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Gender-specific effects of COVID-19 lockdowns on scientific publishing productivity: Impact and resilience

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ABSTRACT

Rationale: The SARS-CoV2 pandemic led to drastic social restrictions globally. Early data suggest that women in science have been more adversely affected by these lockdowns than men, with relatively fewer scientific articles authored by women. However, these observations test broad populations with many potential causes of disparity. Australia presents a natural experimental condition where several states of similar demographics and disease impact had differing approaches in their social isolation strategies. The state of Victoria experienced 280 days of lockdowns from 2020 to 2021, whereas the comparable state of New South Wales experienced 107 days, most of these in 2021, and other states even fewer restrictions.
Objective and methods: To assess how the gender balance changed in Australian biomedical publishing with the lockdowns, we created a custom workflow to analyse PubMed data from more than 120,000 published articles submitted in 2019–2021 from Australian authors.
Results: Broadly, Australian women have been incredibly resilient to the challenges faced by the lockdowns. There was an increase in the number of published articles submitted in 2020 that was equally due to women as men, including from Victoria. On the other hand, articles specifically addressing COVID-19 were significantly less likely to be authored by women than those on other topics, a finding not likely due to particular gender imbalance in virology or viral epidemiology, since publications on HIV followed similar patterns to previous years. By 2021, this imbalance had reversed, with more COVID-19-related papers authored by women than men.
Conclusions: These data suggest women from Victoria were less able to rapidly transition to new research early in the pandemic but had accommodated to the new conditions by 2021. This work indicates we need strategies to support women in science as the pandemic continues and to continue to monitor the situation for its impact on vulnerable groups.

1. Introduction

1.1. Study background

The appearance of SARS-CoV2 in late 2019 and its subsequent worldwide infection of the human population has meant drastic social responses to the global healthcare emergency. These have included at least some form of closure of businesses and schools in at least 186 countries (Hale et al., 2021). The COVID-19 pandemic impact on workloads has been profound. For the scientific community these lockdowns impacted access to laboratories and primary experimentation, necessitated rapid transitioning to exclusive online undergraduate and higher degree (graduate) student research programs, and were compounded in some cases by the necessity to educate younger children who were no longer

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attending school (Myers et al., 2020; Krukowski et al., 2021). Evidence from early in the pandemic has suggested women have been more heavily impacted by many of these societal changes than men (Myers et al., 2020). In assessment of journal articles published, as a surrogate for productivity, Nguyen et al. showed women published fewer articles in ophthalmology journals in 2020 relative to previous years (from 528 articles analyzed) (Nguyen et al., 2021). Ipe et al. particularly revealed a detrimental impact on women first authors in transfusion medicine publishing (Ipe et al., 2021). We have shown similar effects, again highlighting a particular impact on first authors, in articles published in the cross-disciplinary journal Brain Behavior and Immunity (with 265 articles analyzed) (Ribarovska et al., 2021). A more comprehensive investigation by Squazzoni and colleagues has examined data from more than 5 million authors submitting papers to Elsevier journals. These data only cover submissions, not acceptances, but suggest that overall manuscript submissions increased in 2020 relative to 2019 (by 30%) but that this increase was significantly less substantial in women than in men (Squazzoni et al., 2021). The impact on women's productivity was similar across the health and medicine, life sciences, physical sciences and engineering, social sciences, and economics disciplines, but younger women (less than 20 years after their first publication) were more impacted than older. These data also demonstrate that women submitted fewer COVID-19-related manuscripts than men did in the same time frame (Squazzoni et al., 2021). Notably, faculty with younger children (0–5 years) may have been more heavily impacted (Krukowski et al., 2021).

These studies have provided valuable insight into the potential for a women-specific impact on productivity during the COVID-19-related lockdowns. However, many of these investigations have been limited by their small scale, field specificity, and potentially their prematurity in that most cover submissions rather than publications. The difficulty in automating meta-data collection and gender assignment has meant that most studies have been small-scale and focused on individual journals. In addition, the protracted time frame involved in publishing a scientific work (Balas and Boren, 2000; Wratschko, 2009, Grant, 2003) may mean that the full impact of the COVID-19 lockdowns is still becoming evident in scientists' publication records. There is therefore a clear need to generate enduring knowledge assets utilizing high-throughput data--processing methodologies that can be continually built on into the future so that we may understand the full impact of this and future global disasters on the research community. Such data are essential for informing scientific policy to ensure inroads made by women into achieving parity with men are not reversed by external impacts such as this pandemic. As we uncover here, such data may also reveal important sub-sectors of resilience to such impacts, representing resources that can be better exploited going forward. Such studies that have been published so far on this topic have also been complicated by the vastly different impacts the pandemic has had on different populations around the world, meaning it is difficult to understand the primary causes of any impacts in each case.

