxiv between January–July 2020, finding that these preprints received more coverage than the non-COVID-19-related preprints posted to arXiv during the same time period. Again, coverage of preprints before the pandemic period was not considered. Fraser et al. (2020) found that bioRxiv preprints submitted between November 2013 and December 2017 received far less media coverage than either their peer reviewed versions or a control set of peer reviewed articles that were never deposited to bioRxiv. Finally, Waltman et al. (2021) found that, although some COVID-19-related preprints were highly reported on, overall, media coverage of peer reviewed literature outstripped coverage of preprints. Unfortunately, Waltman et al. (2021) did not report the average attention received per preprint vs peer reviewed article. However, the authors did examine media coverage received by a sample of high-profile preprints and their corresponding peer reviewed articles. For 45% of these preprint-article pairs, the preprint received more than 20% of the total news attention; for 11% of the

pairs, preprints received more than 80% of the coverage (Waltman et al., 2021). Again, the authors did not compare these findings to rates of coverage before the pandemic.

Collectively, these results provide some of the first evidence that preprints have historically received less media coverage than peer reviewed research and that this trend may have started to shift during the pandemic. However, given the mixed and incomplete body of evidence, several questions remain unanswered. In particular, it is unclear whether the volume of preprint media coverage increased, decreased, or remained relatively stable in the years leading up the pandemic—information that could help shed light on whether preprint-based media coverage is likely to continue post-COVID-19. It is also unclear whether any changes in coverage seen during the pandemic apply only to COVID-19-related preprints or reflect a change in journalists' willingness to use preprints in general. As such, to examine whether the pandemic has truly introduced a "paradigm shift" in journalistic practice, this study uses a sample of preprints that received coverage in English-language media between 2014–2021 to examine the following research questions:

- RQ1. Has the share of preprint coverage in the media increased during the COVID-19 pandemic?
- RQ2. Do changes in media coverage of COVID-19-related preprints extend to coverage of preprints on other topics?

7.3.2. Preprint Media Coverage in an Evolving Media Landscape

It is also unclear from previous research which types of media outlets have driven media coverage of preprints and whether this has changed as a result of the pandemic. Journalism has evolved in important ways in the years leading up to the COVID-19 crisis, with financial pressures, shrinking news audiences, and changes to the digital communication landscape contributing to declines in specialized science journalism around the world (Saari et al., 1998; Schäfer, 2017). These declines have likely influenced the amount of media coverage that research articles—including preprints— receive, as outlets specializing in science appear to cover more research than general interest publications (Wihbey, 2017). In addition, an array of actors who have historically been considered "peripheral," or outside of, journalism, have entered the field, including

135

bloggers, news aggregators, and other alternative outlets (Hermida, 2019; Schapals, 2022; Stocking, 2019). These peripheral actors may not always adhere to the established norms and practices that shape media coverage at traditional—or "legacy"—outlets (e.g., Harrison et al., 2020; Hurley & Tewksbury, 2012), which may affect how or whether they cover preprints. For example, journalists working at peripheral outlets may not be expected to adhere to professional journalism resources, such as the *AP Style Guide,* which recommend avoiding research that has not been peer reviewed (Froke et al., 2020; Haelle, 2020). Yet, both peripheral and legacy outlets actively covered COVID-19-related preprints during the early months of the pandemic (Fleerackers et al., 2022b). Similarly, outlets that publish content but are not considered journalism, such as university websites and press release distribution services, may also contribute to mobilizing preprint research. For example, the Science Media Centre in Germany—a non-journalistic outlet that provides science journalists with access to research and expert perspectives—began sharing roundups of newly posted preprints during the pandemic (Broer, 2020; Broer & Pröschel, 2022). Again, however, any evidence about the nature of non-journalistic outlets reporting on preprints is limited to the pandemic period. As such, our third research question asks:

- RQ3. Have changes in media coverage of preprints occurred similarly across media outlets?

7.4. Method and Materials

To identify media coverage, this study relies on data from Altmetric,[39] a company that tracks mentions of research outputs across a range of digital media, including news media. Research suggests that Altmetric's "Mainstream Media" category is a relatively reliable source of data but only when working with a predefined list of English-language media outlets (Fleerackers et al., 2022a; Ortega, 2020b, 2020a). In addition, because Altmetric regularly updates both the list of media outlets[40] and research outputs[41] it tracks, the volume of media coverage it collects may vary over time in ways that are

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[39] https://altmetric.com
[40] https://help.altmetric.com/support/solutions/articles/6000235999-news-and-mainstream-media
[41] https://www.altmetric.com/about-our-data/how-it-works-2/

unrelated to actual changes in news reporting. For these reasons, we decided to gather two datasets:

1. A primary dataset comprising media mentions of bioRxiv, medRxiv, arXiv, and SSRN preprints;
2. A comparison dataset comprising media mentions of peer reviewed research indexed in the Web of Science (WoS).

7.4.1. Identifying and Characterizing Media Outlets that Frequently Cover Research

Data were queried from local snapshots of the Web of Science and Altmetric Databases housed at the Observatoire des sciences et des technologies (OST)[42] on January 30, 2023. Data filtering and cleaning were performed using the Python pandas package (The Pandas Development Team, 2023). To identify our predefined set of media outlets, we queried a snapshot of the Altmetric database from June 3, 2021, for media mentions of all WoS research outputs associated with a digital object identifier (DOI). We restricted our search to mentions of research outputs that had been published in 2013 or later and that were mentioned in media stories between January 1, 2014, and June 3, 2021. We then filtered for outlets that consistently covered a high volume of research, defined for the purposes of this study as outlets that mentioned at least 100 WoS research items per year from 2014–2021. We manually checked the resulting 128 media outlets by visiting the URLs for their home pages provided by Altmetric. After excluding 25 outlets that were not written in English, five that were not tracked by Altmetric from 2021–2022 (e.g., because they had changed their domain names), three whose URLs did not resolve, and one with all misidentified mentions, we were left with a final sample of 94 outlets.

Next, we applied a coding protocol adapted from Hermida and Young (2019) to characterize the nature of these media outlets. We analyzed each outlet's main topical focus (e.g., science and technology, health and medicine, general news, etc.) and assessed whether it was best described as legacy journalism (i.e., staffed by professional journalists who adhere to traditional journalistic norms), peripheral journalism (i.e.,

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[42] https://www.ost.uqam.ca/

staffed by individuals who have traditionally worked outside of journalism and who adhere to emerging or alternative norms), or non-journalism (i.e., organizations such as universities, press release services, or academic journals that do not produce journalism). A detailed version of the coding protocol, including examples, is available from Fleerackers and Fagan (2022).

Coding was performed by researchers with professional journalism experience: the lead author and a research assistant who was not aware of the study objectives (cf. Hermida & Young, 2019). The two coders independently explored the media outlets' websites, examining their content, Mission Statement, and, if available, other relevant pages (e.g., Masthead, Editorial Guidelines, Code of Conduct). The coders compared their coding and resolved any discrepancies through discussion, and, if needed, by consulting an outside researcher (also a former journalist). Such double coding approaches are appropriate when data are not very numerous (Krippendorff, 2004), as in the present study. Results of the final coding are reported in aggregate in Table 7.1; coding for the full list of outlets is available at Alperin et al. (2023).

Table 7.1.   Nature of Media Outlets That Frequently Cover Web of Science Research

Topic	N	Type	N
general news	38	Legacy	49
Science and technology	28	Peripheral	35
Health and medicine	15	Non-journalism	10
Other*	13		
Total	94		94

NB. The "other" category includes a mix of other specialized topics that were represented in the sample but were relatively rare (e.g., business, lifestyle, explicit point-of-view). A detailed breakdown of the coding for these other specialized outlet topics is available online (Fleerackers & Fagan, 2022).

7.4.2. Gathering Media Mentions of Preprint Research

We gathered news mentions of preprints from four servers—bioRxiv, medRxiv, arXiv, and SSRN—because these servers were highly used for sharing COVID-19-related preprints (Waltman et al., 2021). These servers were also launched at different times (bioRxiv in 2013, medRxiv in 2019, arXiv in 1991, and SSRN in 1994), with different disciplinary scopes, and have seen different levels of uptake among scholars (Puebla et al., 2022), providing us with a diverse sample of preprints for our analysis. We queried Altmetric for mentions of preprints from these servers in stories published by the 94 outlets since January 1, 2014. This yielded a total of 40,039 mentions of 15,041 preprints across 31,258 media stories. For each of these preprints, we gathered the publication dates from the arXiv and Crossref APIs using the Python arxiv and habanero packages (Chamberlain, 2020; Schwab, 2021).

Next, because previous research suggests publication date metadata can often be incorrect or incomplete (Haustein et al., 2015), we manually checked subsamples of our data and compared the publication dates provided by Crossref, the arXiv API, and Altmetric. The most reliable publication date for each server was retained for analysis. For bioRxiv and medRxiv, this was the DOI creation date (i.e., the date that the DOI for the preprint was deposited in Crossref); for arXiv, it was the date provided by the arXiv API; and for SSRN, it was either the "first posted on" date provided by Altmetric or Crossref's DOI creation date, whichever came first. We removed 3,619 preprints that were published before 2013, as these publication dates were particularly unreliable (perhaps because Altmetric started tracking mentions partway through 2012 and thus has incomplete data for previously published outputs)[43]. Even after excluding these preprints and selecting the most reliable publication date for each server, we noted that publication dates for arXiv and SSRN sometimes differed from the dates visible on the server web page by a few days—a limitation that we kept in mind during data cleaning and analysis.

We made several further exclusions to ensure that the mentions in our dataset were mentions of true preprints (i.e., rather than postprints or journal versions of

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[43] NISO Altmetrics Working Group C "Data Quality" – Code of Conduct Self-Reporting Table

preprints). First, we removed 165 mentions of postprints, which we defined as preprints that were posted on the same day, or after, their journal versions were published. Because, as mentioned above, publication dates for preprints were often incorrect by a few days, we excluded an additional 332 mentions of preprints with a publication date within seven days of the journal version's publication date (i.e., suspected postprints). We also removed 327 mentions of preprints in media stories that were published before the preprint was first posted, using a five-day cut off to allow for the slight inconsistencies we identified in the publication metadata. Because Altmetric does not disambiguate between preprints and journal versions for some preprint servers[44,45] and may thus erroneously include some mentions of peer reviewed research, we removed 3,547 mentions in media stories published after the peer reviewed journal version of the preprint was published, again using a five-day margin. While this approach may have removed some true mentions of preprints, these false removals are likely limited, as journalists strive to ensure their stories are timely and relevant (Rosen et al., 2016; Shoemaker & Reese, 1996) and seldom cover research outputs more than a few weeks after initial publication (Maggio et al., 2017). Finally, we removed an additional 1,021 duplicate mentions (where the same preprint was mentioned in the same media story more than once). In total, filtering led to the exclusion of 9,081 mentions (22.5% of the original dataset). Our final preprint sample comprised 31,028 mentions of 11,538 preprints by the 94 media outlets in our sample.

7.4.3. Gathering Media Mentions of Peer Reviewed Research

We downloaded all the mentions of WoS research from our 94 outlets (i.e., those described in Section 3.1), resulting in 1,657,202 mentions of 466,138 distinct research outputs. From these, we filtered 156,187 mentions of research articles that were published prior to 2013, 579 mentions that were already included in the preprint data, and 14,482 duplicate mentions (where an article was mentioned in the same media story more

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[44] https://help.altmetric.com/support/solutions/articles/6000240580-merging-preprints-and-final-published-versions
[45] https://www.altmetric.com/about-our-data/how-it-works-2/

than once). In total, filtering led to the exclusion of 170,669 mentions (1.3% of original dataset).

The final journal research sample comprised 1,486,533 mentions of 397,446 distinct peer reviewed research outputs by the 94 outlets (Alperin et al., 2023).

7.4.4. Identifying Media Mentions of COVID-19 Research

To identify COVID-19-related preprints and WoS outputs, we searched for the presence of the following COVID-19-related keywords in the outputs' titles using R version 4.3.0 (2023): *coronavirus, covid-19, sars-cov, sars-cov-2, ncov-2019, 2019-ncov, hcov-19, sars-2, pandemic, covid, Severe Acute Respiratory Syndrome Coronavirus 2, 2019 ncov*. These keywords are a combination of those used by Fraser et al. (2021) and those listed in the National Library of Medicine's search strategy for identifying COVID-19-related literature (Chen et al., 2020). We also added the term "pandemic," which wasn't included in either of these lists of keywords but is likely used in many COVID-19 titles. As some keywords (e.g., "pandemic") may have been used in non-COVID-19 contexts, we also filtered for research published in 2020 or later when identifying COVID-19-related research.

7.4.5. Statistical Analyses

Statistical analysis was performed using Stata version 17 (StataCorp, 2021). Throughout our analyses, we examined changes in preprint media coverage in terms of proportions, rather than counts. Specifically, we compared mentions of preprints against mentions of all research in our sample (i.e., mentions of preprints *and* WoS research). Doing so allowed us to control for any fluctuations in the volume of preprint mentions that were created by changes in Altmetric's approach to identifying research mentions during the study period, rather than the result of changing journalistic practices. For ease of reading, we use the term "share of preprint mentions" to refer to the proportion of all research mentions that focused on preprints and "share of WoS mentions" to refer to the proportion that focused on WoS research.

To answer RQ1, we created a model (Equation (1)) to estimate the degree to which the launch of medRxiv and the onset of COVID-19 contributed to changes in the volume of media coverage of preprints after 2019. Disentangling any change in preprint coverage due to these two events was necessary as the creation of medRxiv preprints in 2019 (Kaiser, 2019) coincided closely with the start of the COVID-19 era. As such, in Equation (1), we estimated an ordinary least squares (OLS) regression of a binary indicator indicator (Y_{it}) coded as 1 if the media mention (i) referenced a preprint and coded as 0 otherwise against time (t), encoded as linear days since Jan 1, 2014 and allowed to be identified with 3rd-order polynomial trends (β_1 through β_3), with each vector of 3rd-order polynomial terms estimated in both the pre-COVID-19 era and COVID-19 era (α_0 interacted with the vector of time trends). We differentiated pre-COVID-19 from COVID-19 era mentions through a binary indicator, coded as 1 if the preprint was mentioned in a media story published after January 10, 2020 (i.e., when the WHO first used the term "2019-nCoV" to describe the novel coronavirus; WHO, 2020), and coded as 0 otherwise. We modeled the period between the first media mention of a medRxiv preprint (i.e., on July 23, 2019, which postdates the launch of the site on June 25, 2019 by about one month) and the WHO's statement as a linear intercept shift (β_4). In practice, this variable allowed us to differentiate the change in preprint mentions that occurred with the introduction of medRxiv before (but close to the onset of) COVID-19 from the effect of COVID-19 itself. Similarly, we modeled the mentions of preprints with titles that included COVID-19-related language (i.e., "sars-cov-2" or a related term) as a linear intercept shift (β_5). This last variable is important, as it allowed us to differentiate the change in preprint mentions for COVID-19-related topics in the media from changes in preprint mentions in the COVID-19-era but not about COVID-19 topics. Lastly, to adjust for seasonality and periodicity effects we controlled for week-of-year intercepts (γ_{wy}; e.g., first week of 2014) and day-of-month effects (δ_{md}; e.g., Tuesdays in January). In practice, controlling for periodicity and seasonality had little effect on model parameters but allowed us to rule out correlations between period effects and the onset of COVID-19. The error term (ε_{it}) is robust to heteroskedasticity.

