Meta-research: The effect of the COVID-19 pandemic on the gender gap in research productivity within academia

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Abstract

Background:
A commonly used metric for evaluating academic success, the number of published articles, focuses on processes that select against female academics. Novel social conditions induced by COVID-19 pandemic likely exacerbated this gender-bias if female academics took on the load of caregiving, domestic, service and teaching roles. We investigate the pandemic effect on the gender gap in research productivity through a systematic review and meta-analysis of published articles across scientific disciplines.
Methods:
We identified 50 relevant articles with 115 effect sizes that measure the impact of the COVID-19 pandemic on gender-specific research productivity, commonly as the number of submitted/published articles (n=97). We conducted a meta-analysis to 1) investigate the effect of the pandemic on the gender gap in research productivity within academia and 2) test hypotheses on how research field, breadth of gender gap before the pandemic, and authorship position influence this effect.
Results:
Overall, the gender gap in research productivity within academia has increased during the COVID-19 pandemic compared to before, especially in social sciences and medicine, fields that were previously nearest to being gender equal. We did not detect an influence of authorship position on the effect.
Conclusions:
We detected that gender biases favouring the productivity and perceived impact of men in academia overall strengthened during the pandemic. We encourage academic and funding institutions to consider a range of different metrics to evaluate academic impact, and to further acknowledge and accommodate individual circumstances.

Subjects: Academia, Gender Bias, Research Productivity
Key words: COVID-19, Pandemic, Academia, Gender bias, Women researchers, Research productivity

Introduction

Background

Many traditionally used metrics for evaluating academic merit have clear biases against individuals historically underrepresented in academia (Davies et al., 2021; Shandera et al., 2021). Such metrics include the number (and perceived prestige) of manuscripts or publications (West et al., 2013; Larivière et al., 2013; Huang et al., 2020), or the amount of funding acquisition (Shen, 2013; Valentova et al., 2017; James, Chisnall & Plank, 2019; Safdar et al., 2021). Those who publish less, or acquire less funds are commonly perceived as having lower research productivity. This can negatively impact other metrics for evaluating merit and career progression, "snowballing" the strength of selection against certain individuals in academia (Bol, Vaan & Rijt, 2018). Academic research comes with many traditional restrictions and constraints that bias access to merit and career progression towards those in the right socio-economic circumstances (Morgan et al., 2022). Many of these circumstances intersect with gender, leading to a large body of research showing disadvantages can compound for women compared to men when success is measured using traditional metrics, despite no actual differences in contribution and impact of research (Armstrong & Jovanovic, 2015; Zeng et al., 2016; Langin, 2019; Huang et al., 2020; Romano, 2021; van der Wal, Thorogood & Horrocks, 2021; Kozlowski et al., 2022). The COVID-19 pandemic has influenced social circumstances by creating novel living and working conditions, potentially worsening the research productivity, measured in these traditional ways, of many women worldwide (Anwer, 2020; Boncori, 2020; Guy & Arthur, 2020; Altan-Olcay & Bergeron, 2022). Here, we investigate the potential effect of the pandemic on publication and submission output and other self-reported measures from surveys of research productivity of female and male academics.

Multiple factors are likely to contribute to gender-biased impacts on research productivity during a pandemic. First, women, including those in academia, generally perform more unpaid caregiving and domestic work (Schiebinger, Henderson & Gilmartin, 2008; Schiebinger & Gilmartin, 2010). As many countries enforced social-distancing and closed facilities during the pandemic, this has increased caregiving and domestic burdens (Carli, 2020; Carlson, Petts & Pepin, 2020) at times when community help from nurseries, schools, care homes, house cleaners, laundrettes, nannies, babysitters and family was limited (Myers et al., 2020; Barber et al., 2021; Breuning et al., 2021; Deryugina, Shurchkov & Stearns, 2021; Shalaby, Allam & Buttorff, 2021). These additional tasks, which disproportionately have fallen on women, likely encroached on the time and space for academic research during "work-from-home" conditions (Abdellatif & Gatto, 2020; Boncori, 2020; Guy & Arthur, 2020). Second, the distribution of work within academic institutions is often gendered. Women undertake more 'non-promotable tasks (Babcock et al., 2022) such as administrative, supportive and mentoring roles (Porter, 2007; Mitchell & Hesli, 2013; Babcock et al., 2017; O'Meara, Kuvaeva & Nyunt, 2017; O'Meara et al., 2017; Guarino &

Borden, 2017). Changes in teaching and administration in response to the pandemic were therefore more likely to be facilitated by women (Docka-Filipek & Stone, 2021; Minello, Martucci & Manzo, 2021). Third, labour roles contributing towards publication are also gendered with women generally performing more technical work such as generating data, whilst men assume more core tasks in conceptualisation, analysis, writing and publishing (Macaluso et al., 2016). Pandemic closures to research institutions would therefore likely impact women authorship stronger than men. Additionally, the surge in publications during the pandemic (Else, 2020) could have led to reductions in the quality of peer review, with evaluation being more influenced by cognitive shortcuts. These shortcuts are often associated with biases tending to operate against women (Kaatz, Gutierrez & Carnes, 2014; Reuben, Sapienza & Zingales, 2014; Carli, 2020) such that women tend to have lower success in getting submissions accepted (Fox & Paine, 2019; Murray et al., 2019; Day, Corbett & Boyle, 2020; Hagan et al., 2020).

The role these factors had during the pandemic in shaping the gender gap in research production might differ across research fields (Madsen et al., 2022). One possibility is that research fields that were already more gender-biased may have experienced the most exacerbated gender gaps during the pandemic. In fields that were already traditionally more gender-biased, less support may have been available to women to balance the effects of the pandemic. Male-dominated fields often lack viewpoints of female colleagues, and might therefore be less likely to identify and support paid care work or extended leave options (Clark, 2020; Nash & Churchill, 2020). An alternative possibility is that the pandemic might have eroded the support structures that existed in fields with higher gender balance, thereby reducing the differences in gender biases between research fields. Even in fields that appear more gender-balanced, “glass ceiling” effects remain such that imbalances can increase with higher academic rank (Addessi, Borgi & Palagi, 2012). The pandemic may also have exacerbated a gender gap in authorship position (first, middle or last) (King & Frederickson, 2021) if additional service, teaching, caregiving, and domestic roles taken up by female academics during the pandemic may limit their abilities to perform research (as first authors) or lead research (as last authors) but not supporting research (as middle authors).

