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## RESEARCH ARTICLE

# The role of preprints in neuroscience scholarly communication: A citation analysis

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## ABSTRACT

Preprints—scientific manuscripts publicly shared prior to peer review—are now part of scholarly communication as emerging information resources. While neuroscience researchers have increasingly published preprints, the impact of preprints in this field remains unclear. Through a bibliometric approach, this case study explored preprint citation patterns. The results yielded over 33,000 citations to preprints within Scopus-indexed neuroscience documents (1993–2022). Trends of citations and citation motivations were investigated. Findings indicated that 1.62% of neuroscience publications cited at least one preprint, with citations peaking at 6% in 2021. Review and journal articles cited preprints more frequently, compared to books, notes, and conference papers ( $\chi^2 = 1909.015$ ,  $p < 0.001$ ). The most commonly cited servers were bioRxiv, arXiv, medRxiv, and PsyArXiv. Regarding journals, a moderate positive correlation ( $r_s = 0.353$ ,  $p < 0.01$ ) was found between publications citing preprints and journals' CiteScores. Using Scite.ai, 93% of citations were classified as “mentioning,” with considerably fewer being supporting or contrasting. Most preprint citations appeared in Introduction and Discussion sections, highlighting their role in framing research questions and contextualizing results. The global overview of these results may help contextualize citation behavior in relation to structural and cultural factors, such as disciplinary norms, policy frameworks, researchers' attitudes, and health emergencies.

## 1. INTRODUCTION

Preprints, defined as complete scientific manuscripts publicly uploaded to servers before formal peer review (Alfonso & Crea, 2023), have become an increasingly prominent component of the (open) scholarly communication ecosystem (Joshi, 2024; Maggio & Fleerackers, 2023; Scotti, 2025), as a timely and free of charge method for disseminating scientific findings (Sever, Eisen, & Inglis, 2019). They have been part of scholarly publishing since the 1960s (Smart, 2022), with physical mail as the primary distribution method until the 1990s. In 1991, physicist Paul Ginsparg at Los Alamos National Laboratory launched an automated email server for high-energy physics preprints (Berg, Bhalla et al., 2016), which evolved into arXiv as the first official preprint server. arXiv inspired the creation of other preprint servers, such as the Social Science Research Network in 1994 (Xie, Shen, & Wang, 2021) and Research Papers in Economics (RePEc) in 1997, and since 2010 numerous new preprint servers have emerged, many

supported by the Centre for Open Science (COS) and the Open Science Foundation (OSF)<sup>1</sup>. The COVID-19 pandemic was one of the key factors accelerating the growth of both preprints and preprint servers, when the urgent need for rapid information sharing became more important (Biesenbender, Toepfer, & Peters, 2024; Fleerackers, Shores et al., 2024; Henke, 2024; Smart, 2022; Tian, Liu, & Li, 2024; Wang, Chen, & Yang, 2025).

Preprints offer several benefits, including the immediate sharing of results, the opportunity to receive early feedback from the scientific community, as well as enhanced visibility (Maggio & Fleerackers, 2023; Tian et al., 2024). They also contribute to transparency with the dissemination of nonsignificant or contradictory findings (da Silva, 2018). With regard to readership and visibility, higher citation counts for peer-reviewed publications previously published as preprints (Fraser, Mayr, & Peters, 2022; Lemke & Peters, 2023) can influence authors' preprinting behavior (Fraser, Momeni et al., 2020). However, the rapid dissemination of nonreviewed manuscripts can raise significant concerns. The lack of peer review is a primary limitation, calling into question the reliability, quality, and credibility of the information shared (Maggio & Fleerackers, 2023; Ni & Waltman, 2023, 2024; Scotti, 2025; Smart, 2022). In this respect, some studies have elaborated on the potential concerns and risks associated with the dissemination of non-peer-reviewed health-related works (Bagdasarian, Cross, & Fisher, 2020; Ng, Chow et al., 2024; Ng, Santoro et al., 2024), yet other studies on preprinted peer-reviewed publications have provided counterarguments, reporting only limited changes and overall consistency between the preprint and the peer-reviewed version of the same scholarly work in terms of findings and conclusions (Bai, Jiang et al., 2023; Brierley, Nanni et al., 2022).

The debate over preprint reliability and transparency is widespread, but their adoption and impact vary significantly across different scientific fields. While physics and computer science have long-established preprint cultures (Alvarez & Caregnato, 2017), the life and biomedical sciences have only recently started to integrate them into their workflows. Within this latter group, preprints have gained more popularity, with the development of platforms like bioRxiv (Abdill & Blekhman, 2019; Penfold & Polka, 2020) and with a growing number of biomedical journals accepting preprints for submission (Bove Fenderson, Duffy, & Mannstadt, 2018; Massey, Opare et al., 2020). In the neuroscience domain, however, the pattern of the use of preprints remains unclear. Neuroscience as a field has been at the forefront of adopting and implementing new technologies and practices. Similarly, new initiatives such as Preprints of the R-fMRI Network (PRN) are emerging to address the specific publishing needs of the neuroscience community, complementing traditional publishing with rapid dissemination and opportunities for feedback (Yan, Li, & Gao, 2015). While previous studies suggest that the neuroscience community has adopted publishing preprints (Pagliaro, 2021), their impact on this field remains underexplored. In particular, there remains a gap in understanding how neuroscience researchers incorporate preprints as information resources in their research outputs.

## 2. LITERATURE REVIEW

There is no consensus on the citability of preprints (Bove Fenderson et al., 2018), as perspectives on citing preprints vary widely across the academic and publishing communities. A restrictive approach argues against citing preprints because lacking peer review makes their findings potentially unreliable and suggests that "preprints could promote confusion and

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<sup>1</sup> A list of cited preprint servers in the neuroscience Scopus-indexed documents, along with their number of records, launch year, and maintaining organization, is provided in the Supplementary material.

distortion” (Sheldon, 2018). For example, according to *Journal of Mammalogy* author guidelines, preprints cannot be cited in a peer-reviewed article. According to this approach, citing non-peer-reviewed references, including preprints, is not a common practice (Tenopir, Levine et al., 2016). Conversely, a more permissive viewpoint posits that preprints are a part of scholarly communication and should be freely citable (Ettinger, Sadanandappa et al., 2022; Sarabipour, Debat et al., 2019). According to this viewpoint, preprints are like dissertations and proceedings abstracts, with a less formal peer-review process (Pickler, 2019) and are thus citable. For example, Portland Press has declared that “preprints can be cited in all Portland Press journals”. Likewise, *PLOS Computational Biology* and *eLife* have been noted for supporting citations to preprints (Bertin & Atanassova, 2022). A third, more cautious approach represents a middle ground, allowing citations to preprints but with significant caveats (COPE Council, 2018; JHL Editorial Team, 2021; Worster, 2024). For instance, a joint position statement from the American Medical Writers Association (AMWA), the European Medical Writers Association (EMWA), and the International Society for Medical Publication Professionals (ISMPP) recommends that preprints be cited as a personal communication, appearing as in-text references (using the preprint link, DOI, or both) rather than in the bibliography, and the authors have to clearly disclose that the cited reference is a preprint (Dyer, 2024).