Equation (1)

$$Y_{it} = \beta_0 + \alpha_0 CovidEra \times (\beta_1 Days + \beta_2 Days^2 + \beta_3 Days^3) + \beta_4 medRxiv + \beta_5 CovidLang + \gamma_{wy} + \delta_{md} + \varepsilon_{it}$$

Next, we estimated separate OLS regressions that allowed us to test whether changes in preprint mentions varied across (a) preprint servers, (b) media outlets focused on different topics, and (c) media outlets of different types. Because preprint servers necessarily represent preprint mentions, we discarded mentions of articles from WoS and collapsed the data so that we could observe counts of preprint mentions by day and identify any changes in these counts among the four servers (RQ2). To identify changes among the four media outlet topics and three outlet types, respectively, we kept the data as described previously, with each row representing a unique media mention of a preprint or WoS article. To identify changes in the share of preprint mentions across the four media outlet topics (RQ3), we focused on the three most prevalent topics in our sample—health and medicine, general news, and science and technology—and an "other" category that included a variety of other topics (e.g., business, lifestyle, explicit point-of-view).

Because we were exploring heterogeneity across servers, topics, and types, we simplified the regression Equation (1) by replacing the linear, quadratic, and cubic $Days$ variables with month-by-year fixed effects (λ_{my} in Equation (2) below). These fixed effects control for time trends non-parametrically in a similar way as in Equation (1) but without the need to directly identify the time effects (i.e., these time effects are partialled from the regression equation as "nuisance parameters"). Our estimation equation for these heterogeneous changes therefore appears as follows:

Equation (2)

$$Y_{it} = \beta_0 + \beta_4 medRxiv + \Sigma^J_{j=1}\alpha_j \times \beta_5 CovidEra + \Sigma^J_{j=1}\alpha_j \times \beta_6 CovidLang + \lambda_{my} + \gamma_{wy} + \delta_{md} + \varepsilon_{it}$$

where the key difference is that we identify changes in the pandemic era with and without COVID-19-related titles ($\alpha_j \times \beta_5$ and $\alpha_j \times \beta_6$, respectively) for the four preprint servers

(j=1 through J=4), four outlet topics (j=1 through J=4), and three outlet types (j=1 through J=3).

7.5. Results

7.5.1. Has the Share of Preprint Coverage in the Media Increased During the COVID-19 Pandemic?

Our models suggest that the annual number and share of preprint mentions increased slowly from 2014–2019, then increased dramatically in 2020–2021 (Table 7.2, Figure 7.1). However, even during the pandemic period, preprint mentions made up only a small subset of media coverage of research, at less than 5% of all mentions of research. We also saw evidence of a shift in which servers received the most attention during the pandemic. Before the pandemic, most mentions of preprints cited preprints posted to arXiv or SSRN; yet during the pandemic, bioRxiv and medRxiv became the most frequently mentioned servers.

Table 7.2.   Number and Share of Preprint Mentions

Year	Total WoS	Total	arXiv	SSRN	bioRxiv	medRxiv	Total
2014	98,580	753	.34%	.41%	.01%	N/A	.76%
2015	122,641	1,263	.42%	.56%	.04%	N/A	1.02%
2016	192,414	2,115	.44%	.56%	.09%	N/A	1.09%
2017	214,714	2,412	.42%	.60%	.09%	N/A	1.11%
2018	218,946	2,597	.48%	.58%	.12%	N/A	1.17%
2019	231,503	3,275	.55%	.67%	.16%	.01%	1.39%
2020	279,737	12,484	.46%	.56%	.85%	2.40%	4.27%
2021[*]	127,998	6,129	.50%	.29%	1.27%	2.51%	4.57%
Total	1,486,533	31,028					
% of all research mentions			.46%	.55%	.35%	.68%	2.04%
% of all preprint mentions			22.62%	26.93%	16.95%	33.49%	100%

[*] partial year

144

Figure 7.1.   Share of Preprint Mentions Per Day
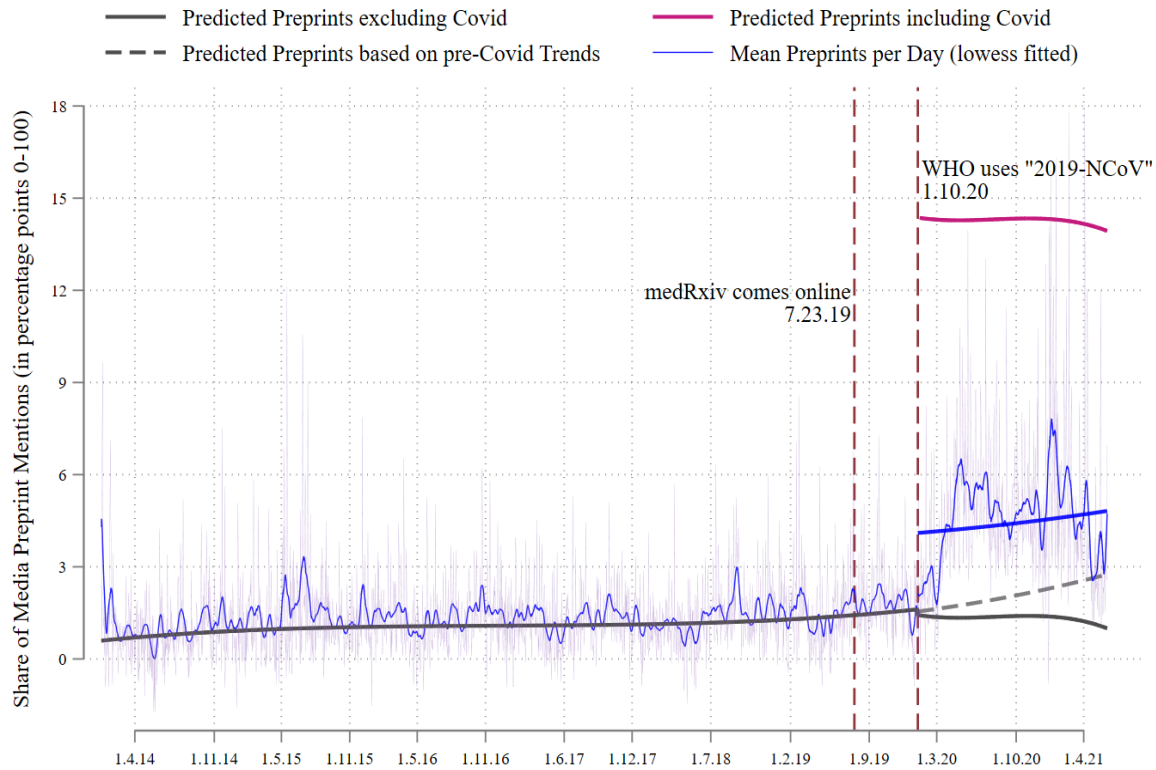
NB: Figure shows the average proportion of preprint mentions in the media per day beginning Jan 1, 2014, and ending June 3, 2021. The fluctuating faded purple line plots residualized mean share of preprint mentions per day, controlling for week-of-year effects (e.g., first week of 2014, second week of 2014, etc.) and day-by-month effects (e.g., Tuesdays in January); the fluctuating blue line is the local linear regression (lowess) fitted line of those data. The solid gray line is the predicted share of daily preprint mentions, with prediction based on a 3rd-order polynomial function, controlling for week-of-year effects and day-of-month effects. We estimated an intercept shift for the period before COVID-19 and after medRxiv was introduced on July 23, 2019, and an intercept shift for mentions of preprints with titles that include COVID-19-related language (e.g., "novel coronavirus" or a related term). The solid fuchsia line represents this last effect and is the estimated change in mean preprint mentions per day among all COVID-19-related mentions of research (preprints and WoS publications). The dashed gray line is the predicted share of daily preprint mentions based on trends observed in the period prior to the emergence of COVID-19. The solid blue line describes the proportion of preprint mentions in the COVID-19 era and is the weighted average of the fuchsia and gray lines. See Equation 1 for details.

With respect to medRxiv preprints, we found that the onset of COVID-19 increased the share of preprint mentions in the media, beyond any increase due to the launch of the server in 2019. Specifically, we estimate that, prior to the introduction of medRxiv and COVID-19, the share of preprints mentioned in the media was increasing at a glacial pace (an *annual* rate of .21 percentage points; p-value<.000; 95% CI [.13– .29]; see solid gray line, Figure 7.1). When medRxiv was introduced, the share of preprint mentions did not change (estimated decrease=.005 percentage points; p-value=.957; 95%

CI [-.17–.16]). In contrast, the share of preprint mentions increased by an estimated 2.58 percentage points after the onset of the pandemic (p-value<.000; 95% CI [2.45–2.70]; see solid blue line). This significant but modest increase applied to all preprint mentions, but masks large differences in the proportion of preprint mentions between COVID-19-related and non-COVID-19-related research during the pandemic.

Indeed, our model strongly suggests that preprints played a far greater role in media coverage of COVID-19 specifically than in coverage of other topics. This can be seen from the "COVID-19" line (in fuchsia) in Figure 7.1, which represents the estimated share of preprint mentions among all the mentions of COVID-19-related research (i.e., both preprints and WoS articles that included COVID-19-related language in the title). We estimated an increase in these COVID-19-related preprint mentions of 12.94 percentage points (p-value<.000; 95% CI [12.84–13.04]), a large increase relative to predicted preprint mentions based on pre-COVID-19 trends (gray dotted line). We explore coverage of non-COVID-19 preprints in more detail in Section 7.5.2.

We further tested whether any changes in the share of preprint mentions seen during the pandemic could be linked to changes in mentions of WoS research during this period. We implemented this test by comparing growth rates of media mentions for preprints and WoS research over time. Given that preprint mentions comprised only about 2 percent of all mentions in our sample and to place preprint and WoS mentions on a common y-axis, we plotted preprint and WoS mentions as growth rates. Growth rates for preprint and WoS mentions were each calculated using the total number of mentions in the first 28 days of our data beginning with Sunday (i.e., January 5, 2014). These mentions in the first 28 days comprised our "base rate," and the total number of mentions in each sequential 28 days were then scaled by that base rate.

Here, we find that the rise in the share of preprint mentions that took place during the pandemic was not simply an artifact of a decrease in WoS mentions. As can be seen from Figure 7.2, WoS mentions increased by about 2.3 percentage points between May 2014 to September 2019, and this pace of growth remained relatively unchanged after COVID-19 began and started to garner media attention. In contrast, preprint mentions

had increased by about 5.7-fold by the time of the WHO's announcement about "2019-nCoV" in January 2020, but skyrocketed to a 30-fold increase at the height of the pandemic in May 2020. This figure thus shows that the increase in the proportion of preprint mentions during the pandemic era was driven almost entirely by an increased number of preprint mentions and not a decrease in the number of WoS mentions.

Figure 7.2.   Growth Rates of Mentions for Preprints and Web of Science (WoS) Articles Over Time
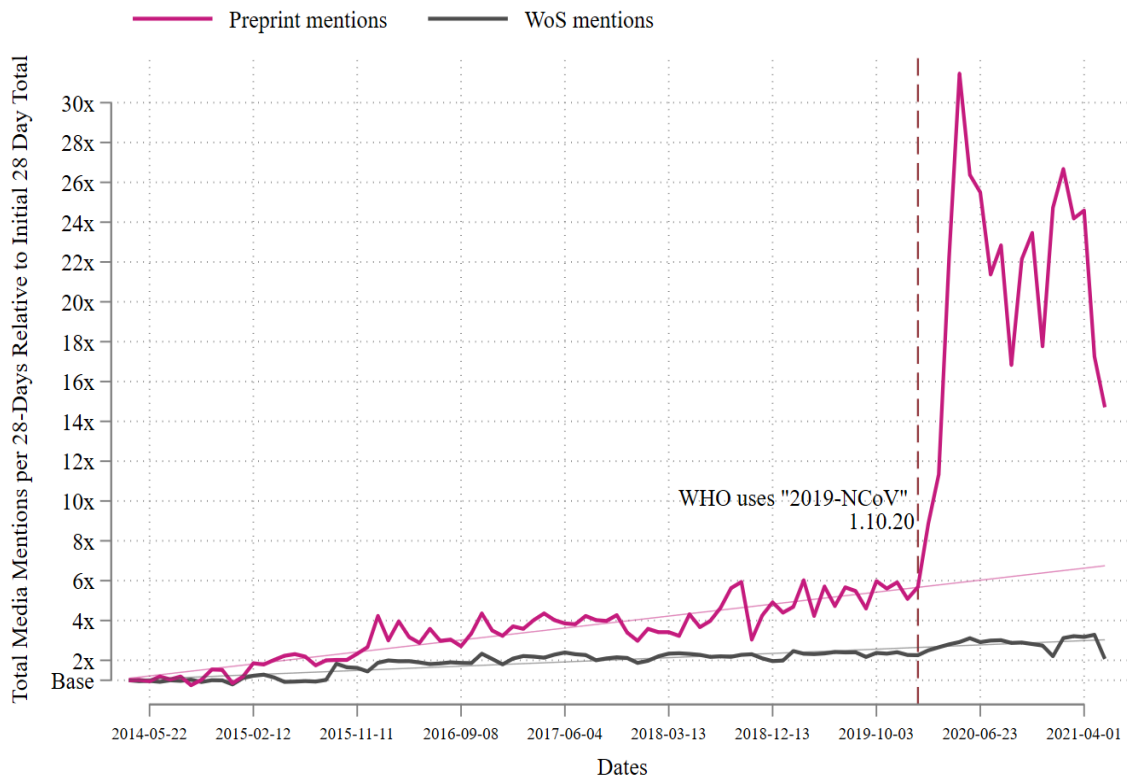
NB: Figure shows the number of preprint and Web of Science (WoS) mentions in the media per 28 days beginning the first 28 days of March 2, 2014, and ending June 3, 2021. We select the first 28 days starting with March 2, 2014, for stylistic reasons, as preprint mentions declined slightly between January 2014 and March 2014; however, starting on January 1 does not change any of the findings we discuss below. Because preprint mentions only comprise about two percent of all media mentions in our data and to put these counts on a common y-axis, we scale monthly (28 day) preprint and WoS mentions by the number of mentions for preprints and WoS, respectively, by the initial number of mentions in the first 28 days of our sample beginning March 2, 2014. Thus, subsequent monthly mentions are relative to this base period. For example, a 28-day media mention count of "2x" means that media mentions in that 28-day period were two times larger than media mention counts from March 2, 2014 to March 29, 2014 (i.e., the initial 28 day period). The fuchsia and gray lines indicate 28-day preprint and WoS media mentions, respectively, in this relative metric.

7.5.2. Do Changes in Media Coverage Of COVID-19-Related Preprints Extend to Coverage of Preprints on Other Topics?

Our results suggest that the onset of the pandemic not only increased media attention to COVID-19-related preprints but may have also decreased attention to preprints on other topics. Among all research that excluded COVID-19-related language (solid gray line, Figure 7.1), we found that the share of preprint mentions during the pandemic decreased by .18 percentage points, although this decrease was not significant (p-value=.129; 95% CI [-.42–.05]). Model-based estimates suggest that by June 3, 2021, if the pandemic had not occurred, we would have expected the share of preprint mentions to be 2.58 percentage points (dashed gray line, Figure 7.1); yet the observed share of non-COVID-19-related preprint mentions comprised only .86 percentage points of all media mentions, a difference of 1.71 percentage points from what would have been expected (p-value<.000; 95% CI [1.13–2.31]). This last result suggests that the pandemic may have shifted media attention away from preprints about non-COVID-19-related topics by a modest amount. In effect, our results suggest that COVID-19-related preprint mentions eclipsed pre-pandemic preprint mentions.