Australia represents a uniquely well-positioned country from which to directly examine the effects of the pandemic upon productivity in scientific research. A key contributor to high-quality international-grade research, Australia has a relatively manageable yearly publication output making computational analyses highly feasible. Comprising six states and two territories of separate jurisdictions and separate pandemic-related health policies, Australia was largely free of the medical impacts of the virus through 2020 and early '21 (relative to other nations) (ABC_NEWS, 2021). Yet social responses to the pandemic were significant in some states. The state of Victoria, for instance, saw one of the world's longest lockdowns in the early course of the pandemic, with more than 150 days of schools-closure and work-from-home restrictions in 2020 (and more than 280 days total to the end of November 2021) (ABC_NEWS, 2021). In contrast, other states of comparable size, including South Australia, Western Australia, and Queensland, had few COVID-19 cases and no such dramatic lockdown periods. This strategy protected Victoria from COVID-19-related deaths and infections in this early phase but also yielded a 20–30% increase in mental health issues, with women being impacted more than men, a pattern that has been seen with lockdown strategies in other countries (Weitzer et al., 2021). Consequences of the COVID-19 pandemic on the scientific research community that particularly impact women are therefore likely to be readily detected by a comparison of the state of Victoria with other Australian populations and these data are likely to be highly relevant to women worldwide.

Here, we hypothesized that a women-predominant impact of the pandemic-related lockdowns would be reflected in a downturn in the numbers of scientific articles submitted and published by Australian women across the 2020 and 2021 periods, an impact that would be particularly evident in the state of Victoria. We aimed to test this by building a custom workflow using the R programming language; a strategy that can be continually updated into the future to provide ongoing assessment of publication patterns.

1.2. Review of relevant literature

To first assess what current information was available on this topic, we conducted a review of the available literature related to biomedical science (Supplementary Tables 2–4). Broadly, 27 of the 38 relevant articles we found identified a significant reduction in women's productivity in 2020 relative to 2019 and/or in COVID-19-related articles relative to all others, although not all measured parameters were affected. Nine articles identified no or minimal changes (Jordan and Carlezon, 2021; Cook et al., 2021; Quak et al., 2021; Williams et al., 2021; Bittante et al., 2020; Mah et al., 2022; Mannix et al., 2022; Marescotti et al., 2022; Ryskina et al., 2022) and one of the articles identified a significant increase in publications by women in 2020 (DeFilippis et al., 2021). Together these works suggest the pandemic has adversely affected women's productivity but that the nuances of such effects are varied.

The 5 million-author study on submissions by Squazzoni and colleagues revealed an increase in manuscript submissions in 2020 relative to 2019 that was more robust in men than women and that manuscripts reporting COVID-19-related work were similarly affected (Squazzoni et al., 2021). In smaller studies of submitted articles, others have reported either a 4–7% decrease in authorships by women (Kibbe, 2020), a decrease in last author publications by women (Ayyala and Trout, 2021), or no gender-related differences in submissions (Jordan and Carlezon, 2021).

The other large-scale studies on this topic are those assessing gender balance in the registration of pre-prints (Supplementary Table 3). We found six of these, each assessing tens of thousands of articles. These studies agree that overall submissions increased in 2020 relative to 2019 (Wehner et al., 2020; Viglione, 2020; Vincent-Lamarre et al., 2020; Muric et al., 2021; Ucar et al., 2022), with several reporting smaller increases in submissions by women than by men in various databases (Viglione, 2020; Vincent-Lamarre et al., 2020; Muric et al., 2021; Ucar et al., 2022; King and Frederickson, 2021). Notably, Wehner showed a statistically significant increase over time in the gender gap between corresponding authors in medRxiv (from 23% in January 2020 to 55% in April 2020) but not in bioRxiv (from 46% in January 2020 to 47% in April 2020) (Wehner et al., 2020) findings supported by (King and Frederickson, 2021).

Studies of fully peer-reviewed accepted and published articles have, to date, been smaller and restricted to specific journals or groups of journals within a particular field. Five of these articles purporting to investigate gender discrepancies in publishing within the pandemic offer no year comparator to relate their data specifically to this time frame (Bittante et al., 2020; Vasti et al., 2021; Pinho-Gomes et al., 2020; Misra et al., 2021; Mazzalai et al., 2022). These articles do reinforce the understanding that women publish fewer papers than men across medical research but allow limited interpretation of the impact of COVID-19.

DeFilippis and colleagues were the only group to identify an increase in the productivity of women relative to men; this in cardiology journals with a study of around 1600 articles. However, they do record that women published less COVID-19-related work than men within the time frame of the study (DeFilippis et al., 2021). Cook et al. found no differences in the gender of first authors in obstetrics journals during the pandemic relative to before it, with a data set of 655 articles (Cook et al., 2021). Likewise, various reports have shown no gendered impact in medical imaging journals, gynaecologic oncology, emergency medicine, and other related fields (Quak et al., 2021; Mah et al., 2022; Mannix et al., 2022; Ryskina et al., 2022). Two others have reported no differences in the proportions for accepted papers despite fewer articles submitted by women (Williams et al., 2021; Marescotti et al., 2022). On the other hand, four articles have shown strong notable impacts of the pandemic on women's productivity in terms of final publication. Nguyen et al. found that women published fewer articles in ophthalmology journals in 2020 relative to previous years (528 articles analyzed) (Nguyen et al., 2021). Ipe et al. particularly revealed a detrimental impact on first authors that was not seen for senior authors in transfusion medicine publishing (Ipe et al., 2021) and we showed similar effects, again highlighting a particular impact on first authors, in articles published in Brain Behavior and Immunity (265 articles) (Ribarovska et al., 2021). Recently, a large scale study of over 400,000 articles has shown an increase in the publishing gender gap by 7% from 2019 to 2020 with a particular effect on early and mid-career women, those in biology and clinical medicine, and those who were initially highly productive (Madsen et al., 2022).