Here, we use a systematic review and meta-analysis to study the impacts off the COVID-19 pandemic on research productivity across scientific disciplines, and to test hypotheses on how research field, breadth of gender gap before the pandemic, and authorship position might influence the strength of the effect. The impact of the pandemic on gender biases in research productivity has been explored in anecdotal accounts (Boncori, 2020; Excess Beth [@El_Dritch], 2020; Fazackerley, 2020; National Academies of Sciences, 2021), surveys of potentially affected people (Myers et al., 2020; Rodríguez-Rivero et al., 2020; Barber et al., 2021; Breuning et al., 2021; Deryugina, Shurchkov & Stearns, 2021; Diaz et al., 2021; Gao et al., 2021; Ghaffarizadeh et al., 2021; Guintivano, Dick & Bulik, 2021; Hoggarth et al., 2021; Krukowski, Jagsi & Cardel, 2021; Maguire et al., 2021; Plaunova et al., 2021; Shalaby, Allam & Buttorff, 2021; Staniscuaski et al., 2021; Yildirim & Eslen-Ziya, 2021; Ellinas et al., 2021; Davis et al., 2022; Stenson et al., 2022), and comparisons of numbers of articles submitted or published by gender before and during the pandemic (Amano-Patiño et al., 2020a; Andersen et al., 2020; Bell & Green, 2020;

Cushman, 2020; Wehner, Li & Nead, 2020; Bell & Fong, 2021; Biondi et al., 2021; Cook et al., 2021; DeFilippis et al., 2021; Forti, Solino & Szabo, 2021; Fox & Meyer, 2021; Gerding et al., 2021; Ipe et al., 2021; Jemielniak, Sławska & Wilamowski, 2021; Lerchenmüller et al., 2021; Muric et al., 2021; Nguyen et al., 2021; Quak et al., 2021; Ribarovska et al., 2021; Squazzoni et al., 2021; Williams II et al., 2021; King & Frederickson, 2021; Gayet-Ageron et al., 2021; Anabaraonye et al., 2022; Ayyala & Trout, 2022; Chen & Seto, 2022; Cui, Ding & Zhu, 2022; Harris et al., 2022; Wooden & Hanson, 2022). Few studies compare between research fields and authorship positions (Andersen et al., 2020; Forti, Solino & Szabo, 2021; Jemielniak, Sławska & Wilamowski, 2021; Muric et al., 2021; Nguyen et al., 2021; Squazzoni et al., 2021; King & Frederickson, 2021; Gayet-Ageron et al., 2021). One review qualitatively evaluated separate findings of the pandemic effect on the gender gap in research productivity (Herman et al., 2021), though the effects were not quantitatively explored. We build on this literature by calculating the overall effect of the COVID-19 pandemic on productivity measures, and further explore how research field, breadth of gender gap before the pandemic and authorship position might influence the effect.

Objective

Our main objective was to quantitatively calculate the overall effect of the COVID-19 pandemic on gender bias in research productivity and whether the bias changed compared to the period just prior to the pandemic. Our focus is on comparing the effect of the pandemic on women relative to men. We recognize that gender extends beyond this comparison, and that biases are even more likely to target individuals whose identities are less represented and often ignored. These biases present in a lack of study of the full diversity of gender precluded our ability to include these effects in a meta-analysis. While several of the surveys we include had the option for respondents to identify beyond the binary women/men, none of these studies report on these individuals, presumably because of the respective small samples. In addition, all studies using numbers of submissions or publications (33 out of 50) to measure research productivity used automatic approaches that are more likely to mis-gender individuals as they inferred binary gender based on first names. While these approaches seemingly offer the potential to identify trends in larger samples, they themselves introduce and reinforce biases in relation to gender that are hard to assess, intersecting with biases in ethnicity as these approaches are often restricted to names common in English speaking countries (Mihaljević et al., 2019). The patterns we describe should be seen as a potential indication that biases exist, but alternative approaches are needed to speculate about potential underlying causes and remedies.

Specifically, we tested three hypotheses and their corresponding predictions. First, we hypothesised that the pandemic has increased the disparity in research productivity of women versus men because of women undertaking more domestic roles at home, and more ‘non-promotable tasks’ at work (Hypothesis 1). We predicted that the gender gap in research productivity has increased during the pandemic compared to the period just before (Prediction 1a). As studies differ in the type of research productivity measured, between individual survey responses, numbers of submissions and numbers of publications, we investigated the influence this might have on the gender gap increase observed during the pandemic, but with no expectation of any differences (Prediction 1b). Second, we hypothesised that the pandemic has increased the gender gap differentially across research fields because of differences in working conditions and support structures in place (Hypothesis 2). We first explored variation in the gender gap increase across research fields (Prediction 2a) and then explored the interplay of research field according to the previous size of the gender gap. We predicted the gender gap is exacerbated in fields that already had a previously greater gender gap, as according to the proportion of female authors, because of less support available to women to balance the effects of the pandemic (Prediction 2b). Third, we hypothesised the disparity in favourable authorship positions has increased because female academics have been especially more limited in undertaking leading, but not supportive research roles in lockdown conditions (Hypothesis 3). We predicted that the pandemic has increased the gender gap more in first and last, rather than middle authorship positions (Prediction 3a).

Results

Our systematic literature review identified 50 articles that met the inclusion criteria (for details on the procedure please see the Methods section). We extracted and calculated 150 effect sizes from these articles, and performed a meta-analysis and meta-regression to test our three hypotheses and related predictions.

1a: Has the pandemic increased the gender gap in research productivity across academia?

Across all samples, after controlling for multiple effect sizes from the same study, we found the relative productivity of women to men decreased during the pandemic at -0.070 compared to before the pandemic (95% CI= -0.1020 to -0.0380, SE= 0.0163, p-value= <0.0001, Fig. 1). There is large variation in the 115 effect sizes, with 32 indicating a clear increase in the gender gap and 43 a trend of an increase, while 12 indicate a clear decrease in the gender gap and 28 a trend of a decrease. Total heterogeneity was high ($I^2 = 97.8\%$), with 49.1% of it explained by whether research productivity was measured by survey responses or submission/publication numbers and 49.8% explained by the individual effect sizes.