Looking at the number of preprint mentions by server, we observed that there was no increase in non-COVID-19-related preprint mentions in the pandemic for any server (Figure 7.3). All point estimates were trivially small—about .7 to 1.8 fewer mentions per day, on average—and not statistically significantly different from zero (p-values range from .217 to .699). For articles that included COVID-19-related language in the titles, there was an average increase in daily media mentions of bioRxiv and medRxiv preprints—of 6.2 (p-value<.000; 95% CI [5.34 - 6.95]) and 19.2 (p-value<.000; 95% CI [18.25- 2.08]), respectively—and a significant decrease in average daily media mentions for arXiv and SSRN—of -2.7 (p-value<.000; 95% CI [-3.75– -1.68]) and -1.6 (p-value<.000; 95% CI [-2.69– -.51]) mentions per day, on average. In total, for the 511 days in the pandemic era in our sample, this amounted to an increase of about 9,800 total mentions of medRxiv preprints and 3,170 total mentions of bioRxiv preprints.

It is important to note that the declines in mentions of arXiv and SSRN preprints were only significant for preprints that included a COVID-19-related keyword in the title.

That is, the media were less likely to mention preprints from these servers that were about COVID-19; instead, when communicating about pandemic research, they tended to mention bioRxiv or medRxiv preprints. These results could suggest that the media drew on the servers they expected would house the research most relevant to their area of interest. It also suggests that COVID-19-related coverage tended to focus on medical aspects of the pandemic and less so on social or economic aspects.

Figure 7.3.   **Change in the Average Daily Count of Preprint Mentions, by Server**

(a) Excluding COVID-19-related Language   (b) Including COVID-19-related Language
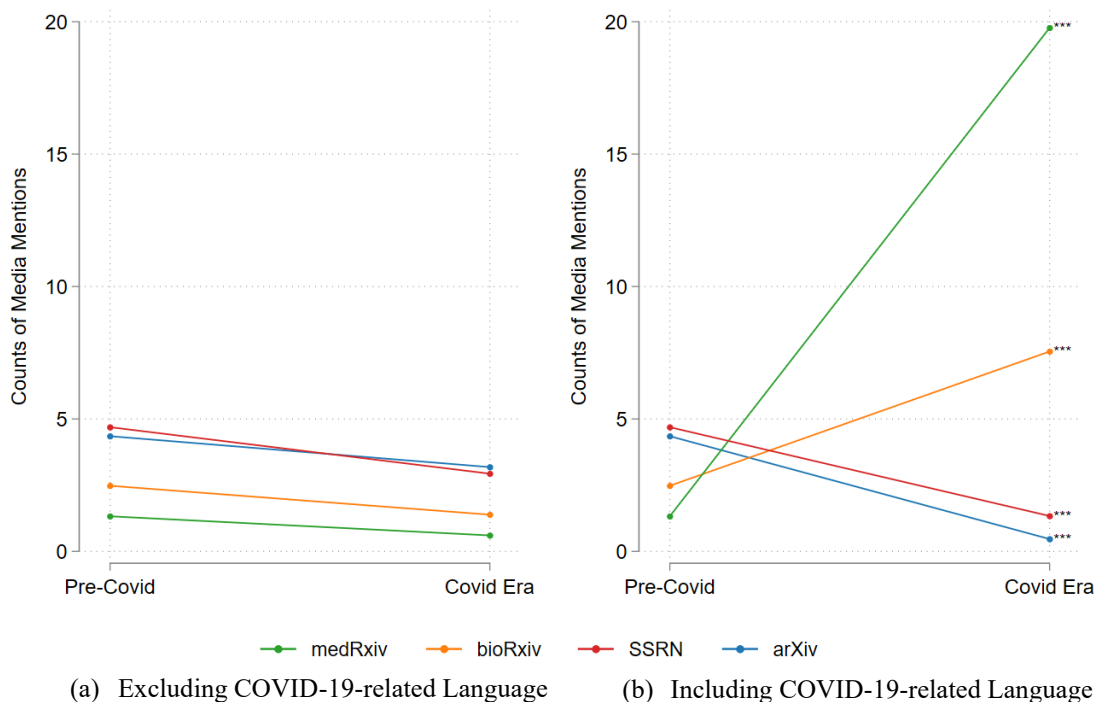
NB: Model parameters are from Equations (2). Statistical significance was determined based on the test of whether pandemic era counts were different from pre-pandemic counts for mentions of preprints with titles that excluded COVID-19-related language (panel a) and included COVID-19-related language (panel b). Key: * 10% significance; ** 5% significance; *** 1% significance

7.5.3. Have Changes in Media Coverage of Preprints Occurred Similarly Across Media Outlets?

Finally, we tested how preprint mentions changed across media outlets with four different topical foci (i.e., general news, science and technology, health and medicine, other) or of different types (i.e., legacy, peripheral, or non-journalism). For mentions of COVID-19-related research, we found that outlets focused on all four topic categories increased their preprint coverage dramatically during the pandemic, but to different

extents. Increases ranged from 8.3 percentage points (science and technology) to 15.6 percentage points (health and medicine) and were all statistically significant (p-value<.000 for all coefficients) (Figure 7.4). Changes in the share of mentions for non-COVID-19-related preprints were trivial, with only the "other" category seeing a small but statistically significant increase (.9 percentage points).

Figure 7.4.   Change in the Average Daily Share of Preprint Mentions, by Topic and Outlet
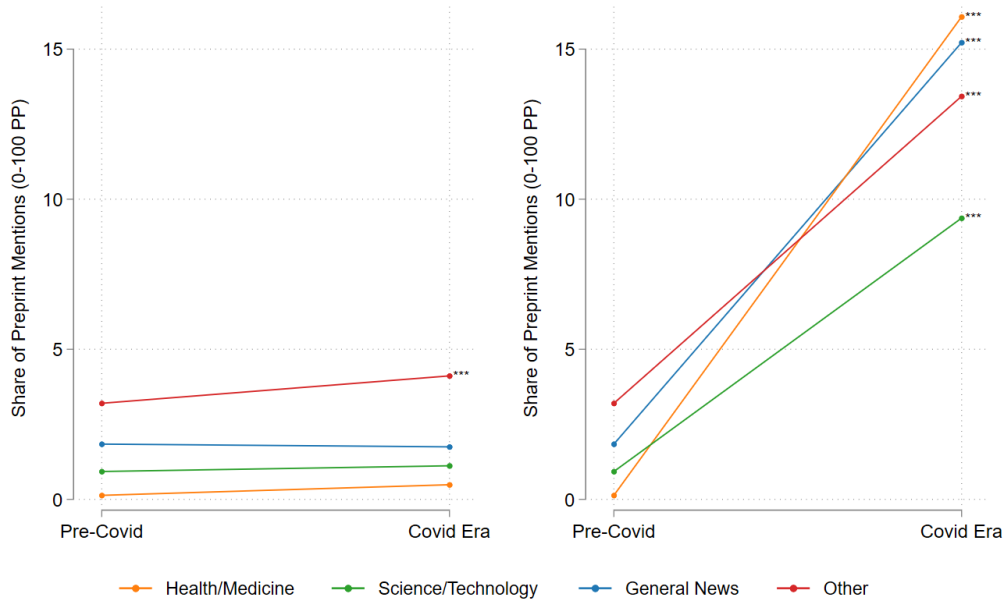
4a. Media Outlet Topics

(a) Excluding COVID-19-related Language   (b) Including COVID-19-related Language
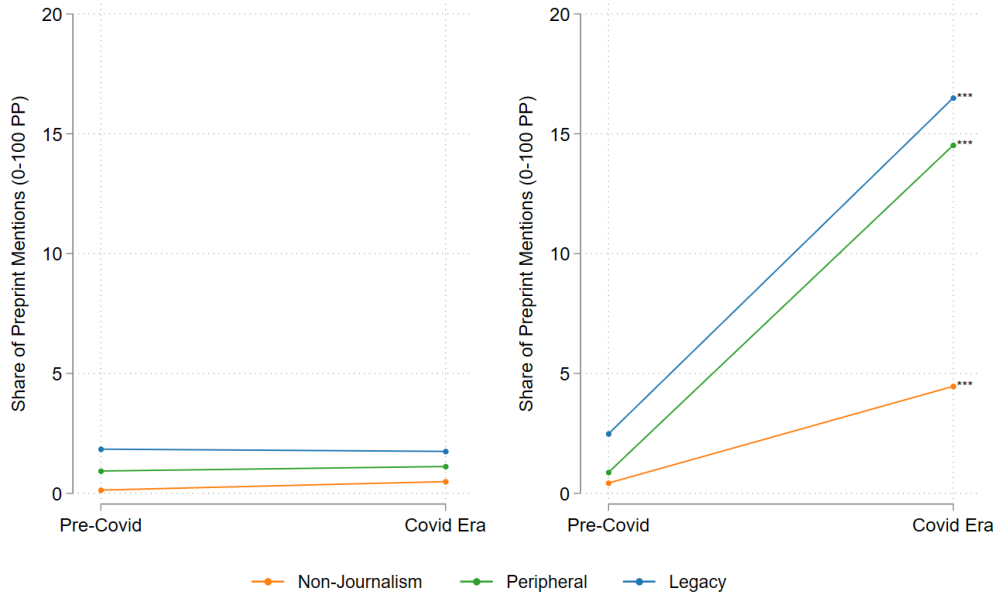
4b. Media Outlet Types

(c) Excluding COVID-19-related Language   (d) Including COVID-19-related Language

NB: Model parameters are from Equations (2). Statistical significance was determined by testing whether pre-pandemic share of preprint media mentions was different from the share seen during the pandemic, both among mentions of research with titles that excluded COVID-19-related language (panel A) and those that included COVID-19-related language (panel B). Key: * 10% significance; ** 5% significance; *** 1% significance

Similarly, none of the outlet types (i.e., legacy, peripheral, non-journalism) saw a statistically significant increase in the share of preprint mentions of non-COVID-19-related articles, and the coefficients themselves were trivially small, never reaching 1 percentage point. However, just as with the topic-based data, all three outlet types increased the share of mentions of COVID-19-related preprints after the WHO announcement in 2020 (estimates ranged from 4 to 14 percentage points for non-journalism and legacy outlet types, respectively).

Finally, to provide a better sense of the nature of the outlets that frequently relied on preprints, we identified the 25 media outlets whose coverage included the largest share of research mentions in general (i.e., mentions of preprints and WoS outputs) and calculated their share of preprint mentions both before and during the COVID-19 era (Table 7.3). The list represents about 75% of all media mentions in our sample and includes a mix of legacy media, such as *BBC News* and the *New York Times*, and peripheral outlets, such as *Reason* and *The Conversation*. Several non-journalism outlets also appear on the list, mostly services such as *EurekAlert!* and *Newswise*, which do not publish original articles but distribute science press releases (many of which include mentions of new research). Among outlets that tended to cover a high proportion of preprints in general, the US libertarian magazine *Reason* stood out, mentioning approximately one preprint for every three WoS outputs—far more than any other outlet in our sample prior to the COVID-19 pandemic. Interestingly, the outlet's share of mentions decreased slightly during the pandemic, from 27% to 24%. Among the outlets that saw the largest increase in their share of preprint mentions, the peripheral health and medicine outlet *News Medical* topped the list, with essentially no preprint mentions before the pandemic but a share of 43% during the pandemic. Several major legacy general news outlets, such as *BBC News,* the *Daily Mail,* the *New York Times*, and the *Guardian*, also saw notable increases in preprint coverage, moving from minimal use of preprints to covering about one preprint for every four or five mentions of research. Although some specialized science and technology outlets (e.g., S*cientific American, Phys.org*) increased their coverage of preprints during the COVID-19 era, these increases tended to be less pronounced than those seen among the major general news outlets.

Table 7.3. Largest 25 Media Outlets Based on Mentions and the Share of Mentions That Include Preprints

	Outlet's Share of All Research Mentions	Outlet's Share of Preprint Mentions	
		Pre-pandemic Era	Pandemic Era
BBC News	1.75%	1.69%	21.85%
Business Insider	2.51%	2.61%	17.45%
Business Insider Australia	1.37%	2.03%	16.32%
Daily Mail	2.07%	1.45%	22.24%
EurekAlert!	1.55%	.24%	2.83%
Forbes	6.37%	9.94%	12.37%
Gizmodo	1.00%	3.33%	14.83%
MedicalXpress	2.42%	.19%	7.75%
New Scientist	1.09%	4.15%	2.84%
New York Times	8.12%	3.69%	23.32%
Newswise	1.28%	.60%	6.98%
Phys.org	3.86%	.99%	5.63%
Quartz	1.47%	4.93%	16.38%
Reason	2.03%	26.83%	24.01%
Salon	1.25%	4.27%	17.27%
Science/AAAS	.98%	2.85%	33.62%
Scientific American	1.02%	2.13%	17.17%
The Atlantic	1.57%	6.48%	23.82%
The Conversation	6.84%	1.75%	9.76%
The Guardian	1.88%	2.01%	2.56%
Medical News	8.73%	.30%	42.70%
Times of India	1.03%	.99%	11.96%
Vox	1.60%	4.79%	19.23%
Washington Post	3.16%	4.66%	13.68%
Yahoo! News	11.44%	1.57%	14.27%

NB: Top 25 outlets shown based on their share of mentions of Web of Science outputs and preprints, representing about 75% of all mentions in our sample. Column 2 (Outlet's Share of All Research Mentions) shows each outlet's share of all mentions of Web of Science outputs and preprints (i.e., number of preprints and WoS research for the outlet divided by total number of preprints and WoS mentions in our sample). Columns 3 and 4 (Outlet's Share of Preprint Mentions) shows the share of each outlet's mentions of preprints (i.e., number of preprint mentions for the outlet divided by total number of preprint mentions in our sample) prior to COVID-19 and the share of each outlet's mentions for preprints during COVID-19. Grayscale conditional formatting is based on column 2 alone and then columns 3 and 4 jointly. Columns do not sum to 100% because only the top 25 outlets are shown.

7.6. Discussion

It has been argued that preprint coverage during the pandemic constituted a break from journalism norms and a paradigm shift in how emergent research is reported on and shared with the public (Burke, 2021; Makri, 2021). Using longitudinal data from the Web of Science (WoS) and four preprint servers, this study sought to establish whether, in what ways, and to what extent this is the case. By identifying how the volume and nature of preprint media coverage has changed over time and what role the pandemic has played in this change, our study makes an important contribution to our understanding of journalists' use of preprints—a topic about which much has been written, but very little is actually known.

A key finding from our analysis is that the volume of preprint media coverage increased by roughly fourfold in the pandemic period, a clear break from the slight but steady upward trend that preceded it. Virtually all of this increase was driven by coverage of COVID-19-related preprints, with little change in coverage of preprints on other topics. Although coverage of peer reviewed research continued to exceed preprint coverage—even during the height of the crisis—the growth in coverage of preprints seen during this period may imply a shift in journalistic norms and practices, including a changing outlook on preliminary, unvetted research and its reporting.