Finally, a consideration that has been explored in the existing literature is the contribution of women to publications related to COVID-19. These data are interesting from an immediacy point of view since they eliminate the need for considerations of the years a primary data fundamental science manuscript can take from inception to publication. Four articles have exclusively and directly addressed the question of whether women are publishing fewer COVID-19-related articles. The most comprehensive of these is by Lerchenmuller and colleagues comparing 42,898 publications on COVID-19 to 483,232 publications on all topics in the same journals the year prior (Lerchenmuller et al., 2021). These authors conclude that the "gap" (the percentage of articles on which men versus women were first authors) widened by 14 percentage points during the COVID-19 pandemic. Andersen et al. came to a similar conclusion with a database of 101,212 articles (Andersen et al., 2020). Similarly, Gayet-Ageron et al. (63,259 articles) show that women are under-represented in COVID-19 research (Gayet-Ageron et al., 2021). With an assessment of 332,458 articles about COVID-19 or related coronaviruses, Liu et al. conclude that women had a smaller increase in first authorship than men in 2019–2020, mixed-gender collaboration was reduced, and articles authored by women were cited less often than expected based on pre-pandemic citation rates. Encouragingly, they found pre-pandemic publishing and citation levels were restored by September 2020 (Liu et al., 2022). Brown et al. (980 articles) show no association between COVID-19 status and having at least one woman first author overall, except that COVID-19-related publications by women were less likely to be invited works (Brown et al., 2021) and Gabster et al.'s work reflected this with fewer women publishing commentaries on COVID-19 in the Lancet from January to May 2020 than published commentaries in 2018 (Gabster et al., 2020).

With this mixed and early evidence in mind, we compared data across the major Australian states as a test-case for a large-scale, cross-disciplinary assessment of the impact of the pandemic on scientific publications. In particular, we assessed the impact of the pandemic on publications from Victoria, a state that experienced particularly heavy lockdown restrictions, relative to other states that did not.

2. Methods

2.1. Original data collection and cleaning

Publishing data were downloaded from PubMed using the R programming language (2022) and the packages RISmed (2021) and easyPubMed (2019) on September 17, 2021 (updated July 15, 2022). We employed the search terms (Australia [Affiliation] AND (("2019" [Date - Publication]: "3000" [Date - Publication])) to capture all publications associated to Australian authors from 2019, 2020, and 2021; the end date "3000" [Date - Publication] ensured we collected articles published beyond 2020 and 2021 that were submitted to a journal in these years. The data were then reduced to first author, last author, or single author to capture seniority in academia. Single authors were allocated last author status since the gender balance of single authors (33% women) closely resembled that of last authors (38% women) rather than first authors (51% women) across 2019 and 2020. Total authors refers only to first + last. Middle authors were not considered. To focus on Australian authors, the country associated to the author was extracted from the address data; the search term Australia [Affiliation] finds articles where any author is affiliated to Australia. 18.3% of first and last authors were from other countries. An author was deemed working from Australia if we could extract the country, Australian state, Australian city, or Australian research institute from the given address. A binary gender-assignment (either woman or man) was then applied to authors' first names using the gender package in R (2020). Any unassigned authors names were analyzed using the Genderize API to attempt gender-assignment. The earliest date associated to the paper of those downloaded was used as an estimate of submission date; only papers submitted (and then published) from 2019 and beyond were considered. A specific submission date was indicated for 68.6% of the articles. Papers were defined as being about COVID-19 if the title or keywords of the paper contained either "COVID-19" or "SARS-CoV2". Data from Australian Capital Territory, Northern Territory, South Australia, Tasmania, and Western Australia were pooled into a category labelled "Other States" due to their smaller individual populations. The data are available on GitHub.

2.2. Analysis

The data were analyzed using two-sample proportion Z-tests and χ^2-square tests of association. Two-sample proportion Z-tests were used to test for differences in the proportion of total research output contributed by women authors publishing about COVID-19 in 2020 and to test for an ongoing effect between 2020 and 2021. Chi-square tests of association were used to test for differences between the total research output contributed by women authors publishing between 2019 and 2021, and used to test whether there was a gender bias in total research output across states in Australia during the lockdown period (March 2020 until December 2020). All p values were then adjusted using false discovery rate adjustments (Benjamini et al., 2001) and deemed significant if they fell below 0.05. Two of the variables analyzed had missing data. In total, we failed to extract the state of 1% (n = 1913) of authors from the given address, and the gender of 6.1% (n = 11,924) of authors (6.4% in 2019, 5.9% in 2020 and 6.0% in 2021). We did not impute the missing data to avoid circular arguments in our analyses and inflated p-values as a result.

3. Results

3.1. The gender-specific impact of COVID-19 on publishing across Australia

The download and cleaning process resulted in information about 213,225 authors from 121,799 papers submitted for publication between January 2019 and December 2021 and subsequently published

and indexed on Pubmed. A gender was assigned to 85.7% of authors using R and a further 8.2% we assigned using the Genderize API. Of the authors with assigned gender, 44.8% were categorized as women. Only authors with an assigned gender were considered, leaving 200,134 authors in the analysis (Supplementary Table 1). Accuracy in gender assignment with the R software package was established at 99% from a sample of ~100 society registrants personally known to the authors.