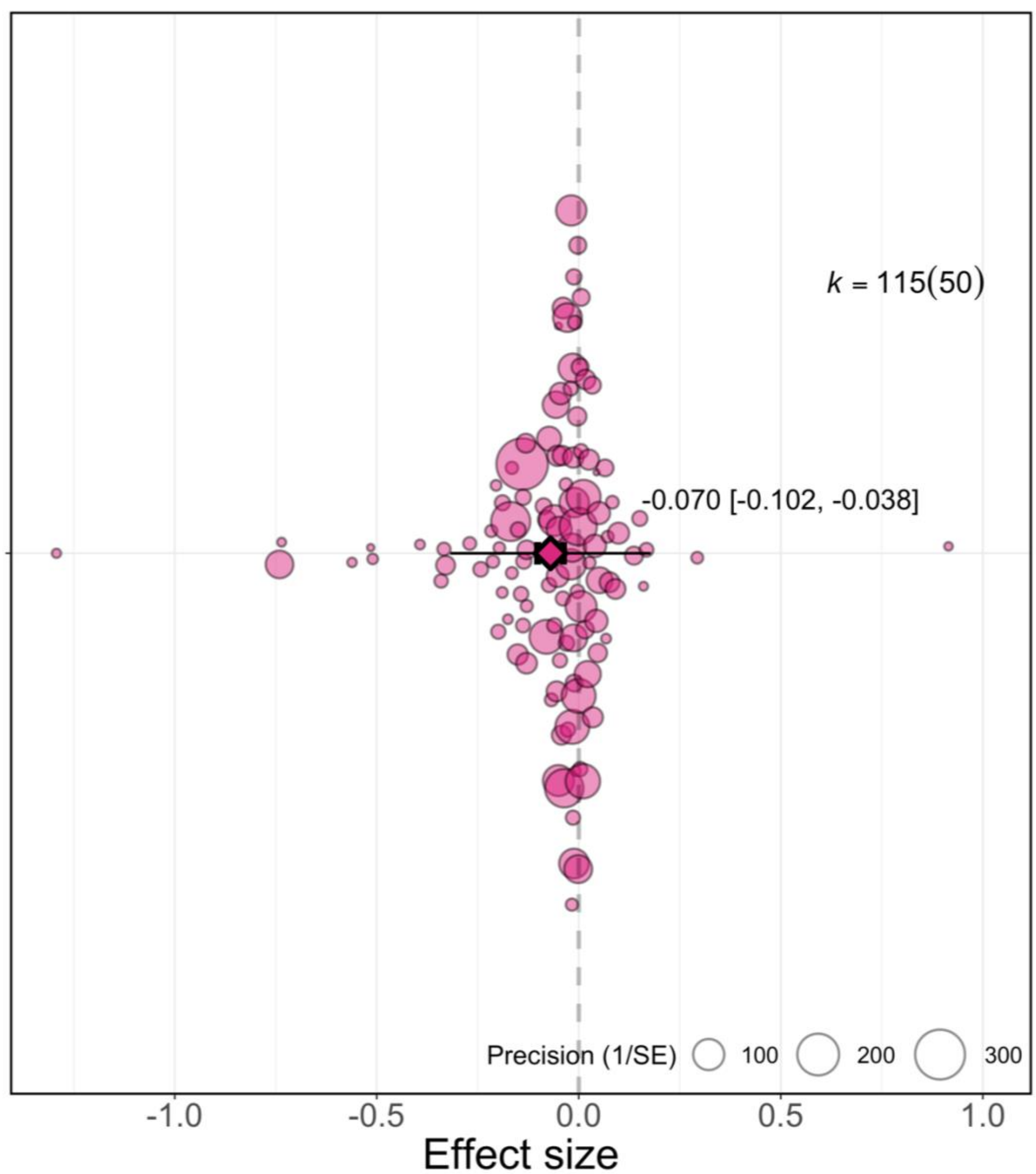

Figure 1. Overall effect of the pandemic on academia's gender gap in productivity. Orchard plot showing all 115 effect sizes (points) and their weight (point size), with the mean effect size (darker coloured point outlined black and vertically centred), the 95% confidence interval (horizontal thick black bar) and the 95% prediction interval of the expected spread of effect sizes based on between-study variance (horizontal thin black bar). k =x(y), where x is the number of effect sizes and y is the number of studies.

1b: Does the type of research productivity measure influence how much the pandemic has changed the gender gap in research productivity?

The degree of increase in the gender gap caused by the pandemic differed according to the type of research productivity measured (p-value= 0.0021, Fig. 2). Studies measuring changes to research productivity during the pandemic based on surveys detected a larger overall effect (-0.193, 95% CI= -0.235 to -0.125, SE= 0.041, p-value< 0.001) than studies that compared the number of articles published (-0.046, 95% CI= -0.082 to -0.009, p-value= 0.014, SE= 0.019) or submitted (-0.039, 95% CI= -0.076 to -0.001, p-value= 0.044, SE= 0.019) by authors of each gender before and during the pandemic.