At the same time, however, we observed a slight (but nonsignificant) decrease in coverage of non-COVID-19-related preprints during the pandemic. This lack of coverage of non-COVID-19-related preprints may simply be the result of outsized media attention to COVID-19 in general (i.e., not just COVID-19-related preprints), which may have

come at the expense of coverage on other topics. Yet, it could also indicate that the surge in preprint coverage observed during the pandemic was a temporary change—a break from established norms that journalists made to cover a rapidly evolving crisis, rather than a true shift in practice. More research is needed to assess the degree to which increases in preprint coverage will persist in the coming years, as media outlets and scientists turn their attention away from COVID-19 and toward other issues.

Interestingly, the sharp rise in preprint coverage seen during the pandemic was most pronounced for health and medical outlets, which appear to have been resistant to covering preprints until relatively recently. While outlets specializing in other topics, such as science and technology, covered preprints at least occasionally before the pandemic, our findings suggest that, for health and medical outlets, the crisis created something closer to the "paradigm shift" described by journalists in previous research (Fleerackers et al., 2022a). Preprints were barely mentioned in health and medical outlets up until 2019—even after medRxiv was launched—but become a frequent source of coverage in these outlets after 2020, particularly in media stories about COVID-19. Again, more research is needed to assess whether this trend will continue beyond the pandemic.

The factors that motivated health and medical journalists to adapt their practices during COVID-19 also remain unclear. While the medical nature of the crisis likely played a primary role, at least some of this shift could be linked to a parallel shift in preprint use among health and medical scholars themselves. Like journalists, researchers in these areas have historically been hesitant to post or cite unreviewed research (Flanagin et al., 2020; Maslove, 2018), but became active users of preprints during the pandemic (Fraser et al., 2021; Waltman et al., 2021). Since journalists who report on research rely heavily on interviews with scientific experts (Schultz, 2023), changing attitudes toward preprints among medical scientists would likely affect reporting practices on medical and related issues. It is possible, in other words, that the uptake of preprints by medical and health outlets reflects the growing acceptance of preprints within the medical and health sciences. This may also be true of preprint-based journalism more broadly, as preprint adoption also grew during the study period (Nane et

al., 2023). Waltman et al. (2021) report that the number of preprints in 2020 was about 150% larger than the number of preprints in 2015, while Penfold and Polka (2020)—working with data from PubMed and 10 preprint servers—found that the number of biology preprints increased almost tenfold between 2013 and 2019 (from .24% to 2.36%). However, just because more preprints are becoming available doesn't mean journalists will automatically cover them. By covering preprint science, journalists may—potentially—be adapting their own norms to follow those of scientists working in the disciplines they report on. It is also possible that journalistic norms in terms of preprint coverage are changing as journalists are increasingly pressured to attract reader attention away from competing outlets. In other words, the rapid and competitive nature of the media landscape may encourage journalists to use preprints even outside the pandemic context—and thus get an 'edge' over other media outlets, as suggested in previous research (Fleerackers et al., 2022a).

In terms of outlet types, we found that both traditional, legacy outlets (e.g., *New York Times*) and peripheral media outlets (e.g., *News Medical*) were covering preprints to some extent before the pandemic, but greatly increased this coverage during the crisis. The similar pattern seen for the two outlet types is surprising, as peripheral media outlets are often conceptualized as following different norms, ethics, and practices than legacy media and as being less beholden to professional guidelines, such as those that urge journalists to avoid covering unreviewed research (Froke et al., 2020). Our findings thus align with previous scholarship which has suggested that the boundaries between legacy and peripheral journalism are blurring and that categorizing outlets this way may no longer be meaningful (Deuze & Witschge, 2018; Witschge et al., 2019). While more research is needed, it is possible that such blurring boundaries are especially likely in contexts where professional guidelines and best practices are still emerging, such as when reporting on preprints (Van Schalkwyk & Dudek, 2022a). Future studies could explore whether the similarities we observed in preprint coverage among peripheral and legacy outlets also apply to larger and more diverse outlet samples, or to other situations in which journalistic practices are rapidly evolving.

Collectively, our findings provide some of the first evidence that journalists are increasingly using preprints—at least in some areas—and that the pandemic has greatly accelerated this use. However, this conclusion should be considered alongside several limitations. First, there are known challenges of working with Altmetric data to identify media coverage of research, particularly in languages other than English (see Ortega, 2020a, for a review). We have attempted to mitigate these challenges by working with a predefined set of English-language media outlets, as recommended in previous research (Fleerackers et al., 2022d). Yet, while the restricted nature of our sample of outlets is a strength of this study, it is also a limitation, as the patterns we observed among these 94 outlets may not apply to those that less frequently report on research or do so in different languages. Relatedly, an increasing number of regional preprint servers are coming online, which offer spaces for authors to share preprints that are relevant to their own geographic context, in languages other than English (e.g., SciELO preprints, AfricArXiv, Jxiv). These servers may become preferred sources for media outlets publishing non-English content. Replicating our findings with a larger set of outlets and servers, or through complementary data gathering methods would be a fruitful avenue for future studies.

We also aimed to make our findings more robust by contextualizing any increases in preprint media coverage alongside changes in coverage of peer reviewed research during the same time period. To do so, we relied on Web of Science data, which is biased towards studies from scientific, technical, and medical disciplines and published in English-language journals from the Global North (Alperin et al., 2014; Mongeon & Paul-Hus, 2016). Given our study's focus on English-language media outlets, the impact of the language bias is likely minimal (i.e., it is relatively unlikely that a journalist working for an English-language outlet would cover non-English research). However, the disciplinary and geographic biases are limitations of our study that should be kept in mind when interpreting the results.

Finally, the nature of our data only enabled us to explore changes in preprint media coverage from 2014 through the first year and a half of the pandemic, leaving many questions unanswered about what the future will bring. Chief among these is

157

whether, or to what degree, the changes in journalists' use of preprints we observed were the result of a crisis response or point to a broader shift in reporting practices. We hope that scholars will build on our findings to provide further insight into whether the preprint coverage seen during COVID-19 will persist long-term.

7.7. Contribution Statement

I participated during all stages of the development of this paper and provided an overall contribution greater than that of any co-author. I developed the concept for the study and contributed to obtaining the funding, with assistance from Juan Pablo Alperin. I worked with Alperin to gather and filter the data and develop the study design. I performed the descriptive statistical analyses, with input from Alperin and Kenneth Shores. Shores led the other statistical analyses, with input from me and Alperin. I led writing of the initial draft, with assistance from all co-authors. All authors contributed to revising the draft.

7.8. Copyright Statement

7.9. Data Availability

Preprint and WoS mention data for this study can be accessed via the Harvard Dataverse at https://dataverse.harvard.edu/ with the doi: 10.7910/DVN/ZHQUFD. Scripts used to analyze the data can be accessed via Zenodo at https://zenodo.org with the doi: NODO.8125008.

7.10. Funding

7.11. Competing Interests

The authors have declared that no competing interests exist.

7.12. Acknowledgements

Chapter 8.

Integration of Findings: Reporting on COVID-19 Preprints as (Semi-) Post-Normal Science Communication

8.1. Abstract

This chapter uses a woven narrative to integrate the findings of the three studies that comprise this dissertation with a goal of understanding whether the preprint-based journalism seen during the pandemic relied on 'post-normal science communication' practices or established journalistic norms for reporting on research. It structures this synthesis using a framework for examining emergent journalistic practices across three stages of news production: access/observation, selecting/filtering, and editing/processing. It also considers factors that motivate and constrain the use of these practices, including the role of the post-normal COVID-19 context itself. The results suggest that journalists working for diverse media outlets have used preprints occasionally since at least 2014, but that the pandemic increased this use—specifically within health and medical journalism. Preprints appeal to journalists because of their timeliness, accessibility, and relevance but raise concerns about misinformation. To find and access preprints, journalists use a mix of active and passive strategies. However, they find it challenging to verify them and rely on a combination of normal and post-normal practices to do so. These include intuitive judgement, triangulation with other evidence, skeptical reading, and seeking input from unaffiliated experts through a process that resembles academic peer review. Although journalists feel it is important to communicate the unvetted nature of preprints, they do not always do so in practice. Often, preprints are simply referred to as "research" or "studies" or via uncontextualized hyperlinks. Collectively, the synthesis suggests that journalists' use of preprints during COVID-19 was only semi-post-normal—a combination of emergent and established practices for reporting on research.

Keywords: post-normal science communication; woven narrative; preprints; journalism; COVID-19; science news

8.2. Introduction

This dissertation aimed to understand why journalists use preprints (RQ1), how they find, vet, and communicate about them (RQ2), whether these practices diverge from established journalistic norms (RQ3), and what role, if any, COVID-19 has played in shaping journalists' use of preprints (RQ4). More broadly, I sought to assess whether journalists' use of preprints during the pandemic can be understood as *post-normal science communication* (PNSC), defined as the novel communication practices that can emerge when decision making is urgent, public stakes are high, values are in dispute, and scientific uncertainty abounds (Brüggemann et al., 2020). I have pursued this overarching goal through three interconnected studies and a theoretical framework that allows researchers to analyze PNSC practices across three stages of news production (adapted from Brüggemann et al., 2020; Domingo et al., 2008). This framework, described in detail in Chapter 3, requires five steps, which the dissertation addresses as follows:

1. *Classify* the situation to assess whether it has post-normal characteristics (Chapter 3);
2. *Examine* how actors (i.e., journalists) have reacted to the situation (i.e., their use of PNSC practices; detailed in Chapters 5–7 and summarized in this chapter).
3. *Compare* this reaction to journalists' practices in 'normal' communication contexts (Chapter 3 and this chapter).
4. *Explain* what might be causing any divergences from the norm (this chapter).
5. *Consider* implications for the future of journalism and society (Chapter 9).

In this chapter, I use a woven narrative approach to integrate the qualitative and quantitative findings of the three studies (Fetters et al., 2013) and synthesize what they reveal about how journalists have reacted to the surge of COVID-19-related preprints seen during the pandemic (i.e., Step 2 of the framework). Specifically, I provide a concept-by-concept overview (Fetters et al., 2013) of the findings, structured around the concepts outlined in Domingo et al.'s (2008) framework that are most relevant to my research questions: the *constraining and motivating factors* that shape journalists' use of

preprints (RQ1), the practices they use to *access/observe* (i.e., find) them, *select/filter* for the most newsworthy and trustworthy among them, and *edit/process* them (i.e., describe the research in their stories) (RQ2). I also consider the role of the COVID-19 pandemic as an additional factor that may have shaped journalists' use of preprints (RQ4), which may help to explain what might be causing any divergences from their normal reporting practices (i.e., Step 4 of the framework). Where possible, I assess the "fit" of data integration by examining the degree to which findings from each study confirm, expand on, or conflict with one another, and how they compare to the results from other studies of preprint-based journalism which emerged during the writing of this dissertation (Fetters et al., 2013).

To complete Step 3 of the framework, I compare the motivations, constraints, and practices journalists used to cover preprints during the pandemic to those seen in 'normal' communication contexts. To do so, I return to journalists' established motivations, constraints, and practices for covering peer reviewed research—detailed in Chapter 3—and use them as a benchmark. In the final chapter of this dissertation, I explore what these emerging practices may mean for the future of journalism, scholarly communication, and society, completing the fifth and final step of the framework.

8.3.   Journalists in Diverse Contexts Use Preprints

While not an explicit aim of this dissertation, the three studies provide some of the first evidence that journalists *do* use preprints in their reporting—both within and beyond the pandemic context (as discussed further in Section 8.7). Every journalist in Study 1 reported that they had covered a preprint at least once before, with some drawing on them heavily; this was the case even though journalists were recruited to participate in the study because of their use of research in general (i.e., including peer reviewed research, not preprints specifically). Study 2 found that diverse media outlets published preprint-based stories early in the COVID-19 crisis, including legacy organizations but also peripheral actors, including aggregators, blogs, niche publications, and research amplifiers. Finally, Study 3 found that preprints have been a small but growing part of journalism since at least 2014, and that they have received coverage in both legacy and

peripheral media outlets specializing in science and technology as well as less obvious topics, such as business, lifestyle, and explicit point-of-view.

These findings are supported by those of other studies that were conducted during the completion of this dissertation. In Massarani and colleagues' (2021b) global survey, more than half of science journalists (55%) said they used preprint articles in their stories. The same was true for the Brazilian journalists interviewed in Massarani et al.'s (2021c) qualitative study. Similarly, 36% of the US health and science journalists surveyed by Schultz (2023) said that they found it acceptable to cite a preprint. Studies conducted in Brazil, Germany, the US, the UK, and South Africa have contributed further evidence that preprints make headlines, at least occasionally, in both peripheral and legacy outlets (Jung et al., 2021; Kousha & Thelwall, 2020; Massarani & Neves, 2022; Molldrem et al., 2021; T. Oliveira et al., 2021; Sebbah et al., 2022; Simons & Schniedermann, 2023; Van Schalkwyk & Dudek, 2022a; van Schalkwyk et al., 2020; Waltman et al., 2021). Although most other studies on preprints in journalism have focused on coverage of COVID-19 preprints, there is evidence to support the finding from Study 3 that non-COVID-19-related preprints have also received coverage (albeit at a far smaller scale)—both during and before the pandemic (Besançon et al., 2021; Fraser et al., 2020, 2021; Simons & Schniedermann, 2023). That is, preprints *are* and have long been a part of journalism—just one that has received almost no scholarly attention until recently.

What is notable in the studies that comprise this dissertation—and across this emerging body of literature more broadly—is that preprints are not only used by one type of journalist working at one kind of media outlet but are a source of evidence that receives coverage across the media ecosystem, at least during crisis contexts. Although there were variations in the frequency with which different media outlets used preprints in Studies 2–3 (Chapters 6–7), there were no consistent patterns in how or how often legacy vs peripheral outlets covered preprints. While some peripheral outlets consistently communicated the preliminary or unvetted nature of the research, others did so less than half the time. However, this variety in communication practices was also seen among legacy outlets—suggesting there were more differences within these two categories than between them. Likewise, journalists in Study 1 (Chapter 5) described similar motivations

and practices for finding, vetting, and communication preprints, regardless of their beat, status as a freelance or staff writer, or the nature of the media outlets they worked for. These findings challenge scholarship suggesting that post-normal journalistic practices are more likely to occur within "new types of journalism" (Brüggemann, 2017, p. 4) and that innovation in journalism is often driven by peripheral actors (Maares & Hanusch, 2022). If anything, Study 3 (Chapter 7) suggests that legacy outlets may be *more* active in covering preprints than peripheral outlets. This may be because legacy outlets such as the *New York Times* are among the most well-resourced in the media landscape (Newman et al., 2022), potentially enabling them to retain and support specialized health or science journalists in ways that are unaffordable to other outlets.

8.4. Motivations to Cover Preprints

8.4.1. Accessibility

In Study 1, several journalists noted that they were motivated to use preprints because of the lack of financial barriers. In some ways, this finding is unsurprising, given that preprints are free to access and use, while many journal articles are not (Piwowar et al., 2018). Still, the finding extends previous research documenting the financial barriers that prevent journalists from accessing research in normal contexts (Boss et al., 2022; Gesualdo et al., 2020; Hinnant et al., 2017; Ordway, 2022; Schultz, 2023). It illuminates how, in post-normal contexts, common constraints for reporting on peer reviewed research can act as motivations for using other types of evidence, such as preprints.