The total included number of Australian authors of published papers in 2019 was 56,383, 68,450 in 2020, and 58,336 in 2021. Of this, 24,928 (44.2%) of authors in 2019 were identified as women, 30,685 (44.8%) in 2020, and 26,437 (45.3%) in 2021 with a significant association between gender and publishing year ($\chi^2 = 14.248$, df = 2.0, $p = 0.002$; Fig. 1, Table 1). This relationship was observed for last authors ($\chi^2 = 10.201$, df = 2.0, $p = 0.01$), but not first authors ($\chi^2 = 5.952$, df = 2.0, $p = 0.064$). A *post hoc* analysis revealed this relationship is due to an increase in the representation of women authors from 2019 to 2021 (Fig. 1, Table 1).

Table 1
The gender-specific impact of COVID-19 on publishing across Australia for January 2019 to December 2021.

	Author Gender		P-values	
	Women	Men	Raw	Adjusted
Year - All authors (FIRST + LAST)				
2019	24,928 (44.2%)	31,455		
2020	30,685 (44.8%)	37,765		
2021	26,437 (45.3%)	31,899	0.0008	**0.002**
Year - First authors				
2019	13,677 (51.1%)	13,074		
2020	16,729 (51.6%)	15,707		
2021	14,330 (52.2%)	13,138	0.051	0.064
Year - Last authors				
2019	11,251 (38%)	18,381		
2020	13,956 (38.8%)	22,058		
2021	14,330 (39.2%)	13,138	0.0061	**0.01**

3.2. The gender-specific impact of COVID-19 on publishing by Australian state

To test whether the COVID-19-related lockdowns acutely affected the research output of women authors within Australia, we focused our attention between March 2020, when lockdowns were introduced to varying degrees throughout Australia, through until December 2020. In 2020, Victoria experienced 150 days of lockdown (including schools' closure), New South Wales had several weeks of restrictions but no