That said, preprints are now regularly cited in peer-reviewed journal articles, books, and conference papers (Pagliaro, 2021); however, the practice of citing prepublication work is not new, as preprints were cited as early as 1922 (Larivière, Sugimoto et al., 2014). In one of the oldest studies on citing preprints, Youngen (1998) addressed the growing importance of electronic preprints in the published literature and their future role in scholarly communication. The research indicated that electronic preprints were becoming an increasingly important tool for disseminating primary research, particularly in physics and astronomy, where a long-standing culture of sharing preprints already existed. Youngen’s analysis of data from 1988 to 1996 showed that while citations to traditional paper preprints declined, citations to electronic preprints, or “e-prints,” nearly doubled every year since their introduction in 1992. Similarly, Brown (2001) analyzed citations to preprints in physics and astronomy journals and found the number of citations and citation rates to be large and increasing. Other research confirmed that the number of high-energy physics researchers citing preprints grew by a factor of approximately 1.25 annually (Prakasan & Kalyane, 2004). Nevertheless, beyond the rising number of preprints and citations to them, preprint supporters note that “the focus has shifted to how preprints should be cited rather than whether preprints should be cited” (Blatch-Jones, Recio Saucedo, & Giddins, 2023).

Further investigations into the use of preprints show that the majority of studies analyzing citations to preprints are published after 2010. For instance, Larivière et al. (2014) found that in physics, mathematics, and astronomy and astrophysics, arXiv preprints are cited more quickly but their citations decay faster than those of their published version as journal articles. This study also highlighted that the arXiv versions of papers, whether published or not, tend to have lower overall citation rates than their final, published counterparts. Another study showed an increase in the number of citations to four subject repositories of arXiv, RePEc, Social Science Research Network, and PubMed Central (Li, Thelwall, & Kousha, 2015). This was further confirmed by another study reporting that arXiv preprints in physics and astronomy, mathematics, computer science, and engineering were the most frequently cited (Noruzi, 2016). Furthermore, a survey among members of the Association for Computational Linguistics revealed that 54% of respondents cited preprints at least occasionally (Foster, Hearst et al., 2017). Another survey revealed that among 174 respondents, 66 cited preprints very often, often,

or sometimes, while 100 respondents cited them rarely or never (Kelly, 2018). In another survey, Ni and Waltman (2024) found that respondents had concerns about the citability of preprints. Conversely, a survey among 218 Slovenian scientists showed that 119 respondents had already cited an arXiv article, while only 21 indicated that they had not (Metelko & Maver, 2023).

Recent analyses revealed that the frequency of citing preprints has increased over the past decade, with the COVID-19 pandemic reinforcing their adoption in medicine and life sciences (Biesenbender et al., 2024). Analyzing over 8,460 preprint citation contexts within seven different *PLOS* journals, Bertin and Atanassova (2022) demonstrated that the number of citations to preprints has been increasing rapidly since 2011, a trend consistent with the creation and development of new preprint servers (e.g., bioRxiv). In addition, Pagliaro (2021) investigated citation patterns of preprints across three major preprint servers: bioRxiv, ChemRxiv, and Research Square and showed that preprints from bioRxiv and ChemRxiv, accounting for more than 93% of total citations, were predominantly cited in original research and review articles. Furthermore, preprints on bioRxiv were cited in conference papers at a rate three times higher than those on ChemRxiv. Also, until late 2018, neuroscience was the leading subject for preprints posted on bioRxiv. In terms of where preprints are cited within scholarly articles, an analysis of *PLOS* journals found that preprint citations appeared mostly in the Methods section, with explicit terminology identifying them as preprints (Bertin & Atanassova, 2022). In another study on medical journals, a significant portion of preprint citations appeared in the Introduction and Background sections, often to reference rapidly evolving research or provide timely context (Gehanno, Grosjean et al., 2022).

Preprints are cited not only in research outputs but also in patents and policy documents. Wang et al. (2025) explored the influence of preprints on technological innovation and showed a growing trend of bioRxiv preprint citations in patents (2013–2021), peaking in 2020 driven by the COVID-19 pandemic. Although biotechnology and pharmaceutical companies cited preprints more frequently given their need for early access to the latest research, academic institutions favored peer-reviewed articles and in case of citing preprints, they would opt for preprints with a corresponding published version. The study concluded that preprints enhance early visibility and knowledge transfer, whereas journals remain key for rigor. Similarly, Xu and Zong (2024) found that COVID-19 preprints published with open peer review were significantly more likely to be cited in policy documents.

However, the decision to cite scholarly works is influenced by multiple factors beyond publication type. Current evidence indicates that structural and cultural factors, including geographic location, scientific discipline, and career stage can shape researchers' motivations and practices in citing preprints (Biesenbender, Smirnova et al., 2024; Janda, Khetpal et al., 2022; Sommer, Sunder-Plassmann et al., 2023; van Schalkwyk, 2024). Recent studies suggest that even author prestige (Miura & Sakata, 2025) and affiliations (Nishioka, Färber, & Saier, 2022) can predict citation patterns, with preprints including disproportionate citations to papers from authors highly recognized in traditional journals or affiliated with reputable institutions. Several theories have been proposed to explain citation behavior: normative theory (citations as acknowledgments of intellectual influence) (Small, 2004), constructivist theory (citations as rhetorical tools for persuasion) (Bao & Teplitskiy, 2024), and Social Systems Citation Theory (SSCT—integrating both perspectives). SSCT conceptualizes citations as communicative acts within scientific communities and distinguishes between an author's motives and the social system of publications (Tahamtan & Bornmann, 2022). Recent research emphasizes the role of social conformity in citation practices. It identifies multiple levels of conformity (normative, informational, identification) and their influence on citation choices. Additionally,

coauthorship and citation networks further reinforce social group cohesion and conformity in citation behavior. Therefore, social conformity and network effects are integral to understanding why and how preprints are cited, complementing cognitive and rhetorical explanations (Tan, Zhou et al., 2025).