Some journalists were also motivated to use preprints for accessibility-related reasons that depart from those identified in prior research. For example, one journalist felt that restricting access to journal articles was unethical, given that many of these articles are publicly funded, and thus preferred to use preprints when possible. Another noted that scientists are usually more excited to discuss research when the findings are "fresh" and are thus often more readily available for interviews about their preprints than about their journal publications, although this was not a common perspective among the journalists. Existing research has noted the frustrations journalists experience in

attempting to interview scientists, who often fail to understand the rapid pace of journalism and do not make themselves available in time to meet news production deadlines (Dijkstra et al., 2015). However, previous studies have not yet considered how this constraint might encourage journalists to turn to preprints to identify accessible experts. The finding provides additional evidence that 'normal' constraints associated with using research can sometimes act as 'post-normal' motivations to explore alternative sources of evidence.

8.4.2. Timeliness

Related to the above, journalists in Study 1 reported that timeliness was a key factor motivating their use of preprint research, especially during a context as urgent as a pandemic. This motivation can be considered 'normal,' as timeliness is often listed among the news values that health and science journalists consider when deciding which (peer reviewed) studies to cover (Badenschier & Wormer, 2012; Dunwoody, 2021; Leask et al., 2010; Rosen et al., 2016).

However, just as with accessibility, this finding suggests that preprint research may be attractive to journalists because it enables them to overcome commonly experienced constraints for reporting on peer reviewed research. Specifically, several journalists noted that the often-lengthy peer review process can mean relevant research is not available when it could be most beneficial, whereas preprints are more immediately accessible. This finding is supported by previous research suggesting that academic and journalistic timelines are poorly aligned and can create challenges for both parties (Dijkstra et al., 2015; Fleerackers & Nguyen, in press), as well as by Massarani and Neves's (2022) conclusion that "when dealing with a health emergency, preprints enable science time to catch up with journalism time" (p. 965; see also Johansson et al., 2018). Other studies have similarly found that the urgent need for timely information was a key motivator for journalists to use preprints (Sebbah et al., 2022), further corroborating the results of this dissertation. As such, the timeliness benefit journalists associate with preprints can be considered both 'normal' and 'post-normal.'

8.4.3. Relevance

Finally, many journalists noted that preprints, especially those about COVID-19, were highly relevant to society and that covering them had the potential to benefit their audiences. Again, this motivation to cover preprints aligns with well-established news values for reporting on research (Badenschier & Wormer, 2012; Rosen et al., 2016), as well as with journalism's broader commitment to serve the public (Kovach & Rosenstiel, 2021). Especially during crisis contexts such as the pandemic (Perreault & Perreault, 2021), covering timely, relevant news is key to journalism's core function within society (Kovach & Rosenstiel, 2021). Protecting and empowering the public through news that directly applies to their lives is thus another motivation to report on preprints that closely mirrors 'normal' science journalism.

8.5. Constraints in Covering Preprints

8.5.1. Fears About Misinformation

Many journalists we interviewed worried that reporting on preprints could mean disseminating false, flawed, or inaccurate evidence. This finding has been corroborated by other studies, including those conducted in other geographic and cultural contexts (Massarani et al., 2021b, 2021c). Journalists' fear about the potential for preprints to spread misinformation represents a marked departure from normal constraints and motivations for reporting on research, as journalists typically see research as *helpful* for debunking misleading claims and, more broadly, bolstering the accuracy of their stories (Wihbey, 2017). In this respect, preprints appear to fundamentally challenge how journalists typically perceive and use research—not as accurate, trustworthy, confirmed 'facts' but as uncertain and potentially fallible information (Murcott, 2009; Murcott & Williams, 2013).

The finding that journalists are concerned about preprints contributing to misinformation provides some of the first evidence to support Peters' (2016) proposal that reporting on "science in the making" challenges journalists' conceptions of research as "a definite truth on which rational policy-making can be based" (Peters, 2016, writing

in Dunwoody et al., 2018, p. 2). It supports previous research demonstrating the importance of accuracy for journalists, who fear errors in coverage could damage their professional reputation and, by extension, their cultural authority (Hettinga, 2013). The finding also aligns with Brüggeman's (2017) assertion that the high levels of uncertainty that characterize post-normal science contexts call traditional notions of journalistic objectivity into question, generating new journalistic practices. Yet, Brüggeman (2017) also argued that this questioning, in turn, encourages "reflexivity through public meta-discourse among journalists and their critics" (p. 3). As will be discussed in Section 8.6.2, very few journalists in Study 1 noted that peer review can be a problematic and flawed quality control mechanism, suggesting that the reflexivity Brüggeman (2017) predicted did not take place for most journalists in this particular post-normal context.

8.5.2. Verification Barriers

Closely related to misinformation concerns, this dissertation found that journalists were often hesitant to use preprints because they found them challenging to vet. This finding adds support to a growing body of evidence suggesting that journalists face challenges in verifying research, even in normal communication contexts (e.g., Crettaz von Roten, 2018; Fleerackers & Nguyen, in press; Murcott & Williams, 2013). Yet this finding also extends existing research, as journalists interviewed in studies of normal science journalism have seldom reported that their verification challenges limit or prevent their use of research. Arguably this is because journalists are normally able to avoid verifying scientific evidence because they can put their trust in peer review and journal reputation (Forsyth et al., 2012; Oransky, 2022; St Lewis, 2011), which is not possible with preprint research. Indeed, journalists in Study 1 noted that they preferred covering journal articles because they felt that the peer review process provided an extra "safety net" preventing the dissemination of flawed evidence. This finding is supported by evidence from Massarani et al. (2021b) and Makri (2021), who similarly found that journalists preferred to avoid preprints because they have not been peer reviewed. In this sense, the challenge of verification that constrained journalists' use of unreviewed studies aligns with what would be expected in normal journalism (Conrad, 1999). Again, however, the finding also demonstrates how post-normal science contexts can invert the

167

relationship between motivations and constraints, such that the very qualities that attract journalists to cover peer reviewed research can discourage them from using preprints.

8.5.3. Strategic Constraints and Motivations

What is less clear from the findings of this dissertation is whether preprints challenge or support journalists' strategic use of research to signal credibility. If, as suggested above, journalists perceive preprints to be an uncertain and potentially misleading information source, they would theoretically also see them as less useful than peer reviewed articles for bolstering their own authority and trustworthiness. However, as shown in Study 2, some journalists do appear to use these studies to signal credibility, by framing preprints as "research" or "studies," without mentioning their preliminary, unreviewed, unvetted, preprint nature. Use of relatively broad terms such as these could also be a defensive strategy, as it allows journalists to avoid mentioning a paper's unreviewed status without misrepresenting it, as preprints are technically also "research."

In addition, journalists frequently referred to preprints using only a hyperlink, with no description of what the link pointed to. Bray (2019) has suggested that referencing research in this way is another form of portraying the findings as established truths—as textbook rather than frontier science (Claassen, 2020). This strategy could also be a way of shifting the challenging responsibility of ascertaining what is 'true' to the audience, who, at least in theory, could click through to read and vet the preprint in question. In this respect, hyperlink-only references could play a similar role as expert quotes, in that they allow journalists to include potentially problematic or incorrect evidence without taking responsibility for any inaccuracies (Dunwoody, 1999). As Karlsson and Sjøvaag (2018) suggest, this strategic use of hyperlinks may be problematic in the long run, as:

> …readers might lose trust in news sites that direct them to compromised sources of information. The news organization might also lose the valuable attention of users if the destination of the external hyperlink provides them with equal or better information (p. 2)

Through this lens, the wide variability in how journalists across different outlets framed the research in Study 2 could reflect different answers to a core question journalists must answer when communicating about preprints: Is it better to highlight the unreviewed and thus potentially misleading nature of the research, or frame the preprint as just another research study? The former strategy has the benefit of protecting the journalist from a potential loss of credibility should the results of the preprint fail to hold up in the long term. This strategy could also protect audiences from being misled and enable the journalist to appear transparent—an emerging journalistic norm (Eide, 2017; Karlsson & Clerwall, 2018).

The second strategy, however, may be appealing because it allows journalists to use the preprint to enhance the credibility of their stories by demonstrating that their claims are supported by objective, trustworthy sources (cf. Carlson, 2009, 2020). Also, as journalists noted in Study 1, describing preprints as "research" or "studies" is potentially more understandable to audiences than noting they are "preprints" or "not yet peer reviewed." This explanation is supported by previous studies that have documented journalists' fears that communicating scientific uncertainty will make audiences feel less confident about the research findings (Maier et al., 2016) and their tendency to simplify science to make it accessible to their audiences (McKinnon et al., 2019). More recent research suggests that disclosing a preprint's unreviewed status does not appear to influence audience members' perceptions of the certainty of the research or the journalist (Ratcliff et al., 2023). This may be because, as suggested by journalists in Study 1, most members of the public lack understanding of what the term *preprint* means, even when accompanied by a brief explanation (Cataldo et al., 2023; Cyr et al., 2021; Ratcliff et al., 2023; Wingen et al., 2022).

8.6. Practices for Reporting on Preprint Research

8.6.1. Accessing/Observing Preprint Research

This dissertation found that journalists use a mix of active and passive strategies to find preprint research, including searching through preprint servers, monitoring

scientists on social media, learning about them through interviews with researchers, and referencing press releases and other science public relations (PR) materials. Several of these strategies for finding research can be considered normal, including the use of science PR, expert interviews, and social media (e.g., De Dobbelaer et al., 2018; Deprez & Van Leuven, 2018; Granado, 2011; Schultz, 2023; Wihbey, 2017). However, seeking out preprints via dedicated preprint servers is a novel practice and suggests that at least some journalists may be motivated to cover preprints *because* they are preprints. That is, some journalists do not simply encounter these studies while searching for other (peer reviewed) literature or talking to experts, but actively seek them out.

To my knowledge, only one other study has examined how journalists find preprints (Sebbah et al., 2022). This study provides additional evidence that journalists—in this case, those working in French-speaking Canada—monitor social media for potentially newsworthy preprints. However, the study also found that journalists had covered some COVID-19 preprints because they were asked to do so by their editors (Sebbah et al., 2022), an access/observation strategy that we did not identify in our research. It is unclear whether this practice is specific to French Canadian journalists or was simply not mentioned by the journalists we interviewed. It is possible that language barriers played a role, as access/observation resources used by the English-speaking journalists in our research (e.g., press releases, research roundups from Science Media Centres) may not be accessible to journalists working in other languages. More research is needed to ascertain whether this is the case and, if so, what alternative strategies editors and journalists working in different languages use to identify preprints.

8.6.2. Selecting/Filtering Preprint Research

Preprint Selection

Some of the practices for selecting preprints identified in this dissertation suggest a resistance among journalists to abandon their established norms. For example, several journalists in Study 1 remarked that they only covered preprints in the absence of relevant journal articles, explaining that "Peer reviewed research is good. Obviously, it means that people have looked at it, and it's fit for publication" (J5, unpublished data) and that they

170

"would never choose a preprint over a peer reviewed article if [they] had the option" (J6, unpublished data). Other journalists described a preference for covering research that had been peer reviewed, highly cited, or published in a known journal (e.g., *Nature*).

This finding has since been replicated among French Canadian journalists, some of whom said they were "rather old school in believing that what is not published does not exist" and regretted that they had abandoned this perspective and covered preprints during the pandemic (Sebbah et al., 2022, p. 129, translated from French). Similarly, almost two-thirds of the US journalists surveyed by Schultz (2023) said they would prefer to cite the final, published version of a journal article over an unpublished or unreviewed one. In some ways, journalists' reluctance to cover preprints unless peer reviewed research is unavailable is unsurprising, given their well-established preference for research that has been peer reviewed, cited, and published in a 'top' journal (e.g., Conrad, 1999; Hansen, 1994). This strategy also enables journalists to transfer the challenging decision of what to consider trustworthy to the journal, as discussed above. This finding thus aligns with what would be considered 'normal' journalistic practice.

Other selection strategies were closely tied to the motivating factors described in Section 8.4, with traditional news values such as timeliness and relevance playing a major role in journalists' decisions to cover specific preprints and avoid others. Again, this approach to choosing the most newsworthy preprints closely resembles journalists' normal research selection practices (Badenschier & Wormer, 2012; Dunwoody, 2021). It also aligns with journalistic norms more broadly, as timeliness and public relevance are among the five "ideal-typical" traits that have been described as comprising the core ideology, or culture, of journalism (Deuze, 2017).

However, preprint selection practices also departed from the norm because journalists reported weighing the news value of each study against potential risks to the public should the findings fail to stand up to the scrutiny of peer review. In this respect, the decision to cover a given preprint can be conceptualized as a careful risk-benefit equation, in which the relevance and timeliness of the research is considered alongside possible dangers of covering the study. This balancing act is a marked departure of the

unquestioning "deference" to science that journalists—especially those specialized in health and science—have long been accused of (Blum, 2021; Figdor, 2017; Murcott, 2009). In many respects, the additional skepticism could be considered a sign of high-quality journalism (Sarabipour, 2018; Sarabipour et al., 2018), as several of the journalists we spoke with noted themselves.

Importantly, the studies in this dissertation were conducted in a particular time and context and may not reflect journalists' current selection and filtering practices. Specifically, journalists such as the *New York Times'* Apoorva Mandavilli have noted that they are "being much more selective about which preprints I cover" now that the urgency of the COVID-19 crisis has waned (quoted in Makri, 2021). In this less timely context, Mandavilli based her selection on the relevance of the research but also her familiarity with the authors: "I usually only cover preprints from groups that have a really good reputation for good work" (Makri, 2021). While not a recurring theme in Study 1, two journalists we interviewed similarly described relying on author reputation when selecting preprints. This practice was also found in Sebbah et al.'s (2022) study of French Canadian journalists, as well as in studies of 'normal' science journalism (Conrad, 1999; Lawson, 2021; Van Witsen & Takahashi, 2021). More research is needed to understand how frequently journalists use this practice to filter preprints, and whether they have developed other practices now that COVID-19 is no longer considered a pandemic. I discuss this ripe area for future research further in the following chapter (Section 9.4.1).

Preprint Verification

The journalists we interviewed in Study 1 reported applying many of the same set of verification tools to evaluate preprints as they did for peer reviewed research, but with an extra level of skepticism. These verification practices included evaluating the study's methods and assessing whether the results aligned with findings from other (ideally, peer reviewed) research. Some of the journalists interviewed by Makri (2021) have similarly described preprints as requiring additional caution, providing support for this finding. Further evidence can be gleaned from a content analysis of media coverage of preprints among South African media outlets, which found that peer reviewed studies made up more than a quarter of sources mentioned in the stories (Van Schalkwyk & Dudek,

172

2022a). That is, journalists not only reference the peer reviewed literature to vet preprints, they also include these studies in their coverage—perhaps to enhance the credibility of the story or to provide additional context.

Again, these verification practices could be considered 'normal' in that they align with those expressed by journalists who vetted numbers and statistics in Witsen and Takahashi's (2021) study, as well as with research verification strategies recommended by professional journalism resources, such as the *Associated Press Style Guide* (Froke et al., 2020) and the *Knight Science Journalism Science Editing Handbook* (Blum et al., 2022). The extra skepticism applied to preprints also provides additional evidence that journalists invest more efforts in verifying controversial stories and when using unfamiliar sources (Barnoy & Reich, 2019), extending previous research to a health and science-focused context. However, this finding departs from earlier studies finding that journalists seldom verify large and complex claims (Shapiro et al., 2013) and challenges assertions that "journalists do not tend to pay special attention or exercise more care in covering studies that were not peer reviewed" (Massarani & Neves, 2022, p. 965). It is possible that journalists reported more rigorous preprint verification practices than they typically performed in practice, a known limitation of research relying on self-report measures (Bergen & Labonté, 2020; Jones-Jang et al., 2020). However, more research is needed to assess whether this is the case.