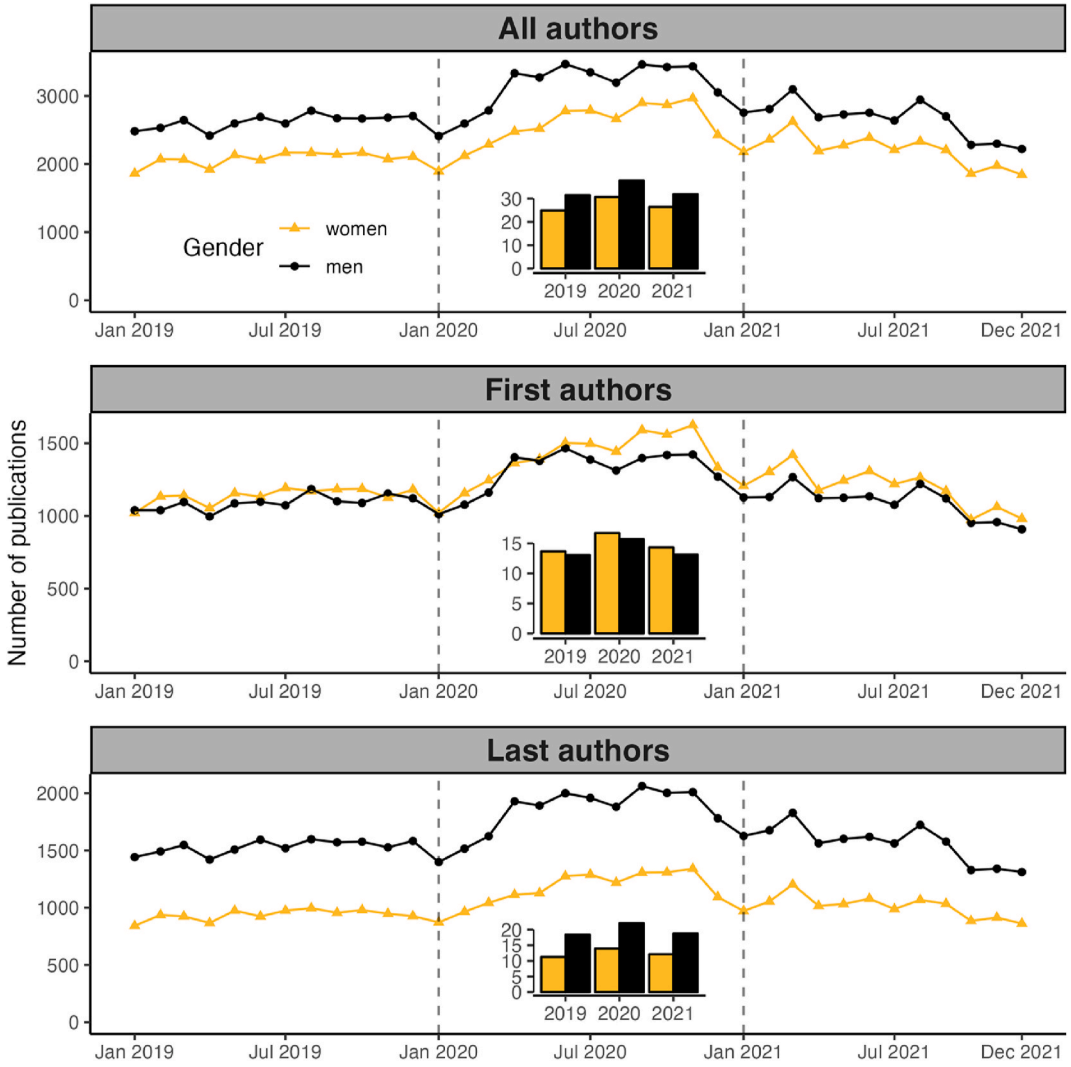

Fig. 1. The gender-specific impact of COVID-19 on publishing across Australia. Although all authors and last authors were less likely to be women, the proportion of women publishing increased from 2019 to 2021. There was an increase in the number of submitted manuscripts in 2020 relative to 2019 and 2021 that was similar irrespective of author gender. There was little gender difference in the number of first author papers across each year. The inset bar graph shows the total number of papers published in each year, in the '000s.

schools' closures, and Queensland experienced around 42 days of lockdowns including schools' closures during this time. We compared the publication output between Victoria, New South Wales, Queensland, and the rest of Australia (Other) to capture varying degrees of lockdown severity.

A chi-square association test showed a significant difference in the number of publications authored by women overall across the states ($\chi^2 = 22.348$, df = 3.0, $p = 0.00018$; Fig. 2, Table 2). This was also seen in first ($\chi^2 = 14.204$, df = 3, $p = 0.0053$) and last authors ($\chi^2 = 10.158$, df = 3, $p = 0.025$). A *post hoc* investigation of these results revealed that this difference was driven by a significant underrepresentation of women authors in Queensland (43.7%) and the "Other" Australian states (43.7%), rather than in Victoria (45.8%) or New South Wales (45.6%). However, these results are not likely due to the COVID-19 lockdowns since the same under-representation is seen in December of 2020 as in March (and in 2019; Supplementary Table 5).

3.3. Gender-specific publication of COVID-19-related articles

Across 2020, 3368 Australian authors submitted and published articles about COVID-19 and/or SARS-CoV2. 1388 of these authors (41.2%) were women, suggesting women authors were publishing significantly less COVID-19-related research than was typical for their publishing in general (z = 4.33, $p = 0.00075$; Fig. 3, Table 3). This effect

Table 2
The gender-specific impact of COVID-19 on publishing by Australian state for March to December 2020.

	Author Gender		P-values	
	Women	Men	Raw	Adjusted
Author state - All authors (FIRST + LAST)				
NSW	8162 (45.6%)	9735		
VIC	8339 (45.8%)	9886		
QLD	4444 (43.7%)	5716		
Other	5475 (43.7%)	7066	0.00006	**0.00018**
Author state - First authors				
NSW	4428 (52.1%)	4076		
VIC	4601 (53%)	4073		
QLD	2411 (50.3%)	2382		
Other	2990 (50.4%)	2937	0.0026	**0.0053**
Author state - Last authors				
NSW	3734 (39.8%)	5659		
VIC	3738 (39.1%)	5813		
QLD	2033 (37.9%)	3334		
OTHer	2485 (37.6%)	4129	0.017	**0.025**

NSW: New South Wales; QLD: Queensland; VIC: Victoria; Other = Australian Capital Territory, Northern Territory, South Australia, Tasmania, Western Australia.