In view of the arguments above, the rapid growth of the field of neuroscience, which has demonstrated the potential to respond quickly to global health-related events, such as COVID-19 (Senden, 2025, 2026) may encourage increasing engagement with preprints and their use as sources of recent findings. Given the complex structural and cultural dimensions underlying citation behavior, a global overview of how preprints are engaged with and cited in the neuroscience literature can provide an empirical basis for contextualizing the role of preprints in this field and possibly others. Therefore, this bibliometric case study of Scopus-indexed neuroscience publications aims to provide evidence-based insights into how rapidly disseminated, non-peer-reviewed work is integrated into formal scholarly communication over time. By quantifying citation patterns, this study addresses these two research questions:

**RQ1:** To what extent are neuroscience researchers citing preprints?

**RQ2:** What are their motivations for citing preprints (supporting, contrasting, or mentioning)?

### 3. MATERIALS AND METHODS

Data were collected from Scopus using two specific queries and analyzed through bibliometric methods. Scopus was chosen for its wide coverage of over 28,000 scholarly sources and the possibility of searching within cited references. The first query retrieved Scopus-indexed neuroscience documents (2004–2022) (Query 1). The second query retrieved neuroscience documents citing at least one preprint, including 35 OSF-listed servers (as of September 20, 2023) and medRxiv (as “the preprint server for health sciences,” hosting preprints related to neuroscience as the study of the nervous system function, drawing on different fields, such as pharmacology, psychology, and genetics (Burk, 2008) included in medRxiv Subject Areas). This query included the titles of preprint servers listed on the OSF portal and medRxiv. The term “preprint” was added to specific terms (i.e., PeerJ, CoP, Law Archive, and FocUS Archive) to avoid potential confusion with journal titles (Query 2).

**Query 1:** The Scopus query for retrieving neuroscience publications

SUBJAREA (neur) AND PUBYEAR < 2023

**Query 2:** The Scopus query for retrieving neuroscience publications with citation(s) to preprint(s)

REFSRCTITLE ('OSF Preprints' OR 'open science foundation Preprints' OR \*africarxiv\* OR \*agrixiv\* OR \*arabixiv\* OR \*arxiv\* OR \*biohackrxiv\* OR \*biorxiv\* OR \*bodoarxiv\* OR \*cogprints\* OR \*eartharxiv\* OR \*ecoevorxiv\* OR \*ecsarxiv\* OR \*edarxiv\* OR \*engrxiv\* OR \*frenxiv\* OR 'INA-Rxiv' OR \*indiarxiv\* OR \*lawarxiv\* OR 'LIS Scholarship Archive' OR \*marxiv\* OR \*mediarxiv\* OR \*metaarxiv\* OR mindrxiv OR \*nutrixiv\* OR paleorxiv OR 'Preprints.org' OR psyarxiv OR \*repec\* OR \*socarxiv\* OR \*sportrxiv\* OR 'Thesis Commons' OR 'CoP preprint' OR 'FocUS Archive preprint' OR 'PeerJ preprint' OR 'Law Archive preprint' OR \*medrxiv\*)

The search yielded 1,299,390 records (2004–2022) with the first query (all document types as specified in Scopus) and 19,941 records (article, book/book chapter, conference paper,

review, note) with the second (2004–2022). The data set, downloaded as a CSV file, included titles, DOIs, sources, and EIDs. References from each publication were split using Python, placing each reference and its citing document's EID on separate lines in a text file for analysis. From the text file, 33,754 references containing preprint server titles were extracted using Python. In documents with multiple preprint references, each preprint reference was counted individually. To ensure relevance, 100 randomly selected references were manually verified to confirm that all the 100 references were published on a preprint server. All data were screened for completeness and consistency prior to analysis. Collected demographic characteristics included the proportion of documents citing preprints per 100 Scopus documents, the distribution of document types citing preprints, cited preprint servers, journals citing preprints, and the geographic origins of documents citing preprints.

To calculate the journal-based proportion of documents citing preprints, neuroscience journals were derived from 1,598,108 neuroscience records (1993–2022), filtered by “Source title” and exported to Excel. From 1,008 initial journal titles, duplicates were consolidated by matching ISSNs, accounting for spelling variations and title changes. During the ISSN retrieval process, it was discovered that some journal titles with minor differences in naming were associated with the same ISSN (e.g., “Multiple Sclerosis Journal” and “Multiple Sclerosis”) and were thus deduplicated. Additionally, some journals had undergone a title change (e.g., “Perception Psychophysics” was changed to “Attention, Perception, & Psychophysics”). The publication counts for these duplicates or merged titles were combined, and the redundant entries were removed. After this deduplication process, 843 unique journals remained in the data set. Subsequently, these ISSNs were searched on the Scopus Sources website (<https://www.scopus.com/sources>) to determine their CiteScore. Among those, 637 journals had a CiteScore (out of 843 journals, ~76%), while 203 did not (their CiteScore was recorded as N/A). Finally, three ISSNs could not be found on the Scopus Sources website. In terms of geographic origins of Scopus-indexed documents citing preprints, countries were extracted from the institutional affiliations of all authors as indexed in Scopus.

To answer the first research question, collected data on trends of citations to preprints were descriptively summarized using IBM SPSS Statistics—version 23.0 (IBM Corp., 2015) to contextualize preprint citation trends. To answer the second research question on motivations for citing preprints and explore the citation context, a random sample of 653 citations was selected from 33,754 citations to preprints within neuroscience documents. The sample size was determined using the Survey System tool (<https://surveysystem.com/sscalc.htm>), with a 99% confidence level and a confidence interval of 5%. Random selection was performed in MS Excel using the RAND() function, which assigned random numbers, sorted them, and extracted the first 653 records for detailed analysis. The records containing the sampled citations were identified, their DOIs were retrieved, searched on Scite.ai (Nicholson, Mordaunt et al., 2021) to identify the location within the document where the preprint was cited (e.g., Introduction, Methods) and the motivation underlying citations (mentioning, supporting, or contrasting).

The Scite.ai (<https://scite.ai/>) web tool was employed to objectively categorize citations and detect self-citations. The Scite.ai ingestion pipeline consists of four main stages:

1. regular retrieval of full-text scholarly documents;
2. identification of in-text citations and matching them with references within the document;
3. linking references to their DOIs in bibliographic databases; and
4. automated classification of citation statements using supervised deep learning models.