In addition to using an extra level of skepticism, this dissertation found that seeking input from unaffiliated experts was by far the most common strategy journalists used to verify preprints. This finding was recently corroborated by a content analysis of preprint-based stories published in Brazilian, UK, and US legacy media, which found that more than two-thirds of stories mentioning a preprint included an interview with a researcher who was not involved with the study (Massarani & Neves, 2022). Similarly, Van Schalkwyk and Dudek's (2022a) found that quotes from a scientist made up 30% of the sources included in stories mentioning preprints published by South African media outlets, although they did not specify whether the researcher was affiliated with the research. The strategy was also mentioned by journalists who participated in an international survey about the impact of the pandemic on their reporting practices

(Massarani et al., 2021b) as well as by the French Canadian journalists in Sebbah and colleagues' (2022) study. The reliance on expert commentary is perhaps unsurprising, since, as discussed in Chapter 3, this practice has long been used to verify research (i.e., in 'normal' science communication contexts) (Conrad, 1999; Gesualdo et al., 2020; Leask et al., 2010; Lehmkuhl & Peters, 2016). Unlike in traditional journalism, however, journalists who verified preprints in this way described the practice differently, as a form of expedited peer review. It is unclear what distinguished this practice from traditional expert verification, as participants did not outline the nature of this "peer review" in detail. Still, it is notable that these journalists attempted to replicate the established system of external, scientist-led vetting rather than developing their own, continuing a long history of outsourcing the verification of research (Forsyth et al., 2012; Oransky, 2022; St Lewis, 2011) and transferring the responsibility for establishing veracity to a secondary source (Dunwoody, 1999). Again, this finding suggests that journalists were resistant to abandon their normal practices for reporting on research, even in a situation that fundamentally challenged these practices.

It is possible that the additional rigour journalists applied to verifying preprints was related to the highly uncertain early pandemic context, as this was a time characterized by concerns over retractions and research integrity among both scholars and journalists (Abritis et al., 2021; Haelle, 2022; Joseph, 2020; Lee, 2023; Ordway, 2022; Santos-d'Amorim et al., 2021). It may be that these growing concerns about the fallibility of the scholarly publishing system played a role in shaping journalists' perceptions (and corresponding use) of preprints. Specifically, some of the journalists interviewed in Study 1 expressed a nuanced understanding of the flaws of peer review as a quality control mechanism, noting its limitations even as they admitted their reliance on it to verify research. This finding that journalists are aware of the fallibility of peer review has, to my knowledge, not been mentioned in previous research.

8.6.3. Editing/Processing Preprint Research

Referencing Preprints

While Study 1 examined the behind-the-scenes strategies journalists use to cover preprints, Study 2 revealed what this coverage looks like in practice. Our content analysis of more than 450 English-language stories mentioning COVID-19-related preprints found that journalists often referred to these unreviewed studies using vague terms such as "research" or "a study" or did not make it clear that the preprint was a research study at all and instead referred to it using an uncontextualized hyperlink. In other words, journalists' practices for referencing preprints mostly resembled those used to refer to peer reviewed research (De Dobbelaer et al., 2018; Fleerackers et al., 2022d; Matthias et al., 2020), at least in the COVID-19 context. They were less 'post-normal' than might be expected.

This study was the first to document how a long-standing (and often-critiqued) journalistic practice for referencing research also extends to preprints, leaving audiences with little, if any, information about the nature of the evidence they have been presented (Fleerackers et al., 2022b). These findings have since been replicated in other geographic and linguistic contexts, using media outlets that were less prolific in covering preprints than those included in our study. These follow-up studies have added nuance to our findings, showing that journalists around the world reference preprints using abstract terms or hyperlinks, but that the frequency with which they do so varies across countries and outlets. Massarani and Neves (2022) found that about 70% of preprints mentioned in COVID-19-related stories published by three legacy media outlets in the UK, US, and Brazil were hyperlinked. They did not explore whether these hyperlinked studies were also described as "research," but they found that the preprint's methodology was described in about two thirds of cases, suggesting that uncontextualized references to preprints (either via hyperlinks or terms like 'studies') were relatively rare. In contrast, Van Schalkwyk and Dudek (2022a) found that preprint studies were often framed as "research" or "studies" by South African media outlets. They also found that journalists hyperlinked to about 60% of the preprints they mentioned, although this part of Van Schalkwyk and Dudek's analysis was not included in their published paper (Van

175

Schalkwyk & Dudek, 2022b). Similarly, Simons and Schniedermann (2023) found that preprints mentioned in German media stories were "often simply called 'studies'" or were "added via hyperlinks but the anchor text does not mention that the link goes to a preprint" (p. 68). In almost all cases, it was possible to identify which preprint was mentioned, either by following a hyperlink or by searching for key article metadata (e.g., author names, titles, publication dates, DOIs). The authors did not specify how frequent hyperlinking was in practice, nor how often the journalist made it clear that the hyperlink pointed to a research study.

Framing Preprints

This dissertation also sought to understand how journalists communicated the unverified nature of preprint research to their audiences. We found that journalists felt it was important to contextualize and describe any uncertainties associated with preprint findings, for example, by describing caveats, limitations, and study weaknesses, and noting that the research had not yet been peer reviewed. However, these good intentions did not always hold up in practice, as two in five stories in Study 2 did not make it clear that the preprints they cited were unreviewed, preliminary, in need of verification, or a "preprint." The use of these uncertainty framing devices also varied widely across media outlets, suggesting that practices for framing preprint uncertainty are still far from established within the journalistic field. It is unclear whether journalists' other self-reported strategies for framing preprint uncertainty were reflected in their work, as we did not code for mentions of study limitations or weaknesses in Study 2.

Arguably, describing preprints as preliminary is one form of highlighting study weaknesses; yet our content analysis of preprint-based media coverage (Study 2) found that this was the least common of all four uncertainty framing devices journalists used to describe preprints, occurring in about 17% of the stories. This has been corroborated by Van Schalkwyk and Dudek, who found that provisionality surrounding preprints was mentioned in only 16% of cases. In 5% of stories, this provisionality was clearly stated and explained but in the remaining 11% the journalist merely suggested that the results of the preprint should be seen as provisional.

Stating that the research was not peer reviewed or was a preprint was another way of highlighting uncertainty that the journalists in Study 1 described as a best practice. Other studies have found similar results among science journalists in diverse geographic contexts (Massarani et al., 2021b, 2021c; Schultz, 2023). Interestingly, journalists in our study felt that providing such disclosures was important—a theme that recurs across the literature (Massarani et al., 2021b, 2021c; Schultz, 2023). At the same time, journalists did not believe their audiences would understand these disclosures unless they were accompanied by a detailed explanation of the peer review process, a superstition that is supported by an emerging body of research (Cataldo et al., 2023; Cyr et al., 2021; Ratcliff et al., 2023; Wingen et al., 2022). In addition, the results of the content analysis in Study 2 suggest that journalists do not consistently provide these disclosures about preprint status or lack of peer review, as only about 40% of stories mentioning a COVID-19-related preprint noted that the study had not yet been peer reviewed and only 20% noted that it was a preprint. Journalists in Study 2 also seldom mentioned that the preprints they covered needed further verification (about 20% of stories). This framing strategy is similar to mentioning that the research has not been peer reviewed but is potentially more understandable to public audiences—although more research is needed to assess whether this holds true in practice. Collectively, these results suggest that journalists' practices for communicating preprint uncertainty may not always reflect their normative beliefs about the value of doing so.

While it is easy to focus on journalists' failures to be transparent about preprint uncertainty, our findings can also be interpreted in a positive light, as they demonstrate an awareness among journalists of the limitations and uncertainties associated with research, and, for some, a willingness to communicate those uncertainties with their audiences. This is a departure from normal journalistic coverage of research, which, as discussed in Chapter 2, tends to gloss over scientific uncertainties (Guenther et al., 2015) unless they are believed to enhance the news value of the story (Dunwoody et al., 2018; Lehmkul & Peters, 2016). In the case of preprints, it is possible that this need to acknowledge uncertainties is self-protective, a way for journalists to mitigate potential damage to their professional reputation (Hettinga, 2013) and a corresponding loss of trust among audience members, colleagues, or editors if the findings turn out not to hold up during

peer review (cf. Dunwoody, 1999). It could also represent an attempt to be transparent, another strategic ritual for increasing journalism's social authority (Allen, 2008). From a less cynical perspective, journalists may choose to highlight uncertainties to inform and protect their audiences, in line with the 'risk-benefit equation' discussed above. Indeed, transparency about uncertainties is a well-established principle for effective, ethical risk communication (Covello et al., 1989; Covello & Allen, 1988). As scholars and journalists have long called for more critical, contextualized science journalism (Crettaz von Roten, 2018; Figdor, 2017; Murcott, 2009), this finding could arguably be seen as sign of a positive shift in journalism practice. Yet, whether this shift towards more critical coverage extends to other forms of research (e.g., peer reviewed studies, conference papers), and whether it will persist post-pandemic, remains an open question.

Finally, while conducting the content analysis for Study 2, we noted that some stories mentioning preprints also included, or hyperlinked to, descriptions of the peer review process or of scientific publishing more broadly. Although we did not code for these descriptions explicitly, we noted that they sometimes presented nuanced reflections on meta-science topics such as the iterative and self-correcting nature of the research process, strengths and limitations of peer review, and ever-present uncertainty that characterizes all science—not just preprints. Massarani and Neves (2022) provided empirical evidence to support our observations, finding that 11 of 76 stories mentioning preprints also included a description of the preprint or journal publishing process. In contrast, Van Schalkwyk and Dudek did not find a single story that provided an in-depth description of what preprints are or why they should be treated with caution, neither in text nor via a hyperlink (Van Schalkwyk & Dudek, 2022a). While this evidence is mixed and preliminary, it suggests that during the pandemic, at least some journalists moved beyond reporting on study findings to describe the process of science itself—a departure from the norm (Matthias et al., 2020) that could be seen as a positive development in science journalism, especially if it extends to coverage of other topics or other types of research outputs.

8.7. The Role of the Pandemic in Coverage of Preprints

Thus far, the findings suggest that journalists reported on the surge of preprints during the pandemic through a mix of established and emerging practices for finding, verifying, and communicating research. This combination of normal and post-normal practices is in line with Bruggeman et al.'s (2020) conjecture that the novel norms that emerge in PNS contexts "do not necessarily replace the traditional order of science communication…[but] are likely to complement existing science communication practices (p. 2). However, truly understanding the degree to which the practices identified in this dissertation are 'post-normal'—and whether the PNS context of the pandemic is responsible for this departure—requires understanding whether journalists have covered preprints in the past. Study 3 sought to develop this understanding through an analysis of more than seven years of preprint media coverage. We found that the share of English-language media coverage mentioning preprints spiked dramatically after the onset of COVID-19, quickly eclipsing pre-pandemic levels of coverage. This spike occurred across all types of media outlets—including legacy, peripheral, and non-journalistic outlets—and all specializations—including general news and science and technology, but particularly health and medicine. As such, this dissertation provides the first empirical evidence that the coverage of preprints that took place during the early pandemic was a marked departure from pre-pandemic reporting norms—especially for health and medical outlets.

The qualitative data from Study 1 support and add nuance to this finding by describing the diversity of perspectives on preprints among journalists and hinting at what the future might bring for pandemic-based media coverage. Specifically, many journalists reported that the onset of COVID-19 fundamentally changed their view of preprints, causing them to embrace these studies for the first time. For some journalists, this shift was contextual and temporary—an exception made in response to the urgency of the crisis and the lack of timely, relevant peer reviewed evidence available. These journalists did not see themselves (nor their colleagues) using preprints in the future, less pressing contexts. For others, however, the pandemic marked a "paradigm shift" in their

approach to preprints—introducing a "new normal" that they planned to carry forward in their coverage of other, non-crisis-related topics.

The move towards preprints has been corroborated by studies of other journalists in other contexts, many of whom reported turning to preprints for the first time during the pandemic. For example, a survey examining the impact of the pandemic on science journalists in 77 countries found that more than half now used preprints in their coverage, with 10% using preprints as a primary source for reporting on COVID-19 (Massarani et al., 2021b). Similarly, more than half of Brazilian journalists interviewed about their pandemic experiences said they had used preprints, many as a primary source, and some with new reporting practices (Massarani et al., 2021c). French Canadian journalists interviewed by Sebbah et al. (2022) reported that they had always referenced preprints as inspiration for story ideas, but only started covering them because of COVID-19. In addition, a study of German media outlets by Simons and Schniedermann (2023) suggests that the pandemic may have changed how journalists communicate about preprints—as fundamentally uncertain (e.g., preliminary, unreviewed, unverified), rather than timely and accessible evidence. The results of this dissertation contribute to this growing body of evidence suggesting that crises such as a pandemic can, indeed, encourage "longstanding [communication] norms to fray, for both scientists and journalists" (Dunwoody, 2021, p. 20).

While the rapid dissemination of science that preprints make possible has obvious appeal during public health emergencies such as the COVID-19 pandemic (Johansson et al., 2018), this dissertation also presents some emerging evidence that the timeliness advantage of preprints might extend to other, less post-normal contexts. Journalists in Study 1 were not only motivated to use preprints because of the urgency of the crisis. They also noted that reporting on them helped them keep their coverage relevant and allowed them to find exclusive stories and, in doing so, maintain an "edge" over competitors who only cover peer reviewed research. To others, preprints were exciting because they were a way to access "science in motion"—cutting edge discoveries, rather than established (and thus less newsworthy) science (cf. Claassen, 2019; see also Dumas-

Mallet et al., 2018). For still others, preprints were appealing because, unlike many published studies, they are free to access and use.

Perhaps for these reasons, several journalists we interviewed said they had been covering preprints for years and that the pandemic had not changed this in any way. Schultz (2023) similarly found that almost three quarters of US journalists she surveyed were already familiar with preprints before the pandemic. Most also said that COVID-19 had not changed their perceptions of Open Access research, which in this study was defined as including preprints as well as journal publications. Complementing these qualitative findings, Study 3 of this dissertation found that journalists have covered preprints at least occasionally since at least 2014, and that this trend had been increasing at a slow but steady rate in the lead up to the pandemic. Coverage of preprints on other topics remained remarkably stable during the pandemic, experiencing a small and nonsignificant decline as COVID-19 began to take over headlines. While more research is needed, these findings align with journalists' reflections that, "[Preprint coverage] was increasing even before, it's just that the pandemic has really accelerated the pace and visibility of preprints" (Mandavilli, quoted in Makri, 2021, p. 19). They suggest that preprints have a history in journalism and will likely remain a source for some journalists as the pandemic wanes—but perhaps a less prominent one.

8.8. Summary: How "Post-Normal" is Preprint-Based Journalism?

Collectively, the results of this dissertation suggest that journalists' use of preprints during the pandemic represented a mix of established and novel science communication practices, motivations, and constraints. This trend—the blurring of normal and post-normal—recurred in all three studies of the dissertation, as well as in the growing body of research that has replicated our work in diverse geographic and linguistic contexts, at different periods in the pandemic, and among a variety of legacy and peripheral media outlets. It resembles the "merging of the old and new logics of content production" (Mitchelstein & Boczkowski, 2009, p. 570) that took place within

journalism as news first shifted online, demonstrating the sector's ability to innovate in response to change but also its reluctance to abandon longstanding traditions entirely.