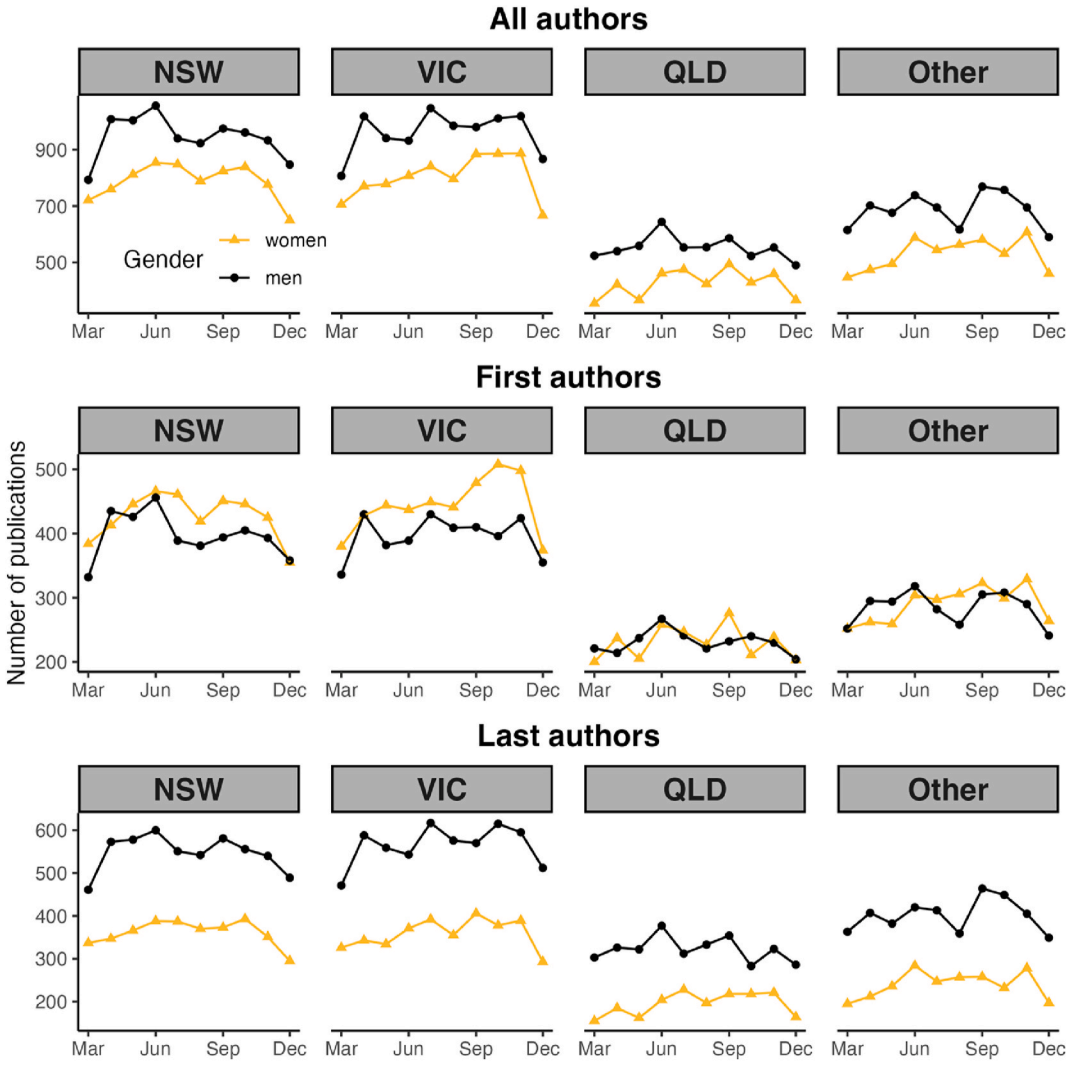

Fig. 2. The gender-specific impact of COVID-19 on publishing by Australian state. There was no significant effect of the submission month on the difference in the number of women authoring publications across the states in 2020.

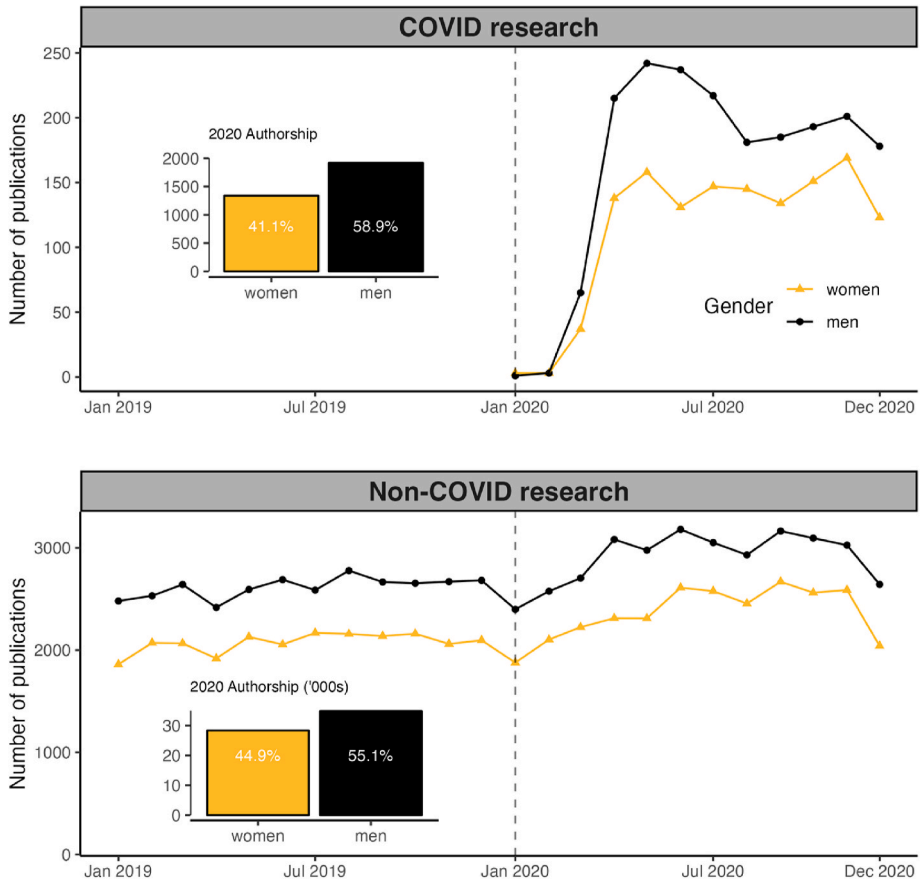

Fig. 3. Gender-specific publication of COVID-19-related articles. Women authors published significantly fewer COVID-19-related articles than was typical for publishing in general in 2020. The inset bar graph shows the total number of papers published in 2020, in the '000s.

Table 3
Gender-specific publication of COVID-19-related articles for January to December 2020.

	Author GENDER		P-values	
	Women	Men	Raw	Adjusted
Research topic - All authors				
non-COVID-19-related	29,297 (45%)	35,785		
COVID-19-related	1388 (41.2%)	1980	0.000015	**0.00075**
Research topic - First authors				
non-COVID-19-related	16,013 (51.9%)	14,864		
COVID-19-related	716 (45.9%)	843	0.0000048	**0.000048**
Research topic - Last authors				
non-COVID-19-related	13,284 (38.8%)	20,921		
COVID-19-related	672 (37.1%)	1137	0.15	0.17

was seen more heavily in first-author women researchers with 45.9% of first authors publishing COVID-19-related work being women relative to 51.9% of first authors of other work being women ($z = 4.57$, $p = 0.000048$).