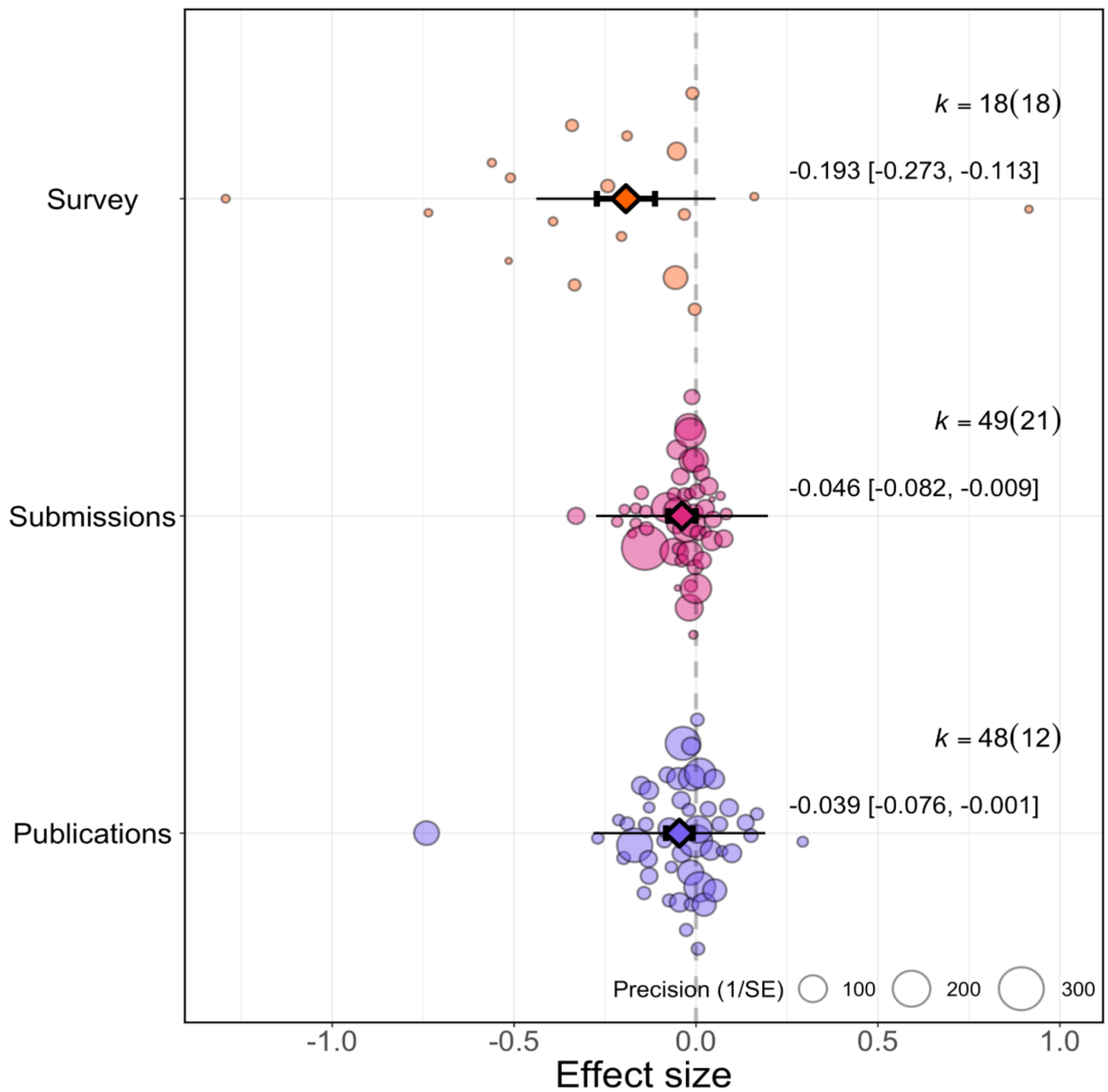

Figure 2. Type of research productivity measure influence on academia's gender gap during the pandemic. Orchard plots comparing the distribution of effect sizes (points) and their weight (point size) depending on the type of research productivity measured for which the mean effect size (darker coloured points outlined black and vertically centred), the 95% confidence interval (horizontal thick black bar) and the 95% prediction interval of the expected spread of effect sizes based on between-study variance (horizontal thin black bar) is given. k =x(y), where x is the number of effect sizes and y is the number of studies.

2a: Has the pandemic affected women differently across research fields?

We found little evidence of a significant differential impact of research fields on the reported effect sizes (QM (df=4)= 6.341, p-value= 0.175, Fig. 3). When considering research fields individually, social sciences showed the greatest increases in the academic productivity gender gap during the pandemic (-0.079, 95% CI= -0.141 to -0.018, SE= 0.031, p-value= 0.011), followed by multidisciplinary fields (-0.058, 95% CI= -0.139 to 0.023, SE= 0.041, p-value= 0.164), and then medicine (-0.051, 95% CI= -0.090 to -0.012, SE= 0.020, p-value= 0.011). The pandemic showed little effect in biological sciences (-0.004, 95% CI= -0.-0.059 to -0.050, SE= 0.028, p-value= 0.874) or Technology, Engineering, Mathematics, Chemistry and Physics fields (0.006, 95% CI= -0.048 to 0.060, SE= 0.028, p-value= 0.827).