Quantitatively, this dissertation found that preprints have been a part of journalism for years but remained marginal until the onset of COVID-19, making such coverage both a new normal and a longstanding trend. Qualitatively, it found that journalists applied a mix of novel and established strategies for finding, selecting, and vetting these fast-moving and unverified pandemic studies. Collectively, the findings integrated above suggest that the media coverage of preprints seen during the pandemic can best be described as *semi*-post-normal science communication—a mix of new and old, innovative and conservative. The results provide additional evidence that post-normal science contexts can encourage communicators to develop novel practices, norms, and roles, even as they continue to rely on those that are already well-established (Brüggemann, 2017; Brüggemann et al., 2020). I consider the implications and future avenues for research suggested by these findings in the following chapter.

Chapter 9.

Discussion: Preprint-Based Journalism in a Changing Digital Communication Ecosystem

9.1. Abstract

This chapter describes the scholarly and practical implications of this dissertation, as well as the questions it raises for future research. By documenting why and how journalists use preprints, and how the COVID-19 pandemic has influenced this use, this dissertation provides some of the first empirical evidence into an aspect of journalism that has important societal implications but has received little scholarly attention until recently. Beyond filling this gap in knowledge, this research contributes to scholarship exploring the blurring and expanding boundaries of journalism and the processes through which new norms become adopted and institutionalized. Theoretically, it validates and extends a framework for understanding the novel science communication practices that can emerge when scientific uncertainty is high, values are in dispute, the need for decision making is urgent, and much is at stake. The research also breaks methodological ground by demonstrating how altmetrics data can be used as an efficient data source for investigating journalists' use of research across the media landscape—not just in science journalism. On a practical level, it provides insights that could be used to guide the development of evidence-based best practices for reporting on preprint research. Collectively, the findings of this dissertation raise important questions that warrant further research, including what the future has in store for preprint-based journalism, how public relations efforts shape journalists' use of these unvetted studies, whether journalists' preprint reporting practices are effective, and how the broader Open Science movement is changing science journalism.

Keywords: science journalism; Open Science; preprints; altmetrics; peripheral actors; innovation

9.2. Introduction

As described in the literature reviewed in Chapter 3 and Chapter 7, scholarship examining journalists' use of preprints before the pandemic was almost nonexistent, comprising mainly anecdotal contributions and studies that examined the topic only tangentially (e.g., Fraser et al., 2019; Sheldon, 2018a, 2018b). This gap had still not been filled when I started working on this dissertation in the early months of the COVID-19 pandemic, despite heavy use of preprints among journalists and scientists (Fraser et al., 2021; Waltman et al., 2021) and claims that "the media [had started] covering them at a rate that far outpaces pre-2020" (Majumder, quoted in Koerth, 2021). The lack of relevant scholarship is surprising, given growing use of preprints among scholars—even before the pandemic (Puebla et al., 2022)—and the potential of these unreviewed studies to support timely, relevant, and evidence-based journalism (Fleerackers et al., 2023a; Sarabipour, 2018). In addition, the lack of scholarship examining this issue means that commonly cited risks about media coverage of preprints have never been investigated, limiting our understanding of how such coverage may contribute to problems that have long plagued science and health journalism, including challenges associated with communicating scientific uncertainty, preventing the spread of scientific misinformation, and maintaining public trust in science and journalism (Caulfield, 2020; Chiarelli et al., 2019b; Glymour et al., 2023; Maslove, 2018; M. Oliveira et al., 2023).

The three studies that comprise this dissertation provide some of the first empirical evidence toward filling these gaps. By documenting why and how journalists use preprints, and how the pandemic has affected this use, they shed light on an overlooked but increasingly common aspect of health and science journalism and address calls for "Further consideration…about the place of preprints and how to counter their possible harm on public discourse" (Caulfield et al., 2021, p. 16). They identify the small but growing role that preprints play in media coverage of science, health, and other topics—highlighting how journalists have adapted to recent changes in scholarly communication introduced by the Open Access (OA) and Open Science (OS) movements and the tensions that have resulted. These studies also show how preprints challenge established journalistic notions of objectivity and scientific 'facts,' pushing some

journalists to reconsider a longstanding reliance on academic expertise and peer review and develop more critical practices for verifying science and communicating the uncertainty inherent within it. More broadly, this dissertation contributes to our understanding of how journalists are navigating a changing digital communication environment, in which both science and journalism are rapidly evolving to meet increasing demands for rapid, reliable, publicly accessible information (Brossard & Scheufele, 2022; Vignoli & Rörden, 2019)—and how post-normal crises such as COVID-19 can accelerate these evolutions.

9.3.   Implications

9.3.1. Scholarly Implications

While building knowledge of journalists' use of preprints is an important end in itself, this dissertation also contributes insights into how and where innovations in journalism practice can emerge and diffuse, contributing to scholarship exploring the blurring and expanding boundaries of journalism (Belair-Gagnon & Holton, 2018; Carlson & Lewis, 2015; Eldridge, 2017b) and the processes through which new norms become adopted and institutionalized (Ryfe, 2019). Specifically, the findings of the three studies suggest that novel journalistic practices do not always emerge at the margins or boundaries of the field but can also be found among the legacy outlets that are believed to represent its "core," in line with some previous research (Belair-Gagnon, 2015; Usher, 2014). In addition, the diversity we identified among the media outlets and journalists who had altered their practices to cover preprints suggests that there is value in investigating multiple sites of journalistic innovation, including those that have historically been overlooked by scholars, such as news aggregators, blogs, niche outlets, and other emergent forms of journalism (Hanusch & Vos, 2020; Lewis, 2020b).

More broadly, this dissertation provides support for recent scholarship arguing that it is necessary to move beyond oversimplified categorizations of media outlets and journalists to truly understand the diverse, fragmented, and evolving nature of journalism today (Maares & Hanusch, 2022; Schapals, 2022; Wahl-Jorgensen & Hanitzsch, 2019).

Like other scholars, we found that the practices and motivations of peripheral actors often resemble those of the core (Coddington, 2020; Schapals, 2022; Schapals et al., 2019), suggesting that theoretical distinctions between the these two types of actors oversimplify the complexity within the journalistic field (Belair-Gagnon et al., 2019; Deuze & Witschge, 2018).

In addition, this dissertation points to how challenges and barriers can spur, rather than prevent, journalistic innovation. This can be seen in the role of the pandemic as an accelerant of preprint-based journalism, as documented in Study 3 (Chapter 7) and discussed by other scholars and journalists during the COVID-19 crisis (Fraser et al., 2021; Koerth, 2021; Makri, 2021). The findings of this dissertation suggest that such challenges do not need to be global catastrophes to encourage journalists to explore new practices. As discussed in the previous chapter, several of the factors that have long constrained journalists in covering peer reviewed studies, such as accessibility and timeliness, also motivated them to begin covering preprints. Meanwhile, motivations to cover peer reviewed research—such as to dispel misinformation or build credibility— became constraints when it came to using preprints. Collectively, these findings offer a novel way of conceptualizing the mounting challenges that face journalists in the digital communication ecosystem: not only as barriers to high quality reporting but also as potential sites of innovation. Investigating other points of tension in journalism through this lens could thus point to evolving journalistic practices which have not yet been explored by scholars and help to identify innovations that may prevent high-quality science journalism from moving from "expendable" (Allan, 2011) to nonexistent.

Theoretically, this dissertation applied and extended Brüggemann et al.'s (2020) framework for understanding the "post-normal science communication" practices that can emerge when "facts [are] uncertain, values in dispute, stakes high and decisions urgent" (Funtowicz & Ravetz, 2020, p. 1). This framework—while potentially applicable to many communication contexts—had been used exclusively in studies of environmental communication and journalism at the time I began my doctoral program (Brüggemann, 2017; Walter et al., 2019). This dissertation provides additional validation of the framework and demonstrates its applicability to another post-normal science

186

communication context: the use of preprints during the COVID-19 pandemic. This context differs from those examined in previous scholarship in both its scope and urgency. Unlike more classic understandings of post-normal science, the pandemic has been described as an all-encompassing condition in society—an aspect of a post-normal 'age' whose impacts extend beyond any specific science issue or topic to influence many aspects of our daily lives (Funtowitz & Ravetz, 2020). The pandemic is also an example of a post-normal context with the highest possible stakes, in which the work of both scientists and journalists had life and death consequences. This dissertation highlights how journalists reacted to this heightened level of urgency and responsibility and, in doing so, demonstrates the applicability of the post-normal science communication framework to contexts whose risks and implications are both greater and more wide-ranging than those envisioned by Funtowitz and Ravetz (1993) three decades ago.

This research also goes further by integrating a second, well-established framework for understanding evolving journalistic practices (Domingo et al., 2008) to guide scholars in completing steps 2–4 of Brüggemann et al.'s (2020) framework: *2) documenting the 'post-normal' practices journalists are using to respond to the post-normal situation, 3) comparing these practices reaction to their 'normal' practices,* and *4) explaining what might be causing the divergences*. As I have demonstrated, the integration of Domingo et al.'s (2008) framework into Brüggemann et al.'s (2020) allows for a structured, systematic examination of normal and post-normal communication practices across each stage of the news production cycle that takes into account the motivating and constraining factors that may encourage journalists to abandon (or adhere to) their well-established norms. Future scholarship could build on and further validate this integrated framework by applying it to other post-normal science contexts or topics that may encourage journalists to adopt new practices or norms, such as artificial intelligence (e.g., ChatGPT) or gene editing (e.g., CRISPR).

Methodologically, this dissertation presents an innovative way to identify and examine coverage of preprints among diverse media outlets. Specifically, it relies on data from the company Altmetric, one of several 'altmetrics' providers that gather mentions of research outputs in blog posts, news stories, tweets, and other digital spaces. Unlike more

187

common methods for identifying science media coverage (i.e., using keyword-based searches; Hansen, 2008), altmetrics data are an efficient way to identify media stories that mention specific research *studies,* rather than scientific *topics* or *issues.* While altmetrics data have their limitations, they are faster than manual methods for identifying science news coverage and enable scholars to do so with a high degree of precision (Fleerackers et al., 2022d).

Altmetrics data are seldom used in studies of journalism or science communication, but, as this dissertation demonstrates, these rich data sources can offer important benefits for researchers in these fields. For example, identifying stories that mention a research output rather than a particular keyword can enable scholars to examine how and how often journalists use academic research as supporting evidence rather than the focus of a story. Keyword-based data collection approaches likely overlook many of these supporting evidence stories (Hansen, 2008), meaning we know very little about how or the extent to which journalists draw on academic knowledge to make sense of societal issues that are not focused on health or science. It is likely that such non-science-focused coverage of research is more common than suggested by existing scholarship. This can be seen in one survey of more than 400 US journalists who use research in their work, which found that these journalists covered a wide range of beats, including economics/business (43%), state/local politics (40%), education (36%), and more (multiple responses possible; Ordway, 2022). For more than a decade, scholars have called for journalism that provides in-depth, critical, evidence-based reporting of issues of public importance (Nisbet & Fahy, 2015; Patterson, 2013; Van Witsen & Takahashi, 2018). Using altmetrics data sources to examine stories that mention academic research offers one way to examine whether and how such 'knowledge-based' journalism takes place beyond dedicated health or science sections.

In addition, altmetrics data sources such as the one used in this dissertation offer a streamlined method for identifying peripheral media outlets that are active disseminators of academic research. Recent scholarship has highlighted the role these outlets can play in communicating science with diverse publics (Barel-Ben David et al., 2020; Ginosar et al., 2022; Hermida et al., 2022; Hermida & Young, 2019), filling some of the gaps left

behind by ongoing declines in specialized science reporting among legacy media (Saari et al., 1998; Schäfer, 2017). This dissertation has underscored just how prolific some of these peripheral outlets can be when it comes to coverage of science. In Study 2, more than half of the top 15 outlets that covered preprint research during the early months of the pandemic would be considered peripheral. In Study 3, peripheral outlets comprised more than a third of outlets that frequently cover peer reviewed research. More broadly, peripheral media outlets are playing a growing role in journalism (Majid, 2023) but are still understudied compared to major, legacy media outlets (Hanusch & Vos, 2020; Lewis, 2020b). Altmetrics data offers one way to identify these outlets and begin to unpack the complex question of what counts as "journalism" in our increasingly fragmented and participatory digital media ecosystem (Eldridge, 2017a; Hermida, 2019; Wahl-Jorgensen & Hanitzsch, 2019).

9.3.2. Practical Implications

With growing support for Open Access to research knowledge, a growing number of scholars have embraced preprints as a form of scholarly communication (Puebla et al., 2022). COVID-19 further established their use by demonstrating their value for enabling rapid and unfettered access to research knowledge—for both science and society (Fraser et al., 2021; Kwon, 2021). Their use among scholars is likely to become even more mainstream in the coming years, as funders and governments introduce mandates requiring that research outputs be made publicly available (e.g., Government of Canada, 2023; Sayer, 2022) and journals and platforms experiment with new forms of public and post-publication peer review (Berenbaum, 2023; Eisen et al., 2022). As societies grapple with rapidly evolving science-related issues such as climate change and artificial intelligence, journalists need to learn to report on unreviewed studies to deliver on their public service mission—even when doing so challenges their established conventions for finding, verifying, and communicating science.

Despite their growing role in scholarly communication, best practices for reporting on preprints remain scarce, perhaps because journalists have long been discouraged from using them. This dissertation has revealed some of the consequences of

this lack of guidance, including concerns among journalists about how to assess the trustworthiness of preprints and how to frame their unreviewed status in ways that audiences will understand. While journalists were motivated to use preprint research during the pandemic to provide relevant, timely evidence to help audiences navigate a deadly virus, they often failed to communicate the preliminary and unverified nature of this evidence. The inconsistency in practices for verifying and reporting on preprints is concerning, given that several misleading and flawed preprints received extensive media coverage during the pandemic (see Majumder & Mandl, 2020; Massarani & Neves, 2022; van Schalkwyk et al., 2020 for overviews of these cases) and that these stories were often further amplified by social media users (Fleerackers et al., 2022c). Moreover, preprints appear to have long been used in journalism (as seen in Study 3 of this dissertation) and were covered with even less transparency about their unvetted nature before COVID-19 (Simons & Schniedermann, 2023). As one journalist put it in Study 1, they are a "dirty secret" in journalism (J2, unpublished quote)—one with the potential to benefit publics but also cause great harm if not treated with care (Caulfield et al., 2021).

Beyond simply identifying a need for best practices or guidelines, this dissertation provides evidence that could be used to develop the guidelines themselves. Specifically, it documents the aspects of covering preprints which are most challenging to journalists, including how to vet them effectively, assess whether they could misinform audiences, and communicate about their unreviewed nature in transparent and understandable ways. Addressing these key areas of concern should be a priority when developing guidelines to support journalists (and other science communicators) in covering preprints effectively. In addition, the studies in this dissertation provide examples of strategies that journalists already use to find, select, verify, and communicate about preprints, which could guide the development of these best practices. Professional journalism and communication organizations could make use of these findings through an "assets-based approach, identifying what is going right in a community in order to amplify it, as opposed to focusing on what is going wrong in a community and fixing it" (Rogers et al., 2019, p. 427). This would involve assessing the benefits and risks of the preprint reporting practices described in this dissertation and supporting wider use of those that appear most useful. In particular, organizations may wish to investigate the practices used by

journalists who frequently report on research (e.g., the highly experienced science journalists interviewed in Study 1), as research suggests these journalists are more likely to have greater preprint knowledge than others (Schultz, 2023). Ideally, any assessments of emerging practices would be guided by further research examining their effectiveness and impacts on news audiences, as discussed further in Section 9.3.3 below.