To assess if this effect was likely to be reflective of a specific paucity of women in virology or viral epidemiology, we also compared the proportion of Australian women publishing in HIV research in 2020. Unlike with COVID-19-related research, the proportion of women authors of HIV-related publications in 2020 (46.8%) was not significantly different ($z = -1.10$, $p = 0.273$) to that of women authors publishing in other areas (44.4%).

3.4. Recovery in 2021

To investigate whether the impact of publication on COVID-19-related articles is an issue of ongoing concern, we downloaded and processed a new batch of data from PubMed on July 15, 2022, using the same search terms. This search returned all articles published in 2021 (35,392 articles from 62,099 first and last authors). Investigating papers relating to COVID-19, we found the proportion of women authors had increased to 48% in 2021 (Fig. 4), suggestive of a recovery of publishing by women in this field. In fact, these data suggest there has been an increased number of women authors publishing on COVID-19 in 2021 when compared with all other research (45% women authors, $z = 3.29$,

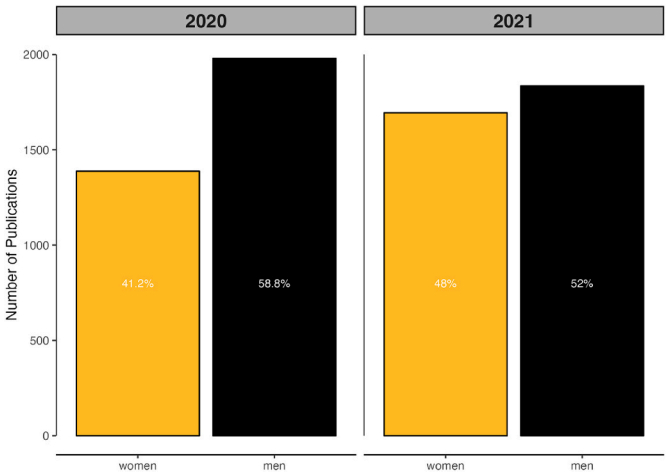

Fig. 4. Gender-specific publication of COVID-19-related articles in 2020 and 2021. Women authors published fewer COVID-19-related articles than was typical for publishing in general in 2020, but this was normalized in 2021.

p = 0.00101).

4. Discussion

4.1. Key findings

The COVID-19 pandemic has affected all facets of society with job losses and mental illness, in addition to the obvious health implications of contracting the virus itself. Our study presents a large-scale assessment of already-published manuscripts as well as the evaluation of different lockdown impacts on productivity to assess the effect of the pandemic on women in Australian biomedical scientific research. Our data demonstrate that in the very short-term, women in Australian science have been largely resilient to the impacts of the pandemic. We show no overall difference in the proportion of Australian publications listed on PubMed that were authored by women between 2019, 2020 and 2021; no difference when these data were analyzed by authorship; and no detrimental effect of being a resident of Victoria, which experienced at least 150 days of lockdowns in 2020, 280 to the end of 2021. We do reveal a concerning early impact of the lockdowns on the proportion of women in Australia publishing articles specifically related to the virus in 2020. This finding was not likely to be due to the relative proportion of women in the fields of virology or epidemiology in this country, since there was no such impact of studies of HIV in the same year. These data suggest that the capacity of women to transition rapidly to new work and new publications was compromised early in the pandemic. Our data accord with other observations that women published proportionally less COVID-19-related work than men in 2020 in biomedical fields (Lerchenmuller et al., 2021; Andersen et al., 2020; DeFilippis et al., 2021; Gayet-Ageron et al., 2021; Liu et al., 2022). Encouragingly, though, this deficit in COVID-19-related publishing seems to be normalizing as the pandemic continues.

Most importantly for the conclusions of our study is that our data collection represents a relatively early stage in the publication process following the initial impact of the pandemic, as does all of the studies on this topic to date. A scientific study often takes many years from inception to publication, and the translation of fundamental discoveries into patents, drug development, and clinical trials takes even longer (Morris et al., 2011). Although exceedingly difficult to calculate an across-the-board mean for the time to fruition of a scientific project (Morris et al., 2011), three teams have independently calculated the lag to translation to practice to be around 17 years (Balas and Boren, 2000; Wratschko, 2009, Grant, 2003). The mean delay from submission to publication within a single journal (i.e. not considering multiple attempts at different journals) is 100 days, and this takes place after a study is largely completed (Powell, 2016). Thus, when working with a time-frame of 5–10 years for an output, it would not be surprising if pronounced and ongoing detrimental effects on women are real but are not yet evidenced in the publication record, despite the apparent recovery into 2021. This idea is supported by the handful of studies that have shown a larger increase in submissions by men than by women in 2020 (Squazzoni et al., 2021; Kibbe, 2020); a larger increase in preprint submissions by men than by women (Viglione, 2020; Vincent-Lamarre et al., 2020; Muric et al., 2021; Wehner et al., 2020); and, as we also show here, a greater proportional contribution by men to COVID-19-related papers published in 2020 than by women (Lerchenmuller et al., 2021; Andersen et al., 2020; DeFilippis et al., 2021).