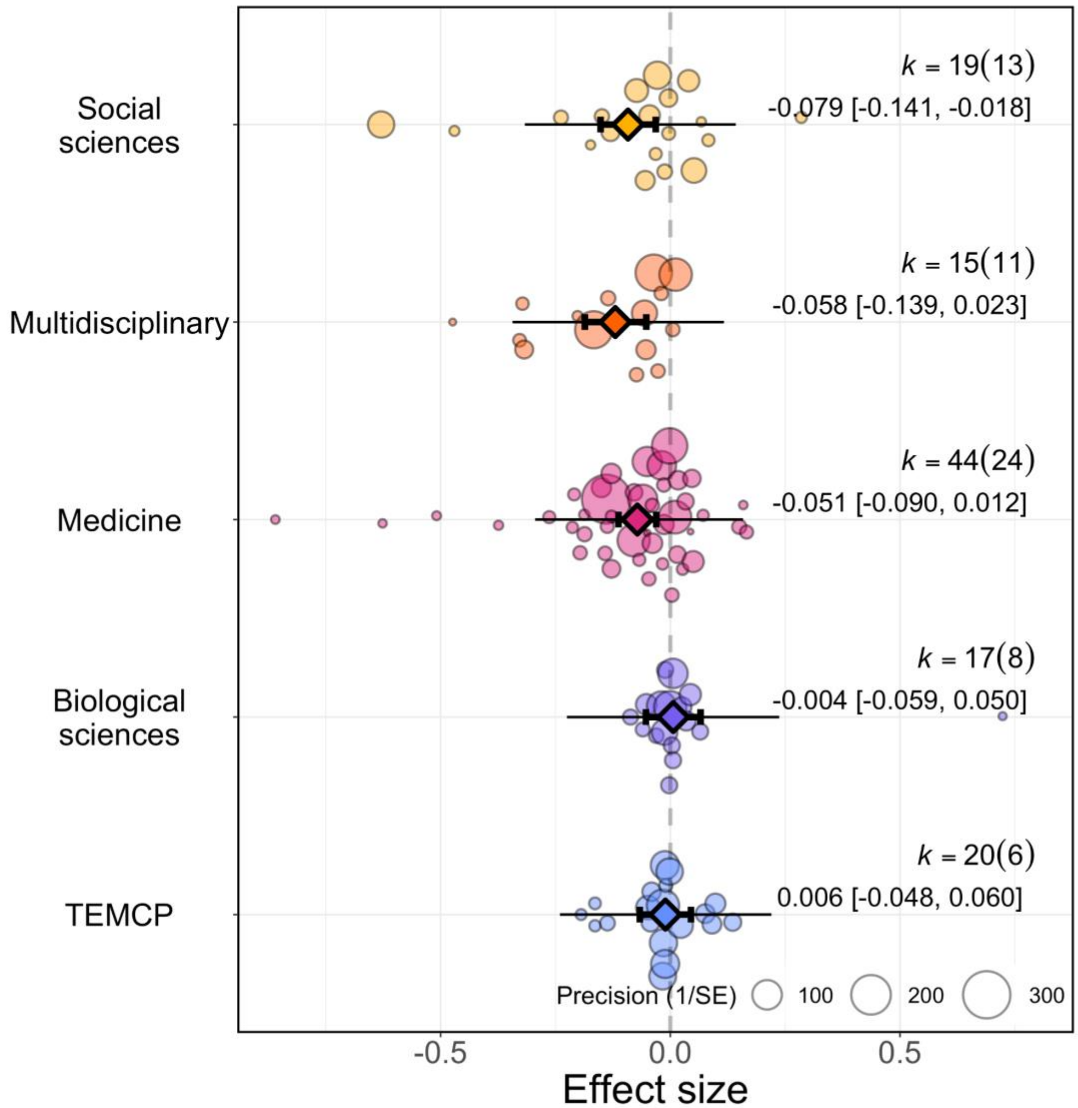

Figure 3. Research field influence on academia's gender gap during the pandemic. Orchard plot comparing the distribution of effect sizes (points) and their weights (point sizes) depending on the research fields sampled, for which the mean effect size (darker coloured points outlined black and vertically centred), the 95% confidence interval (horizontal thick black bar) and the 95% prediction interval of the expected spread of effect sizes based on between-study variance (horizontal thin black bar) is given. TEMCP stands for Technology, Engineering, Mathematics, Chemistry and Physics. k =x(y), where x is the number of effect sizes and y is the number of studies.

2b: Has the pandemic exacerbated existing differences in gender biases across research fields?

The pandemic has increased the gender gap in article output more in journals/repositories/pre-print servers that were previously less gender-biased (QM(df = 1) = 11.0156, p-value= 0.0009). When grouping studies by research fields (Fig. 4), those with a smaller gender gap prior to the pandemic experienced greater increases in the gender gap in academic productivity during the pandemic compared with fields where the gender gap was already large to start with (Social sciences: 0.377% to 0.358%, medicine: 0.369% to 0.346%, multidisciplinary: 0.392% to 0.367%, biological sciences: 0.328% to 0.328%, Technology, Engineering, Mathematics, Chemistry and Physics: 0.222% to 0.222%).

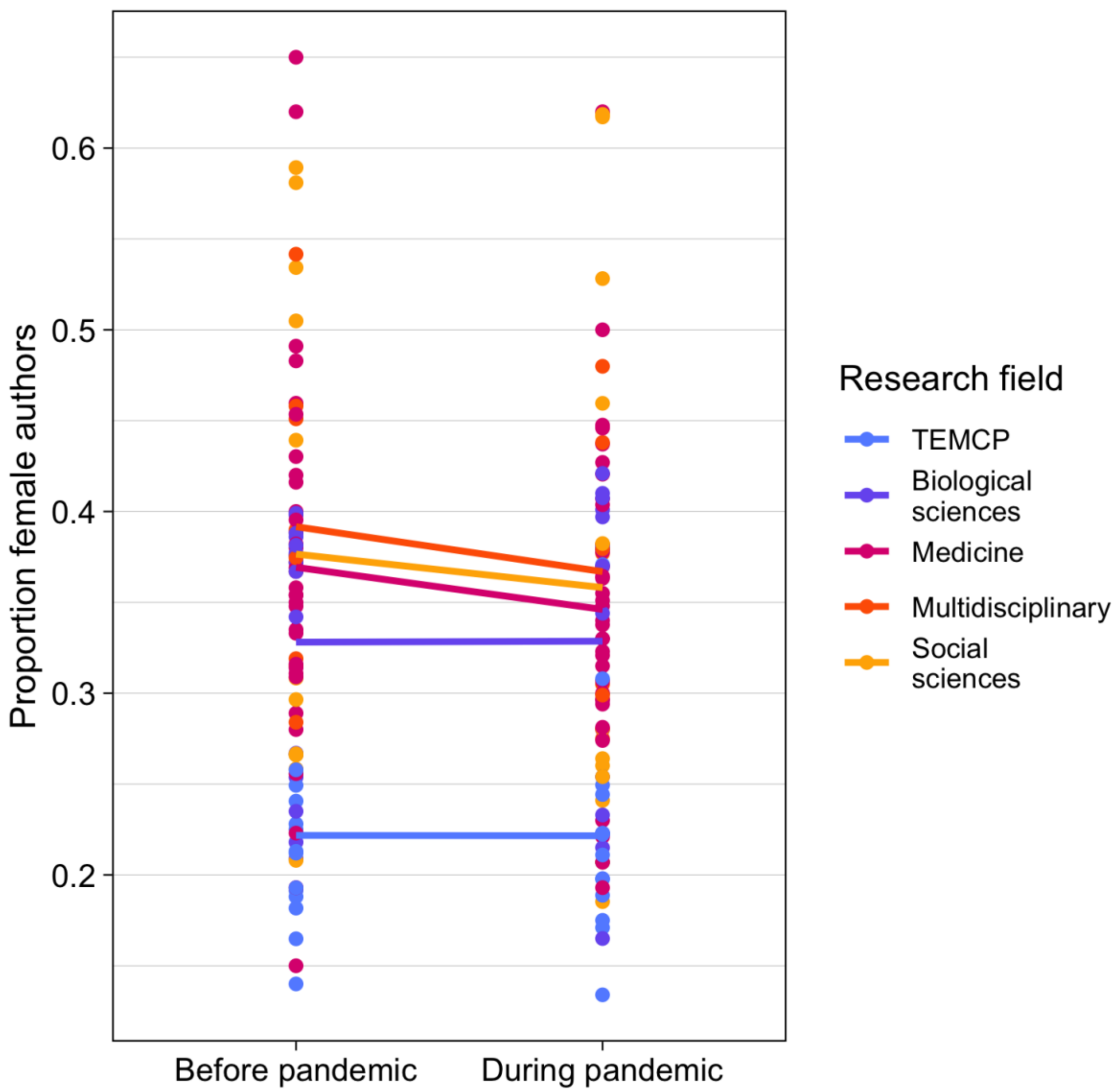

Figure 4. Research field influence on academia's gender gap in submissions and publications during the pandemic. Line plot of gender gap in authorship before and during the pandemic, grouped by research field. Points show gender gap as the proportion of female authors publishing and submitting before or during the pandemic and are coloured according to research field. Lines take the mean value of these points according to research field. TEMCP stands for Technology, Engineering, Mathematics, Chemistry and Physics.

3a: Has the pandemic affected women more in their ability to lead rather than support research?