While supporting journalists in covering preprints is an important next step, journalists are not the only actors responsible for effective, ethical, and accurate communication of science (Figdor, 2017; West & Bergstrom, 2021). Rather, journalists, scholars, public relations professionals, journals, and preprint servers must work together to maximize the societal benefits and minimize the risks of public dissemination of research knowledge. Such collaboration is perhaps especially important in the case of preprints, which, as unreviewed research studies, have not yet benefited from the input of other scholars that journal articles presumably receive during peer review. As such, I agree with Glymour et al.'s (2023) suggestion that, "Cooperation between journalists and researchers is needed to ensure adequate scientific communication: The burden of clearly contextualizing preprint findings falls upon both researchers and journalists" (p. 3).

Roy and Edwards (2022) and Kardos et al. (2023) have already proposed several ways in which researchers could share this burden. These include first assessing whether the potential benefits of posting the preprint outweigh any potential risks, being "extremely cautious" about ensuring data and results are accurate and that results are appropriately communicated, choosing words with care when writing press releases or lay summaries, and clearly communicating that the research has not yet been accepted by a scholarly journal. The findings of this dissertation build on these recommendations by illuminating the importance of accepting interview requests about preprints, especially those authored by other scholars. As discussed in Study 1, journalists rely heavily on interviews with experts to verify and decide whether to cover preprints, treating these interviews like an expedited form of peer review. To ensure accurate and balanced coverage of preprints, scholars should approach such interviews as they would a formal peer review request—that is, by carving out time to read the study (in as much depth as possible given the journalist's deadline); identify its strengths, weaknesses, and flaws;

assess whether the conclusions are valid; and consider their wider significance. Unlike in traditional journal peer review, these informal peer review reports must emphasize the potential implications for society, rather than science (Elliott, 2022b) and do so on a highly protracted timeline in a way that journalists can understand. However, fulfilling these interview requests will likely be challenging for many researchers, who are already too time-poor to complete academic peer reviews on much longer deadlines (Publons, 2018) and lack clear incentives for engaging in publicly beneficial forms of scholarship (Alperin et al., 2019; Calice et al., 2022; Rose et al., 2020). To support scholars in supporting journalists, universities and research institutions must thus join faculty members' efforts by rewarding them for engaging with the media. Ideally, journalists and their editors could contribute to these efforts by providing researchers with additional time to vet research thoroughly, although this may be challenging—or even impossible—given the rapid pace of today's digital news production cycle.

Finally, this dissertation demonstrated that many of the challenges and problematic practices journalists used to report on preprints also apply to coverage of research in 'normal' communication contexts. For example, journalists felt they lacked the skills and expertise needed to verify preprints, with some relying on gut feeling and instinct instead of more rigorous methods. This tendency has been noted in studies of verification of peer reviewed research (Hansen, 1994), as well as journalistic verification in general (Diekerhof & Bakker, 2012). Journalists' lack of skill in verifying numbers and statistics also aligns with previous, non-preprint-focused research (Harrison, 2016; Nguyen, 2018), suggesting that providing additional training to journalists in areas such as research methods, statistics, or scholarly communication could benefit (science) journalism more broadly. Journalism schools could also encourage students to develop expertise in the subject area(s) most relevant to their future beats (e.g., biomedicine, astronomy, psychology, etc.), as has been recommended by other scholars (Brüggemann, 2017; Nisbet & Fahy, 2015).

Likewise, journalism education would benefit from teaching students 'process knowledge' about how research is produced and communicated (Patterson, 2013; Van Witsen & Takahashi, 2018). Developing such skills and expertise is essential for future

journalists who plan to use research, given that the effectiveness of peer review as a quality control mechanism remains an open question (Jefferson et al., 2002, 2007; Malički et al., 2022). It is also possible "that the scientist-journalist relationship might change for the better if journalists became more scientifically informed than in the past" (Van Witsen & Takahashi, 2018, p. 727), potentially resulting in more critical, in-depth, and accurate science journalism (Moorhead et al., 2023).

9.4. Future Directions for Research

As discussed above, this dissertation fills several important gaps in knowledge, contributing to both journalism scholarship and practice. At the same time, however, it raises important questions that warrant further research: about the future of preprint-based journalism, the role of public relations efforts in journalists' use of these unvetted studies, the effectiveness of journalists' preprint reporting practices, and the broader relationship between OS and science journalism.

9.4.1. The Future of Preprint-Based Journalism

Both Studies 1 and 3 hinted that preprints will continue to play a role in journalism beyond the COVID-19 pandemic, but how prominent that role will be remains an open question. In Study 1, some journalists said that the pandemic had radically and permanently changed their perspective on preprints, creating a "complete paradigm shift" (J12) in their willingness to use these studies as sources in their reporting. Scholars have made similar claims that preprints represent a long-term "cultural shift" in journalism (Fraser et al., 2021, p. 18; Stollorz, 2021; Van Schalkwyk & Dudek, 2022a). However, other journalists in Study 1 saw the shift towards preprints as temporary, an exception to the rule made in the urgency of the pandemic. Similarly, Study 3 found that the proportion of media coverage that incorporates preprints had been slowly increasing for years but remained a tiny part of all media coverage until the onset of the pandemic. Even during the COVID-19 period, the proportion of research-based media coverage that included preprints remained small—less than 5%—and this increase from pre-pandemic levels of coverage was entirely driven by coverage of COVID-19-

193

related preprints. Yet, because the study only focused on media coverage up to summer 2021 (i.e., the middle of the second year of the pandemic), it is unclear whether this increase in coverage has persisted despite decreased media attention to COVID-19—especially among the health and medicine-focused media outlets, which almost never covered preprints pre-pandemic. Future research could examine the extent to which journalists continue to use preprints, and whether their practices for doing so differ from those described in the crisis context I have focused on in this dissertation. Doing so would provide further insight into how public emergencies may alter journalistic routines and how or whether any of these novel journalistic practices become established norms.

9.4.2. The Role of Science PR

Another ripe area for research relates to the role of press release distribution services and other forms of *science public relations* (PR) (Weingart, 2022) in preprint-based journalism. While not a focus of this dissertation, several journalists in Study 1 noted that they had encountered preprints via press releases, and science PR services such as *EurekAlert!* and *Newswise* were well-represented in the list of 'non-journalism' outlets that shared preprints in Study 3. Similarly, about 6% of the media stories mentioning COVID-19-related preprints in Study 2 were press releases that had been republished. Although (science) journalists' reliance on science PR is well-documented (Lemke et al., 2021; Sumner et al., 2016), the use of preprints in press releases is novel and surprising. Services such as *EurekAlert!* or *Newswise* are closely intertwined with the journal publishing industry, reliant on the high volume of press releases they receive from interdisciplinary 'mega-journals' such as *PLOS ONE, PNAS,* and *Nature* (Lemke et al., 2021; Orduña-Malea & Costas, 2023). In contrast to these 'top' journals, which have significant resources to contribute to promoting their research, preprint servers are often under-resourced and reliant on volunteer labour (Mallapaty, 2020) and thus unlikely to create their own press releases. Doing so would also conflict with the disclaimers some

servers now feature on their websites, which warn that preprints should not "be reported in news media as established information."[46]

University communications officers are also key sources of academic press releases (Moorhead et al., 2023); yet, they have similarly been reluctant to promote preprints, even during the pandemic (Bollen & Nelissen, 2020). Finally, services such as Science Media Centres, which provide journalists with information and materials about new studies, have historically been hesitant to distribute preprint research (F. Fox, 2018; Sheldon, 2018a, 2018b) but appear to have become more lenient during the pandemic (Broer, 2020; Broer & Pröschel, 2022; F. Fox, 2020). Additional research is needed to understand the nature of the actors who promote preprints through science PR, their motivations and communication strategies for doing so, and how the resulting press materials shape the nature of the media coverage of these unvetted studies. Doing so would provide insights into the increasingly tight coupling between science journalism and science PR and the implications of this mutual reliance for society.

9.4.3. Effectiveness of Journalists' Practices for Covering Preprints

Very little is known about whether the practices journalists have adopted to find, verify, and communicate about preprints support high quality journalism that is useful and understandable to the public. The results of this dissertation thus raise multiple unanswered questions that warrant additional research. For example: Is "sifting" through preprint servers for interesting content an effective way to identify research that is trustworthy or relevant enough to cover? Is the "toolkit for looking at a [peer reviewed] paper and evaluating its newsworthiness" [J6] also appropriate for vetting preprints? If not, what additional qualities of the research should journalists consider? Does framing preprint research as "unreviewed," "preliminary," or "in need of further verification" help audiences understand the nature of the evidence or support them in making informed decisions about their health and wellbeing? Answering these and other, related questions is essential given that existing guidelines for covering preprints recommend some of

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[46] https://connect.medrxiv.org/relate/content/181

these practices, despite a lack of evidence to support their effectiveness (see Supplementary Materials in Van Schalkwyk & Dudek, 2022a for an overview).

Among these untested strategies, the journalist-driven, expedited peer review system described by journalists in Study 1 is perhaps the most important to investigate further. While this strategy aligns with best practices for high quality science journalism (e.g., Blum et al., 2022), it is also potentially problematic. Specifically, this expedited peer review may not be an effective way to verify preprints, as the 'reviewers' are asked to work on a highly protracted timeline, are likely aware that their name may appear alongside their comments in the news story, and may not realize that their commentary is meant to function as a review report. Future research could examine the degree to which the informal commentary journalists solicit from scientists helps prevent problematic preprints from receiving media coverage or ensures that the resulting coverage takes a critical, rather than celebratory, stance.

A related, and perhaps more fundamental, area for exploration is the changing relationship between journalism and peer review. A growing body of scholarship has highlighted the fallible and biased nature of the traditional journal review system (Csiszar, 2016; Jefferson et al., 2002) and the scholarly community has responded by experimenting with novel forms of peer review, such as open review and post-publication review (Berenbaum, 2023; Eisen et al., 2022; Tennant et al., 2017). It is unclear how journalists and their audiences understand the nature of peer review and how these recent experiments may be changing it. More research is thus needed to assess how journalists perceive and use peer review as an indicator of sound science (Berenbaum, 2023; Glymour et al., 2023) and what this means for how science is communicated.

9.4.4. Journalists' Broader Engagement with Open Science

As discussed in Chapter 2, preprints are just one facet of a larger movement within academia that seeks to provide free and unfettered access to both the process and outputs of science. Support for this OS movement has been building for years but accelerated rapidly during the COVID-19 pandemic (Waltman et al., 2021). Scholars now not only share their work as preprints but also publish other OS outputs, such as OA

papers, datasets, software, code, protocols, and peer review reports. Journalism reporting on these publicly available outputs has the potential to further 'open' science to the public by highlighting and contextualizing their societal implications and communicating their relevance in ways that non-specialists can understand (Arbuckle, 2021; Elliott & Resnik, 2019). OS outputs, for their part, can also support high quality journalism, as they enable journalists to access research knowledge without having to circumvent paywalls or request data from scientists or journals—saving them considerable time.

Such OS-based journalism also has the potential to do damage, if, for example, it relies on sensitive datasets that put marginalized research participants at risk (J. Fox et al., 2021) or perpetuates existing imbalances in the types of scientists who typically make headlines (Joubert et al., 2022; Ross-Hellauer, 2022). This potential for great benefit but also great harm underscores the importance of exploring the changing relationship between OS and (science) journalism. However, so far, very few studies have explored the intersections of these two interconnected domains (Fleerackers et al., 2023a; 2023b, leaving these and other pressing questions unanswered (Glymour et al., 2023).

9.5.   Conclusion

This dissertation has found that the surge of preprint-based journalism seen during the COVID-19 pandemic represents a form of 'semi'-post-normal science communication—evidence of journalists' resistance to abandon their established norms and practices, but also their capacity to innovate and adapt when faced with seemingly insurmountable challenges. It has done so through three complementary mixed method studies that collectively address why journalists use preprints (RQ1), the practices they use to find (RQ2a), verify (RQ2b), and communicate (RQ2c) about them, the degree to which these motivations and practices depart from journalists' 'normal' practices for reporting on peer reviewed research (RQ3), and the role of the pandemic in accelerating journalists' use of preprints (RQ4). In addressing these questions, this dissertation sheds light on a set of practices that have been a small but consistent part of journalism for years but which have been overlooked by scholars until now.

The results reveal that some of the factors that normally motivate journalists to incorporate research into their reporting—such as to improve accuracy and debunk misinformation—can discourage them from using preprints. Similarly, factors that normally constrain journalists' use of peer reviewed research—such as challenges accessing paywalled studies and the misalignment between journalistic timelines and the lengthy peer review process—can motivate them to use preprints. However, other constraining and motivating factors associated with preprints closely align with those associated with peer reviewed research. That is, journalists use preprints for a mix of 'post-normal' and 'normal' reasons. These unreviewed studies act as a stand-in for journal articles, even as they challenge journalists' long-standing perceptions of research as accurate, trustworthy, confirmed "facts."

To cover preprints, journalists again rely on a combination of tried-and-true strategies and novel practices. They find them passively, through the PR efforts of press officers and scientists, but also actively seek them out from preprint servers and social media. They struggle to verify preprints, as they do with any research, but this challenge is amplified because they are unable to rely on peer review or journal status as proxies of quality. To overcome this challenge, journalists rely on a mix of gut instinct, skeptical reading, and an expedited, self-orchestrated form of peer review. Journalists say it is important to be transparent in their coverage about the limitations associated with preprints, demonstrating an embrace of scientific uncertainty that is relatively rare in coverage of peer reviewed research. Yet, these good intentions do not always hold up in practice, as only about half of stories mentioning preprints note the unreviewed, unvetted, or preliminary nature of the research. In some cases, preprints are simply referred to as "research," again acting as a stand-in for the journal articles that normally lend journalists' stories credibility.

While this dissertation found that preprints have been used in journalism since at least 2014, the role of the pandemic in amplifying this use cannot be understated. This was particularly true among health and medical media outlets, which almost never used these unvetted studies pre-pandemic, but became the most active disseminators of COVID-19 preprints during the crisis. Although preprint use has been increasing slowly

for years, they have remained a small part of journalism. At the same time, they are used by a wide range of outlets, including the traditional outlets that are seen as comprising journalism's core and those that exist at the periphery of the field. In this sense, coverage of preprints is both a mainstream and marginal part of journalism—a post-normal practice that is slowly but consistently becoming more normal.

Although many questions remain unanswered, collectively, these results suggest that journalists responded to the highly uncertain, politicized, value-laden, and urgent nature of the pandemic by falling back on established strategies but also exploring novel ones that extend and even challenge their longstanding norms. This semi-post-normal response demonstrates how the ongoing effort to make science more open and transparent has encouraged a return to the status quo, even as it has pushed journalists to experiment with, and in some cases, embrace a new way of reporting on research—one that is more critical, transparent, and aware of the uncertainty inherent in all science.

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