Citation contexts are categorized as “supporting,” “contrasting,” or “mentioning” using a pretrained language model based on BERT (Beltagy, Lo, & Cohan, 2019), trained on a large expert-annotated data set. “Mentioning” citations provide background context, “supporting” citations confirm previous findings, and “contrasting” citations challenge them. More precisely, rather than performing sentiment analysis, this tool classifies citations based on the factual information within the citation context (e.g., experimental facts, reproducibility results, or theoretical agreement/disagreement). The training data set was generated through a rigorous multiblind expert annotation process, with independent review and consensus reconciliation, resulting in nearly 50,000 labeled citation statements and high interannotator agreement. A fixed holdout set ensured unbiased evaluation, while oversampling techniques addressed class imbalance to improve the detection of rare citation types, especially “contrasting.” The Scite.ai database includes over 800 million classified citation statements derived from more than 25 million scholarly publications, enabling large-scale analysis of citation context across the scientific literature (Nicholson et al., 2021).

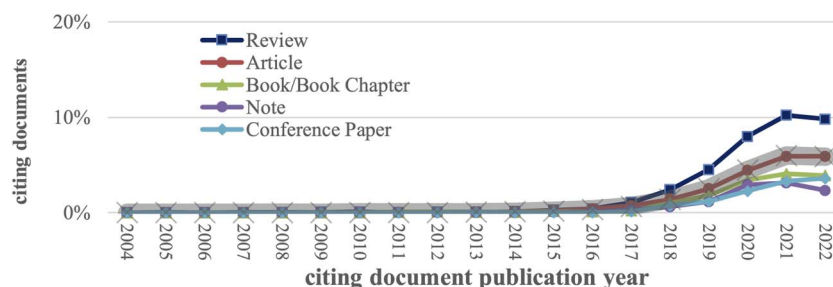
Overall, an overview of how preprints are cited in the neuroscience literature is presented for the past 2 decades. To substantiate the results of this study, Pearson’s chi-square and Spearman’s rank-order correlation tests were conducted via the IBM SPSS Statistics—version 23.0 (IBM Corp., 2015) to investigate associations between preprint citation counts and document types, explore the relationship between journals’ CiteScores and citations to preprints, and identify potential differences in motivations underlying citations to preprints.

#### 4. RESULTS

In total, 19,633 Scopus-indexed neuroscience documents with at least one preprint citation were identified. Figure 1 illustrates the temporal trend of Scopus-indexed neuroscience documents with at least one citation to a preprint.

Figure 1 shows a steady rise in the number of neuroscience documents citing preprints per 100 Scopus documents, starting below 1% in the early 2000s and increasing notably after 2014, reaching about 6% in 2021. From 2016 onward, citation patterns vary across document types: Reviews cite preprints most frequently, followed by journal articles, which align with the general upward trend. Conference papers, book chapters, and notes exhibit similar, lower citation rates. Table 1 complements this figure by summarizing the proportions of publications that cite (“Yes”) or do not cite (“No”) preprints across different document types in neuroscience.

As shown in Table 1, the chi-square test results indicated a statistically significant association between document type and the likelihood of citing preprints. Reviews and journal articles are significantly more likely to cite preprints compared to book chapters, notes, and conference papers ( $\chi^2 = 1909.015$ ,  $p < 0.001$ ).



**Figure 1.** Documents citing preprints per 100 Scopus documents.

**Table 1.** Descriptive representation and chi-square test results of citations to preprints (1993–2022) in different document types

|                  |     | Review              | Article             | Chapter            | Note               | Conference         | Total                 |
|------------------|-----|---------------------|---------------------|--------------------|--------------------|--------------------|-----------------------|
| Citing preprints | No  | 124,684<br>(97.09%) | 960,720<br>(98.45%) | 40,644<br>(99.09%) | 29,487<br>(99.21%) | 35,216<br>(99.51%) | 1,190,751<br>(98.38%) |
|                  | Yes | 3,735<br>(2.91%)    | 15,117<br>(1.55%)   | 375<br>(0.91%)     | 234<br>(0.79%)     | 172<br>(0.49%)     | 19,633<br>(1.62%)     |
| Total            |     | 128,419             | 975,837             | 41,019             | 29,721             | 35,388             | 1,210,384             |

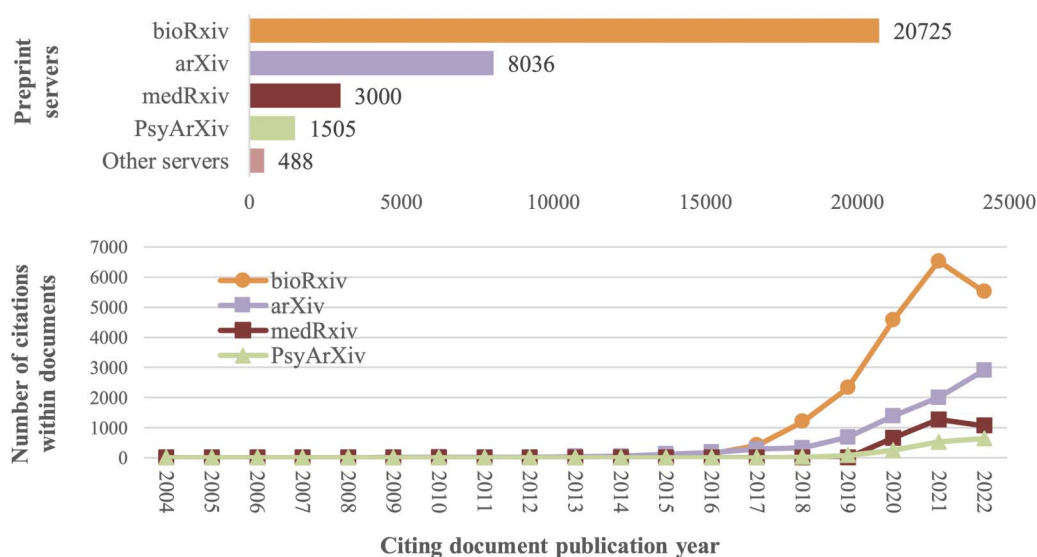
  

| Pearson's chi-square test |           |    |                                   |
|---------------------------|-----------|----|-----------------------------------|
|                           | Value     | df | Asymptotic significance (2-sided) |
| Pearson chi-square        | 1909.015* | 4  | .000                              |
| Likelihood ratio          | 1819.511  | 4  | .000                              |
| N of valid cases          | 1,210,384 |    |                                   |

\*0 cells (0.0%) have expected count less than 5. The minimum expected count is 482.09.