We found no evidence of a significant differential impact of authorship position on effect sizes (QM(df = 5) = 8.133, p-value = 0.149, Fig. 5).

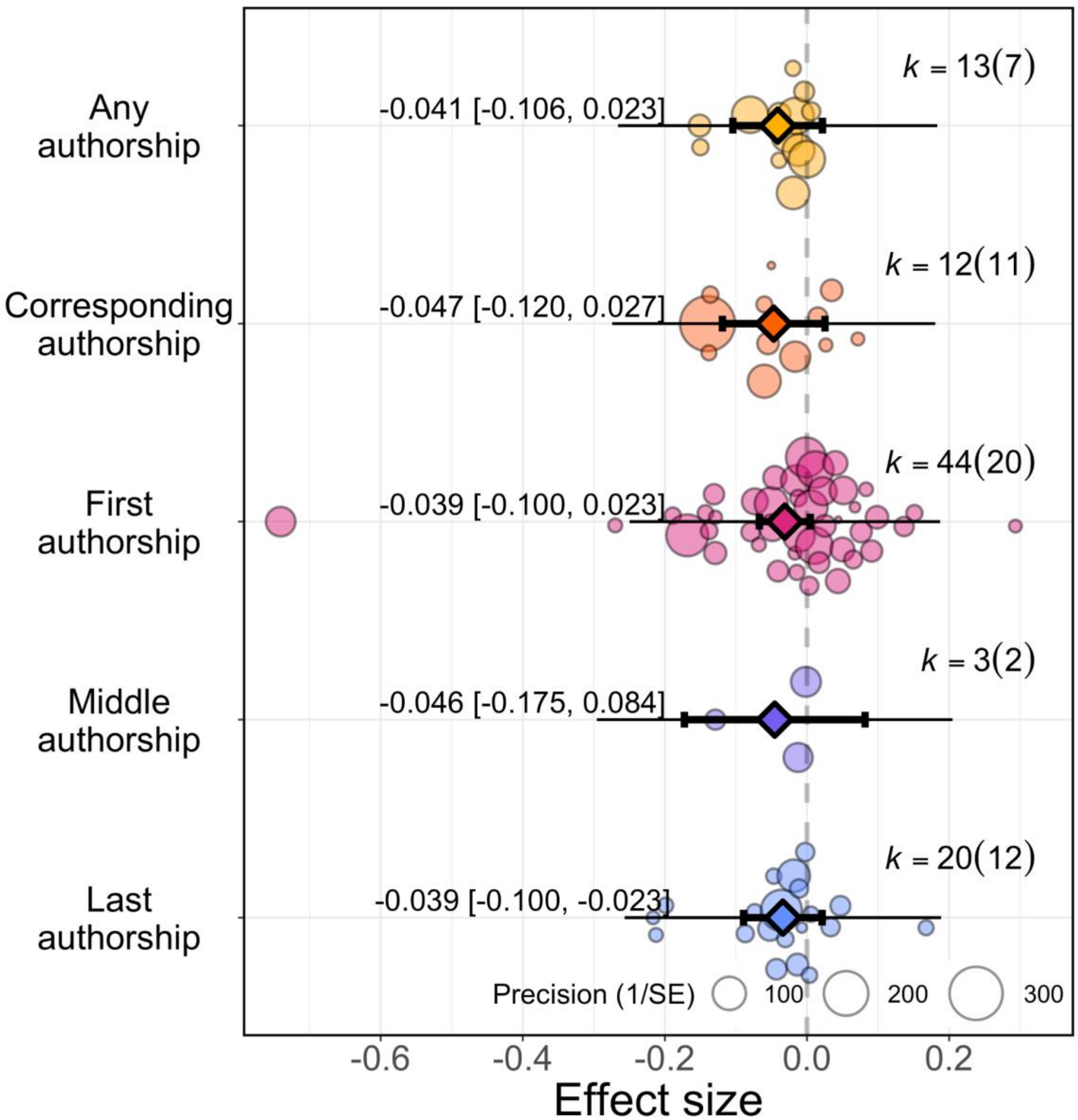

Figure 5. Authorship position and academia's gender gap during the pandemic. Orchard plot comparing the distribution of effect sizes (points) and their weight (point sizes), depending on the authorship position sampled in publication studies, for which the mean effect size (darker coloured points outlined black and vertically centred), the 95% confidence interval (horizontal thick black bar) and the 95% prediction interval of the expected spread of effect sizes based on between-study variance (horizontal thin black bar) is given. k =x(y), where x is the number of effect sizes and y is the number of studies.

Is there evidence of publication bias?

We found no evidence of publication bias based on our multilevel meta-regression, suggesting small studies with large effect sizes did not skew our model (Article-output studies: slope= -0.026, 95% CI= [-0.061- 0.009], SE=0.018, $p=0.140$; Survey-response studies: slope= -0.190, 95% CI= [-0.286- -0.095], SE=0.049, $p<0.001$). A visual inspection of the funnel plots (Fig. 6) similarly did not indicate any suggestion of publication bias.