4.2. Limitations

We acknowledge that our research should be interpreted with some caveats. We are unfortunately unable to categorize authors by self-declared gender, since this information is yet unavailable. Some journals have started collecting preferred gender and preferred pronouns, which will be useful going forward, but it is unclear how this information will be applied to a wider dataset (such as all of PubMed) or applied retrospectively. Our own small-scale test of the gender package in R yielded around 99% accuracy in assignment of gender based on first name, but it should be noted most of the names in this data set were Anglo-Saxon. Names with an Asian derivation, for example, may be less accurately assigned with this software. Nonetheless, previous study has identified this software as performing at least as well if not better than manual identification for large data sets (Rincon and Dominguez, 2021). We also expanded our assignment process with additional software, Genderize, which was able to assign an additional 8% of names. While we are confident that small errors in gender allocation here are likely to have minimal effect on our conclusions in that they would be likely to apply equally across the years, this limitation does highlight the need for further data collection in this area. Unquestionably, comprehensive study of other minority or disadvantaged groups in science is also needed, and appropriate opt-in data collection on these groups is an essential step in this process.

Publication number is, of course, a fairly crude metric of the ultimate contribution to science. Further study on publication quality is also needed, as well as recognition of quality over quantity at the institutional and grant funding levels when considering employment, promotions and award winners. In this regard, it is interesting to note that one of the few studies that has so far investigated both submissions and publications during 2020 notes a disproportionate increase in submissions by men, but not in articles that were ultimately published (Williams et al., 2021). Again, timing may cloud this picture, but these data may also reflect that women have been continuing to produce high-quality work despite the COVID-19-related challenges.

4.3. Going forward

Clearly, we need more data on this issue going forward. Even the absolute impacts of lockdowns are very difficult to estimate. There are no published summaries with data on exactly how many days of lockdown each state experienced, or how many days of schools and childcare closures for each state and district. Even within the states some social isolation rules were applied based on post-code and were not state-wide. Some universities had extremely stringent lock-out policies and others allowed researchers to return to laboratories because of the critical or timely nature of their work. We can definitively report that Victoria experienced 280 days of lockdown (including 111 days consecutively) within the two years, New South Wales, 107, other states markedly fewer, but detail beyond this needs to be formalised and reported (ABC_NEWS, 2021). Likewise, supports and funding for women researchers were not uniformly applied across institutions, so it is very difficult to estimate their impact. This paucity of data highlights that we need to continue to carefully examine the ongoing impact of the COVID-19 pandemic and the social strategies associated with it with expanded studies such as this one. At an individual level, we need to support and promote our women colleagues, including promoting the visibility of expert women scientists. As Ioannidis et al. demonstrate, women are involved less often in media exposure, including around COVID-19, despite frequently being equally if not more qualified (Ioannidis et al., 2021). As a small example, an analysis of the reference list for this article using the gender program in R tells us that 50.0% of the gender-assignable authors we list here are women (12% unassignable). This higher than average proportion may be due to a predominance of women investigating and commenting on gender disparity, but nonetheless this example illustrates that it is possible and relatively simple for authors to ensure we are quoting an appropriate balance of researchers in our publications and this strategy could be adopted as preferred practice by journals.

Together our findings and those of previously published investigations suggest that women may have been disadvantaged in the publishing arena by the pandemic-related social restrictions. In particular, we suggest a reduced capacity to transition rapidly to the imperative work on understanding this SARS-CoV2. Precise reasons for this

are not yet clear but are likely related to an increased burden of caregiver responsibilities (Myers et al., 2020; Weitzer et al., 2021; Krukowski et al., 2021; Blackburn, 2022). Our findings highlight the crucial need for comprehensive data collection going forward, including persistent identifiers across individuals and their project involvement, so that we may understand the scale of the problem of gender inequity and the ultimate value of any interventions. This work also needs to be extended to fields outside the biomedical sciences, since a similar diversity of findings (from pronounced, to no impact) is being revealed in fields as diverse as economics, ecology, and political science (Amano-Patino et al., 2020; Dolan and Lawless, 2020; Fox and Meyer, 2021).

5. Conclusions

Our data demonstrate that in the very short-term, women in Australian science have been largely resilient to the impacts of the COVID-19 pandemic-related lockdowns. We report no impact of the pandemic on the proportion of Australian publications listed on PubMed that were authored by women, and no effect of being a resident of heavily locked-down Victoria. However, with the present study we show that the COVID-19 pandemic has significantly impacted the capacity of Australian women biomedical scientists to publish work on COVID-19-related research within the first year of the pandemic. This finding does not seem to be directly related to the length of government-imposed lockdowns, however. Further research in this area is essential to pinpoint the scale of and reasons for disproportionate negative impacts of the COVID-19 pandemic on women in this arena.

Credit author statement

Matthew Ryan: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Validation; Visualization; Roles/Writing – original draft; Writing – review & editing.Jonathan Tuke: Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Software; Supervision; Validation; Writing – review & editing.Mark Hutchinson: Conceptualization; Methodology; Project administration; Writing – review & editing.Sarah Spencer: Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Resources; Roles/Writing – original draft; Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

We have shared a link to the data in the Methods section

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Appendix A. Supplementary data

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