In total, 33,754 preprint citations were identified. Figure 2 provides a server-based overview of the number of citations to preprints within Scopus documents in the field of neuroscience.

As Figure 2 represents, bioRxiv emerges as the most frequently cited preprint server, with a substantial count of 20,725 citations from all Scopus-indexed neuroscience documents. Following bioRxiv, arXiv ranks second with 8,036 cited preprints. In the third and fourth places, medRxiv and PsyArXiv have 3,000 and 1,505 cited preprints, respectively. The category “Other servers” encompasses not commonly cited preprint servers (i.e., OSF Preprints, SocArXiv, MetaArXiv, EcoEvoRxiv, RePEc, CogPrints, MindRxiv, SportRxiv,



**Figure 2.** Number of citations to preprint servers in neuroscience Scopus-indexed documents (total and per year).

ChinArxiv, EdArXiv, Preprints.org, engrXiv, NutriXiv, PaleorXiv, AfricArXiv, BioHackrXiv, EarthArXiv, Frenxiv, INA-Rxiv, LIS Scholarship Archive, and Thesis Commons) with a total of 488 cited preprints. Also, an increasing trend in citations to preprint servers is observed, particularly over the last few years. Regarding the trend of citations to preprint servers, bioRxiv has emerged as distinctively more frequently cited since 2018 along with a consistent increase in the number of citations to other preprint servers.

An analysis of Scopus-indexed neuroscience journals (1993–2022) reveals that in 62% of these journals (524 out of 843 journals), one preprint was at least cited. Table 2 shows the 20 neuroscience Scopus-indexed journals most commonly citing preprints and presents the total ratio of documents citing preprints per 100 journal publications in the field of neuroscience.

According to Table 2, journals frequently citing preprints (e.g., *eLife*) tend to have relatively higher CiteScores. A statistical analysis of the correlation between the number of publications citing preprints (per 100 publications) in Scopus-indexed journals and journals' CiteScores was performed via Spearman's rank-order correlation.

**Table 2.** Top 20 Scopus-indexed journals most commonly citing preprints

| Journal                                              | No. of publications<br>(1993–2022) | No. of publications<br>citing preprints | Documents citing<br>preprints (%) | CiteScore<br>2023 |
|------------------------------------------------------|------------------------------------|-----------------------------------------|-----------------------------------|-------------------|
| <i>Network Neuroscience</i>                          | 232                                | 74                                      | 31.9                              | 6.4               |
| <i>Neurobiology of Language</i>                      | 80                                 | 20                                      | 25.0                              | 5.9               |
| <i>Neuroscience of Consciousness</i>                 | 114                                | 28                                      | 24.6                              | 6.9               |
| <i>Frontiers in Neuroinformatics</i>                 | 898                                | 184                                     | 20.5                              | 4.8               |
| <i>Neuroimage Reports</i>                            | 130                                | 20                                      | 15.4                              | 1.9               |
| <i>Frontiers in Computational Neuroscience</i>       | 1,673                              | 254                                     | 15.2                              | 5.3               |
| <i>Brain Informatics</i>                             | 175                                | 25                                      | 14.3                              | 9.5               |
| <i>Biological Psychiatry Global Open Science</i>     | 61                                 | 8                                       | 13.1                              | 4                 |
| <i>eLife</i>                                         | 14,091                             | 1815                                    | 12.9                              | 12.9              |
| <i>Current Opinion in Behavioral Sciences</i>        | 1,188                              | 147                                     | 12.4                              | 10.9              |
| <i>PLoS Computational Biology</i>                    | 9,562                              | 1106                                    | 11.6                              | 7.1               |
| <i>Brain Computer Interfaces</i>                     | 140                                | 16                                      | 11.4                              | 4                 |
| <i>Personality Neuroscience</i>                      | 27                                 | 3                                       | 11.1                              | 2.9               |
| <i>Current Biology</i>                               | 4,094                              | 452                                     | 11.0                              | 11.8              |
| <i>Frontiers in Synaptic Neuroscience</i>            | 469                                | 51                                      | 10.9                              | 7.1               |
| <i>Current Protocols</i>                             | 607                                | 65                                      | 10.7                              | 4                 |
| <i>Journal for the Cognitive Science of Religion</i> | 64                                 | 6                                       | 9.4                               | 1.7               |
| <i>Neuronal Signaling</i>                            | 108                                | 10                                      | 9.3                               | 4.6               |
| <i>Frontiers in Neural Circuits</i>                  | 1,513                              | 139                                     | 9.2                               | 6                 |
| <i>Cognitive Computation</i>                         | 984                                | 90                                      | 9.1                               | 9.3               |

**Table 3.** Correlation test results of citations to preprints and journals' CiteScores

|                |                      |                         | Citing preprints (%) | CiteScore 2023 |
|----------------|----------------------|-------------------------|----------------------|----------------|
| Spearman's rho | Citing preprints (%) | Correlation coefficient | 1.000                | .353**         |
|                |                      | Sig. (2-tailed)         | .                    | <.001          |
|                |                      | N                       | 637                  | 637            |
|                | CiteScore 2023       | Correlation coefficient | .353**               | 1.000          |
|                |                      | Sig. (2-tailed)         | <.001                | .              |
|                |                      | N                       | 637                  | 637            |

\*\*Correlation is significant at the 0.01 level (2-tailed).

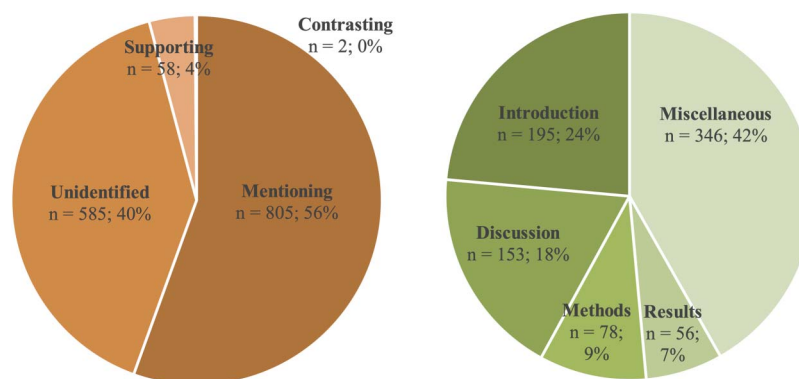
Table 3 shows a moderate positive correlation between journal CiteScore and the proportion of documents citing preprints ( $r_s = 0.353$ ,  $p = 0.01$ ). However, Pearson test results showed that there is no significant correlation between the number of publications citing preprints (per 100 publications) and the total number of journal publications ( $r_s = -0.046$ ,  $p = 0.248$ ).