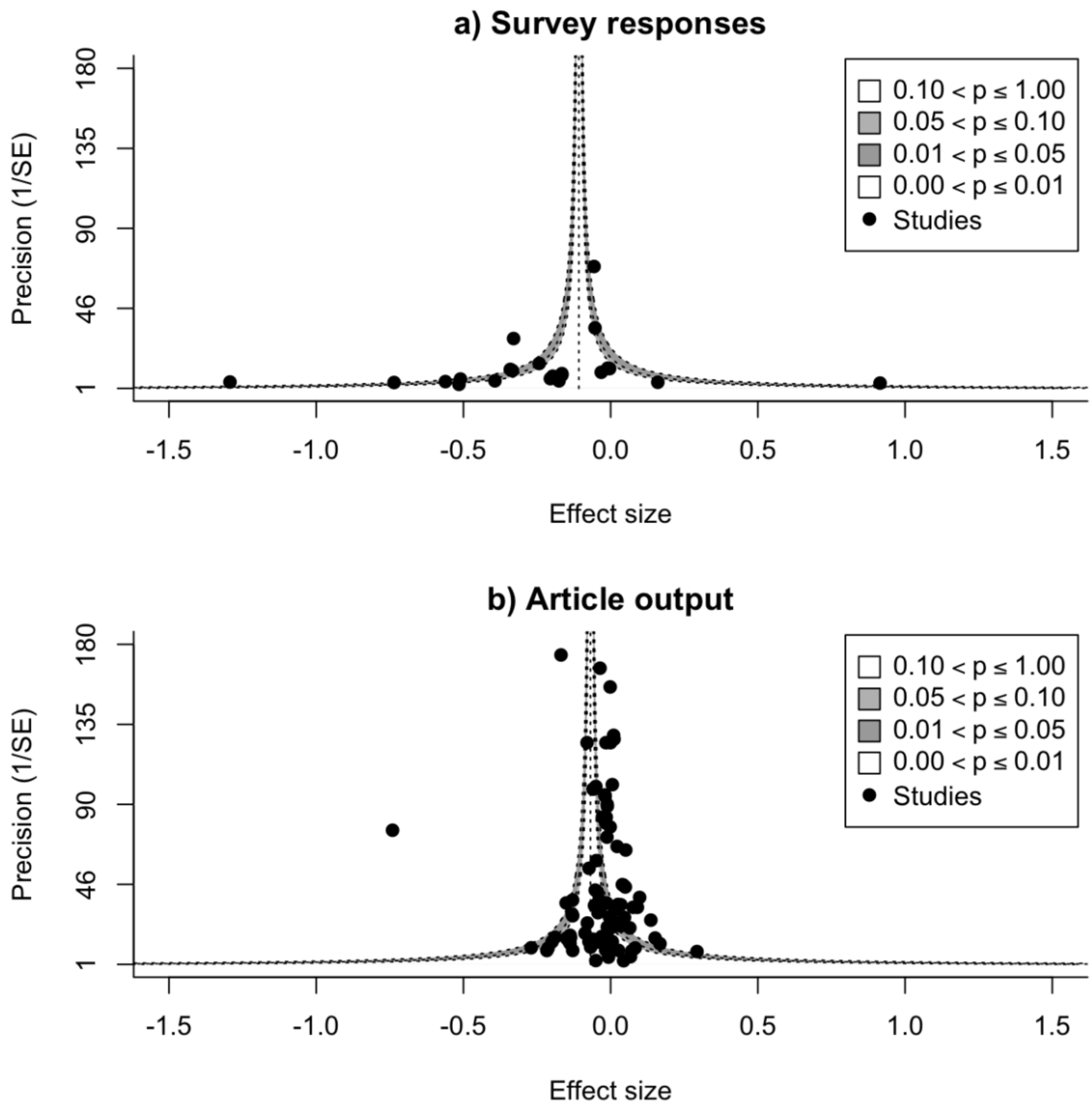

Figure 6. Investigating publication bias. Funnel plot of effect sizes and their precision, as a function of standard error, from studies that measure research productivity by (a) survey-responses (b) article output. The vertical dashed line is the summary effect size. The legend outlines levels of statistical significance for effect sizes based on their precision.

Discussion

Our study finds quantitative evidence, based on 50 studies and 115 effect sizes, to support the hypothesis that the COVID-19 pandemic has exacerbated gender gaps in academic productivity. These findings are consistent with the notion that novel social conditions induced by the pandemic have disadvantaged women in academia even more than before. Overall, the studies summarised in our meta-analysis suggest that the gender gap in research productivity within academia has increased during the pandemic by 7%. We found no evidence of a publication bias. There is high heterogeneity in the effect sizes reported from different studies, arising from the type of research productivity measured. When measuring research productivity as the number of published or submitted articles, we find a slightly smaller increase in the gap of around 4%. This corresponds to the proportion of authors on submitted/published articles who are women declining from an average of 34.0% pre-pandemic to 32.6% during the pandemic (-0.04*34.0%=-1.4%). Such a change might reflect lower submission and acceptance rate of articles by women compared to their male colleagues or an increased drop-out of woman from academia caused by the pandemic.

Our study likely underestimates the pandemic effect on article productivity in women because writing and publishing can take a long time (Powell, 2016). Many of the articles submitted or published during the pandemic were likely started and at least partially completed prior to the pandemic, given that most research grants span multiple years. With restricted access to laboratories, field sites and collaborators, many new projects have been delayed (Corbera et al., 2020), making it likely that the article-output studies we could include by the time our study started in 2021 underestimates the true effect of the pandemic, which might span over many years. In support of this view, we find some indication for a larger, real-time effect from the effect sizes based on survey responses, which indicate a much stronger negative effect of the pandemic on women's productivity compared to men's (effect size = -0.19). This signals that women are one fifth more likely than men to indicate that the pandemic has negatively affected their academic activities, which may stem from a combination of women on average feeling a larger strain, and a larger proportion of women being severely affected by the pandemic. In the literature used within our meta-analysis, five of six survey studies report evidence of a negative interaction effect of being both female and a parent on research productivity during the pandemic, presumably because of increased caregiving demands. Effect sizes are highly varied in survey response studies, which may reflect subtle differences in the measure of research productivity asked in the survey or some populations of survey respondents having strong opinions of the pandemic.

Our analysis suggests the pandemic may have differentially impacted female researchers across research fields, with increases in gender gaps particularly visible in research fields that were nearest gender-equality before the pandemic. Social sciences and medicine were two fields closest to gender equality that experienced the most significant decrease in female authors.

Female researchers working in fields with previously gender-equitable environments may have experienced new, difficult research conditions induced by the pandemic, whereas in gender-biased fields, these difficulties might already have been present. For example, financial structures or childcare arrangements that could previously assist parents with caregiving responsibilities may have broken down during the pandemic (Fortin & Taylor, 2020; National Academies of Sciences, 2021). Alternatively, social sciences and medicine are fields that could have had the greatest surge in COVID-19 and pandemic-related research. Women in social sciences and medicine potentially had less opportunities to pursue this new pandemic-related research because of extra work performed in gender roles, or because women already had relatively smaller collaborative networks, fewer senior positions and less funding. Additionally, many medical journals sped up the publication process (Horbach, 2020), so the real-time effect of the pandemic on research productivity in women versus men may be reflected more in the biases in papers submitted and published in medicine than in other fields.

We did not find a clear signal that biases in research productivity differed according to authorship positions on submitted/published articles. We were limited in addressing this prediction because the samples used for calculating effect sizes for particular authorship positions were too small to infer whether there was a differential change in the gender gap.

Our study cannot identify the causes of the increased biases in research productivity during the pandemic. It seems unlikely that this increase in the gender gap simply represents a normal temporal fluctuation. The survey results, which report the strongest effects, specifically focused on the influence of the pandemic above and beyond the pressures researchers might already normally experience. The 4% decline in the proportion of authors who are women also likely indicates the extraordinary circumstances of the pandemic. This decline is remarkable given that a study comparing the change in the proportion of female authors between 1945 and 2005 showed a steady increase from 14% of all authors being women to 35%, with no apparent year-on-year decline since at least 1990 (Huang et al. 2020). As discussed above, the patterns likely reflect a combination of many individuals reducing their productivity rate as well as particularly affected individuals dropping out of academia, with the potential for longer-term effects in the coming years.