Table 4 displays the number of publications within 20 countries with the highest number of publications citing preprints. Also, it provides context by presenting the ratio of documents citing preprints per 100 country publications.

As presented in Table 4, the United States leads in the total number of publications citing preprints, followed by the United Kingdom, Germany, China, and Canada. However, considering the ratio of documents citing preprints per 100 country publications, several European countries, namely Norway, the Netherlands, and Switzerland, exhibit higher ratios as compared to North America.

**Table 4.** Top 20 countries by preprint citation count and ratio

| No. | Country        | No. of publications citing preprints | Documents citing preprints (%) | No. | Country | No. of publications citing preprints | Documents citing preprints (%) |
|-----|----------------|--------------------------------------|--------------------------------|-----|---------|--------------------------------------|--------------------------------|
| 1   | United States  | 9,264                                | 1.1                            | 11  | Spain   | 736                                  | 1.4                            |
| 2   | United Kingdom | 3,571                                | 1.8                            | 12  | Japan   | 638                                  | 0.5                            |
| 3   | Germany        | 2,731                                | 1.5                            | 13  | Sweden  | 540                                  | 1.2                            |
| 4   | China          | 1,795                                | 1.3                            | 14  | India   | 498                                  | 1.6                            |
| 5   | Canada         | 1,575                                | 1.3                            | 15  | Belgium | 463                                  | 1.7                            |
| 6   | France         | 1,266                                | 1.3                            | 16  | Israel  | 387                                  | 1.5                            |
| 7   | Netherlands    | 1,236                                | 1.9                            | 17  | Denmark | 372                                  | 1.7                            |
| 8   | Australia      | 1,092                                | 1.5                            | 18  | Norway  | 336                                  | 2.4                            |
| 9   | Italy          | 983                                  | 1.0                            | 19  | Brazil  | 335                                  | 0.8                            |
| 10  | Switzerland    | 924                                  | 2.0                            | 20  | Austria | 334                                  | 1.6                            |



**Figure 3.** Types of citations to preprints and their locations in neuroscience Scopus-indexed documents.

To answer our question regarding motivations for citations to preprints, Scite.ai identified 1,450 citation statements within 451 out of 653 (68% of the research sample) retrievable neuroscience-related publications. Out of the 1,450 citations, Scite.ai identified 865 and categorized them as “mentioning,” “supporting,” or “contrasting” (Figure 3).

Figure 3 provides an overview of the nature of preprint citations within a sample of Scopus-indexed neuroscience documents, with “mentioning” being the most prevalent, occurring 805 times. An example of a “mentioning” citation is “To the best of our knowledge, two other methods **have recently been proposed** in [11; a preprint, 12]” (de Weck, Golji et al., 2018). However, “supporting” citations are less frequent with 58 instances. An example of a “supporting” citation is “**This is consistent with** conclusions from (Elliott et al., 2019; a preprint) who reported that the test–retest interval had little impact on reliability estimates” (Hassel, Sharma et al., 2020). Nonetheless, “contrasting” citations are the least common, occurring only twice. An example of a “contrasting” citation is “**In contrast with a recent preprint** (Saldaño et al., 2021; a preprint), the predicted flexibility values failed to correlate with their pLDDT values, ...” (del Alamo, Sala et al., 2022). As observed in the last example, the lexical content—a recent preprint—can also be informative of the attitude towards preprints. It should be noted, however, that the remaining 585 unclassified citations account for 40% of the total mentions, which Scite.ai was unable to categorize.

Table 5 indicates a statistically significant difference among different types of citations to preprints (contrasting, mentioning, or supporting;  $r = 2091.250$ ,  $p < 0.001$ ). Based on the

**Table 5.** Chi-square test results of differences in the type of citations to preprints

|                    | Value      | df | Asymptotic Significance<br>(2-sided) |
|--------------------|------------|----|--------------------------------------|
| Pearson chi-square | 2,091.250* | 2  | .000                                 |
| Likelihood ratio   | 2,413.804  | 2  | .000                                 |
| N of valid cases   | 2,595**    |    |                                      |

\*0 cells (0.0%) have expected count less than 5. The minimum expected count is 288.33.

\*\*In SPSS, each category had 865 rows. For example, in the “Mentioning” category, there were 865 rows: 805 with “Yes” and 60 with “No” answers. This consistency across categories is why the total number of valid cases is 2,595.

results, the likelihood of a study citing a preprint is significantly higher in the “mentioning” category.

Figure 3 also represents the context where preprints are most frequently cited in Scopus-indexed neuroscience documents. Scite.ai could only locate 828 out of 1,450 citation statements, revealing that preprints were most frequently cited in the Introduction section (195; 24%), followed by the Discussion (153; 18%) and Methods (78; 9%) sections. The location of a considerable number of citations (346; 42%), however, was not appropriately identified by Scite.ai, so they were categorized as “miscellaneous.”

On a complementary note, the ratio of self-citations to preprints in neuroscience-related Scopus-indexed documents was investigated using Scite.ai. Author self-citation refers to citing one’s own previously published work in an upcoming publication (Sri-Ganeshan, Walker et al., 2021). Out of 451 records of the research sample found by Scite.ai, 77 (17%) were identified as author self-citations to preprints.

## 5. DISCUSSION

The current study provides insights into preprint citation patterns within the neuroscience domain, showing that 1.62% of neuroscience publications included at least one preprint citation, with an annual increase. Preprints, as a relatively new reference type, display citation rates comparable to other less formally peer-reviewed sources such as dissertations and conference proceedings (Pickler, 2019). A previous study showed that conference proceedings were cited in 1.7% of natural sciences and engineering and 2.5% of social sciences and humanities publications (Lisée, Larivière, & Archambault, 2008), while Rasuli, Schöpfel, and Prost (2018) found that approximately 1.5% of all Scopus-indexed documents contained at least one citation to theses/dissertations. A relevant study with a different perspective on citation counts of working papers (i.e., equivalent of preprints in economics and business studies) reported relatively low citation engagement. The results of this study indicated that among 4,065 working papers retrieved from EconStor, only 1,613 (35%) were found in Crossref, of which 14% had at least one citation and 8% had exactly one citation (Nuredini & Peters, 2019). While these results are not directly comparable with those of the present study, they nevertheless suggest that citation engagement with non-peer-reviewed research outputs may be discipline specific.

While the trend of citing preprints is on the rise, the overall citation rate remains low at 1.62%, likely reflecting researchers’ attitudes towards preprints. Notably, despite the general upward trend, citations to bioRxiv and medRxiv preprints declined in 2022. Given that these servers primarily host preprints on biology and health sciences, this decrease may be linked to the reduced urgency for rapid dissemination following the acute phase of the COVID-19 pandemic. During the pandemic, the need for immediate access to emerging evidence may have driven higher citation of preprints, whereas citation practices may have since shifted back toward more established norms and greater reliance on peer-reviewed sources. Additionally, findings from a recent survey on preprinting reported substantial decreases in the number of COVID-19 preprints posted across multiple servers in 2022, compared to 2020–2021 (Biesenbender et al., 2024). This preprint citation pattern appears consistent with preprinting trends in life and medical sciences as well as in social and behavioral sciences (Rzayeva, Pinfield, & Waltman, 2025). These observations suggest a possible association between the number of available preprints and citation frequencies. Nonetheless, these explanations remain relatively speculative and need to be more systematically investigated in future research.

Regarding quality-related arguments, in a recent survey, 36% (110 out of 392) of researchers in medicine expressed their concerns about potential harms of disseminating

non-peer-reviewed works (Ng et al., 2024), which might also impact the use of preprints. While changes between a preprint and its peer-reviewed published version are a legitimate concern, the findings of a recent study on COVID-19 randomized controlled trials showed that the main results and conclusions remained consistent in 98% of peer-reviewed published versions (Bai et al., 2023). Another study on bioRxiv and medRxiv records showed changes in the conclusions of 17.2% of COVID-19 and 7.2% of non-COVID-19 preprints after peer review, though most changes did not alter the overall qualitative interpretation (Brierley et al., 2022).

Besides neuroscience preprints, citations to arXiv preprints in physics and astronomy have also increased (Brown, 2001). Conversely, the reception of preprints in chemistry has been notably poor, with no citations in traditional literature (Brown, 2003). However, more recent studies indicate a shift in citation patterns. For instance, a metaresearch on COVID-19 studies found that 29.3% of articles in major medical journals cited at least one medRxiv preprint (Gehanno et al., 2022). Another metaresearch revealed that bioRxiv preprints with a published version received 2,021 citations, while preprints without a published version received 2,258 citations (Fraser et al., 2020). According to these findings, the early 2000s witnessed a relatively low rate of citations to preprints. Yet, findings of the present study showed slight changes from 2014 onward in how neuroscience researchers engage with preprints and illustrated a potential rise in the recognition of preprints as citable sources (Sterling, 2018), which could have been accelerated more recently by the spread of COVID-19, leading to a tsunami of preprints (Rzayeva et al., 2025; Watson, 2022). Also, until 2014, there were a limited number of preprint servers (Li et al., 2015), but the number has since expanded at institutional, national, and global levels.

The increasing trend in the proportion of neuroscience publications citing preprints can be attributed to the need for timely references in this rapidly evolving field. Neuroscience researchers are often on the cutting edge of knowledge, requiring references that reflect the latest discoveries. This need can be fulfilled through freely available preprint servers for sharing findings with the scientific community (Irawan, Zahroh, & Puebla, 2022). As anticipated, review articles demonstrated a larger proportion of citations to preprints, as compared to other publication types. This observation aligns with the perspective of Tentolouris, Ntanasis-Stathopoulos et al. (2021), who noted that “many preprints are cited by reviews.” Considering that review articles aim to synthesize the existing body of knowledge and identify research gaps within a specific field (Palmatier, Houston, & Hulland, 2018), they are more likely to include preprints to ensure comprehensive coverage of current developments. Furthermore, as preprints allow immediate dissemination of results, they are more likely to appear more often in review articles, where new insights are critically evaluated (Palmatier et al., 2018). It should be noted, however, that review articles typically contain more references overall, which may also explain their higher rate of preprint citations. Empirical investigation of this matter through qualitative research could be further enlightening.

On the other end of the spectrum, books (chapters) remain notably hesitant to cite preprints, likely due to their specific objectives and content, because books (chapters) often prioritize well-established and reputable sources rather than the latest findings, as they aim to provide comprehensive and lasting knowledge. This careful selection of references may suggest a cautious approach among authors of books (chapters), given that preprints do not undergo traditional peer review. Overall, further empirical research is needed to better understand citation behaviors across document types.

A closer look at the journals with more citations to preprints shows that preprint citation trends in a journal may be linked to journals' policy. For instance, *eLife* specifies that: “eLife

only peer reviews submissions that are available as preprints” and reviewers’ reports would be published alongside the paper to combine “the immediacy and openness of preprints with the scrutiny of peer-review by experts.”<sup>2</sup> Conversely, the *SLEEP* journal has pointed out that it

... does not allow citation of preprint manuscripts in final published articles. Prior to publication of accepted papers, preprint citations must be replaced with the final, peer-reviewed version of record. If the cited preprint work has not been published by acceptance, it must be removed from the reference list.<sup>3</sup>

Such policies highlight how journal guidelines can shape researchers’ decisions to publish or cite preprints. In relation to this, a survey in the field of complementary, alternative, and integrative medicine revealed that 37% of researchers (112 out of 392) believed preprinting would lower the chances of getting their paper accepted by a journal (Ng et al., 2024).

Additionally, the findings of the present study suggest a moderate positive association between citations to preprints and journal CiteScores, implying that high-impact neuroscience journals seem to be more open to citing preprints and might be leading a growing acceptance of preprints in the field. From a geographical perspective, North America, China, and Europe emerge as prominent users of preprints. However, further statistical investigations are warranted to confirm regional differences. Geographical variations in the use of preprints can be attributed to several factors, including funding policies that formally recognize and endorse preprints (Kaiser, 2017). Notably, the European Commission recently promoted the development of policies supporting open research practices (European Commission, 2023). On the other hand, restrictive measures, such as the Australian Research Council’s preprint ban in grant applications (Ciriminna, Scurria et al., 2021) can discourage the use of preprints. These findings, in line with the literature, suggest the role of policy-driven open science practices, particularly in terms of citing and potentially posting preprints within neuroscience and possibly in other disciplines.

The analysis of preprint citation motivations showed that “mentioning” citations were the most prevalent. This pattern suggests that researchers may be more cautious about citing preprints, often citing them in the Introduction section to provide context rather than to endorse or contradict their findings. This aligns with the literature indicating that the Introduction section typically contains most citations to establish context. However, Bertin and Atanassova’s (2022) study on *PLOS* journal citations indicated that preprint citations appeared more frequently in the Methods section when considering relative numbers (i.e., the proportion of preprint citations within the Methods section compared to total citations), while the current study focused on absolute numbers.

Regarding self-citations, the present study showed that 17% of preprint citations were self-citations. An overall self-citation rate of 9% was reported across disciplines (varying from 3% to 15%) (Szomszor, Pendlebury, & Adams, 2020). The rate of neuroscience researchers’ self-citation to preprints is comparable to that in physical sciences (15%). This rate might reflect researchers’ motivation to comply with open access requirements from funding agencies and increase visibility and recognition of their work. However, further research is needed to better clarify the patterns and motivations of self-citations to preprints.

By providing empirical evidence of how preprints are cited, this study offers insights into the evolving dynamics of scholarly communication, which can contribute to open science

<sup>2</sup> [https://web.archive.org/web/20231006105925/https://elifepreprint.org/html/elifepreprint\\_author\\_instructions.html#process](https://web.archive.org/web/20231006105925/https://elifepreprint.org/html/elifepreprint_author_instructions.html#process).

<sup>3</sup> [https://academic.oup.com/sleep/pages/General\\_Instructions](https://academic.oup.com/sleep/pages/General_Instructions).

policymaking. Despite their free accessibility, preprints are not as commonly used as peer-reviewed publications. Various reasons could be underlying the use or nonuse of preprints, indicating the need for further empirical investigations.

### 5.1. Research Limitations

Considering that this is a case study with limited scope, the findings are neither temporally stable nor generalizable across fields. In particular, preprint citations should be further investigated in light of the COVID-19 pandemic, which significantly accelerated scientific publications and preprints, initially leading to a 60% increase in submissions to Elsevier journals and a tenfold increase in submissions on medRxiv (Clark, 2023). With respect to data sources, neuroscience documents were retrieved exclusively from Scopus, which offers a wide coverage of scholarly sources. However, this may constrain the generalizability of the findings across bibliometric platforms. Future investigations integrating multiple databases and cross-database comparisons could expand on the present results. Along the same lines, this study relied on a predefined list of preprint servers to identify preprint citations. This approach enabled a targeted, transparent, and reproducible search strategy while maintaining a balance between coverage and precision. However, some citations may not have been captured due to variations in reference formatting, Scopus indexing, or journal citation styles (e.g., only a DOI/URL is provided, server name appears only in auxiliary fields such as the note field). Nevertheless, some of these variations are likely to be partially mitigated during Scopus indexing. Furthermore, despite careful quality assurance, considering that massive amounts of data were managed and processed using Python code, some citations might have been missed in our final data set.

Finally, although the artificial intelligence-based tool (Scite.ai) effectively facilitated a more objective and reproducible bibliometric analysis, it could not be fully automated and required supervision. More precisely, Scite.ai identified only 68% of the research sample. In terms of context, Scite.ai could only locate 828 out of 1,450 (57%) citation statements, with 42% categorized as miscellaneous. For instance, if a Scopus-indexed document included a subsection in the Introduction section, Scite.ai could not attribute citations in that subsection to the Introduction, requiring manual corrections. This output can possibly have broader methodological implications in terms of the importance of standardized reporting practices to enable reliable automated extraction of information from publications. Regarding motivations for citing preprints, Scite.ai classified 865 out of 1,450 citation statements (60%) of which 40% were classified as miscellaneous, indicating a considerable proportion of missed cases. Nevertheless, the identification of context of citations and classification of motivations for citing preprints remained fully automated via Scite.ai and *post hoc* manual completion of the outputs was deliberately avoided for two primary methodological reasons. First, to maintain methodological consistency and ensure reproducibility, any author-driven modifications that could compromise comparability with future replication studies were avoided. Second, exclusively algorithmic classification by Scite.ai was conducted to avoid conflating automated outputs with authors' subjective classifications, particularly with respect to motivations for citations to preprints. Integration of manual classifications would have introduced outcome bias and interpretative variability and could have jeopardized the methodological transparency and internal validity of the study.

### 5.2. Future Research Recommendations

The present study revealed that a small but growing number of neuroscience publications cite preprints. This increase may reflect the easier accessibility of preprints or a rising acceptance of their use in scholarly communication. From a cross-disciplinary perspective as well,

publication/citation behavior can have significant implications. For example, although preprinting has increased in economics over the recent years (Rzayeva et al., 2025), citation counts for such outputs remain limited (Nuredini & Peters, 2019). A similar dynamic might be underlying publication/citation behavior in neuroscience. The reasons underlying this pattern, as well as systematic cross-disciplinary comparisons of preprint-related practices, warrant further investigation. Also, because different lexical expressions are used when citing preprints (Bertin & Atanassova, 2022), linguistic content analysis could help assess the perceived credibility of preprints within the scientific community.

Moreover, investigating the scientific profiles of the authors of cited preprints can clarify who benefits most from them. A recent survey on familiarity with preprints (Ni & Waltman, 2024) highlighted that 55–96% of researchers (in disciplines other than mathematics, computer science, physics, and astronomy) had never read a preprint, suggesting the need for a survey on researchers' attitudes towards preprinting and citing preprints. Such research would also help clarify whether authors who are more supportive of open access are also more likely to cite preprints. In this respect, a previous case study on preprint citations during COVID-19 found that authors with lower open access affinity cited higher proportions of closed-access literature (Lemke, Biesenbender, & Peters, 2024). Along the same lines, qualitative research approaches (e.g., interviews, focus groups, content analysis of policy documents) can provide insights into attitudes towards preprints among not only researchers and research institutions, but also funding associations and publishers. Such studies can further contextualize how preprints are evaluated and integrated into evaluation frameworks and potentially inform relevant policy development practices.

Given the (current) limitations of artificial intelligence-based citation analysis using Scite.ai, future studies incorporating multiple automated tools/platforms can enable validation of citation classifications. Additionally, sensitivity analyses evaluating the stability of results under different classification parameters can provide a more robust appraisal of artificial intelligence-assisted bibliometric inferences.

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#### **AUTHOR CONTRIBUTIONS**

Behrooz Rasuli: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Visualization, Writing—original draft, Writing—review & editing. Fatemeh Seyfzadeh: Data curation, Investigation, Methodology, Project administration, Visualization, Writing—original draft, Writing—review & editing. Aurore Thibaut: Supervision, Writing—review & editing. Olivia Gosseries: Funding acquisition, Supervision, Writing—review & editing.

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The authors have no competing interests.

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#### DATA AVAILABILITY

All relevant data are posted on Zenodo: <https://doi.org/10.5281/zenodo.8356108> (Rasuli, Seyfzadehdarabad et al., 2023).

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