Conclusion

Overall, our study highlights an exacerbated gender gap in academic research productivity during the COVID-19 pandemic. This gender gap was exacerbated more in social sciences and medicine, which are fields that were previously less gender-biased and may represent regression in progress made towards gender equality. Academic institutions should acknowledge and carefully accommodate the pandemic period when using research productivity to evaluate female academics for career progression in the coming years. Measures designed to reduce the gender gap in research may inadvertently exacerbate the gap by extending the period that advantaged individuals can outperform. At the broader level, the pandemic presents one social circumstance of many, including class, ethnicity, nationality, religion, disabilities that can interactively compound individual research productivity. More support should be given to academics disadvantaged by social circumstance, and those historically under-represented in academia. Simultaneously, more emphasis could be placed evaluating academic merit using more holistic measures and on an individual basis.

Methods

Search process

We carried out a systematic review to identify, select and critically evaluate relevant research through data collection and analysis. We reported it following PRISMA guidelines (Moher et al., 2009). We carried out the literature search process in three steps: 1) a scoping search, 2) an initial search with pre-selected author terms, and 3) a refined search using terms as recommended by the litsearchR 1.0.0 (Grames et al., 2019). We initially performed a scoping search to determine if there were over ten texts with primary research investigating differences by gender in academic productivity before and during the pandemic. The scoping search was conducted on 30/06/2021 by Google searching combinations of synonyms for: 1) the COVID-19 pandemic, 2) gender, 3) academia, 4) inequality and 5) productivity. The scoping search identified 21 original research publications with quantitative metrics investigating differences in academic productivity by gender before and during the pandemic (scoped texts). Of these 21 articles, 14 were indexed by Web of Science, and 17 (including the same 14 from Web of Science) were indexed by Scopus.

Terms for the initial search were selected by scanning the title, abstract and keywords of scoped texts. We constructed an initial Boolean search string according to the PICO (Population, Intervention, Comparator, Outcome) framework (Livoreil et al., 2017). Population was represented by “academia”, Intervention by “pandemic”, Comparator by “gender” and Outcome by “inequality” and “productivity” (Table S1). A sixth concept group contained terms used to exclude irrelevant studies that did not investigate studies in hypothesis one. Terms within concept groups were connected by the Boolean OR operator, and the concept groups were connected by the AND or AND NOT operators, enabling searches for any combination that includes one term from each of the six concept groups. Terms in the initial search were selected by scanning the title, abstract and keywords of scoped texts. The initial search in Scopus generated 722 texts, published from 2020 onwards, including 14/17 (82.4%) of scoped texts indexed by Scopus.

To improve the 14/722 (1.9%) efficiency of finding scoped texts from our initial search, we imported all 722 texts into R and used litsearchR. Using litsearchR, potential key terms were extracted from the title, abstract and keywords of texts using the Rapid Automatic Keyword Extraction algorithm. A ranked list of important terms was then created from building a key term co-occurrence network (Table S2). Six high-strength terms within the key term co-occurrence matrix, describing research not relevant to our study, such as those of an epidemiological or experimental nature, were added to the AND NOT operator concept group to exclude texts mentioning these terms. Table 1 describes terms of the refined Boolean search string and their respective concept groups. We performed the refined search on 27/07/2021 and generated 700 total texts combined from Scopus (126 texts, including 14/17 articles found in the scoping search), the Web of Science core collection (199 texts), EBSCO (276 texts and Proquest (99 texts) from 2020 onwards. The final search hit rate had an efficiency of 11% (14/126) on Scopus, above the 10% recommended hit rate (Foo et al., 2021). After removing duplicates, 580 articles remained to enter the study screening stage.

Study screening

To be included in our meta-analysis, a study had to quantitatively investigate gender differences in productivity within academia before and during the pandemic. Thus, we screened the titles, abstract and keywords to keep only those suggesting the study investigated: 1) academia, 2) genders, 3) pandemic and 4) some measure of productivity (Table S3). To ensure repeatability of the screening process, we used Rayyan.ai (Ouzzani et al., 2016) to blind the inclusion or exclusion of 420 randomly selected texts by two reviewers (K.L. and D.L.). The agreement rate between reviewers was 97%, with 49 articles that both authors agreed to include, 357 articles which both excluded, ten articles one reviewer included but the other excluded, and 4 articles only included by the other reviewer. This agreement rate resulted in a, “strong” (McHugh, 2012) to “near perfect” (Landis & Koch, 1977) Cohen’s kappa of 0.86. Of the 14 articles which were included by one but excluded the other, 3 were included after joint review. Of the remaining 160 texts not included in the screening by two reviewers, we included 18 and excluded 162 during the initial screen. Overall, out of the 580 texts, 70 were retained (Fig. S1) for the full text screening. Full texts were then screened, including studies that had: 1) for both genders, 2) some metric of academic productivity measured, and 3) for before the pandemic compared with during the pandemic. Texts mentioning all criteria as secondary data were excluded. Thus, 25 articles that all contained necessary metrics to calculate effect sizes were retained for data extraction, excluding 45 articles (Fig. S1).

Iterating the search

To find articles that had been published since the 27/07/21 search (Table 1), we iterated the search and screen process. The second search was repeated on 28/02/2022, generating 1646 total texts combined from Scopus (258 texts, including 14/17 articles found in the scoping search), the Web of Science core collection (413 texts), EBSCO (542 texts) and Proquest (433 texts) from 2020 onwards. We removed 438 duplicates using Rayyan.ai, leaving 1208 de-duplicated articles. To ensure our methods are repeatable, we checked and found all 580 de-duplicated articles from the previous search were also found again. Out of the 1208 texts from the final search, we included 169 after screening titles, abstracts and keywords. For these 169, we screened the full texts, excluding 116 articles and keeping 50 (including the 25 identified in the original search) that all contained the necessary information to calculate the effect sizes.

Table 1. Final Boolean search string used in full literature search for texts since 2020. Terms in italics were added using litsearchR.

Concept group	PICO group	Terms
Academia	Population	(academi* OR author* OR database* OR journal* OR research OR scien*)
Gender	Population	AND (female* OR gender OR male* OR men OR women)
Pandemic	Intervention	AND (coronavirus OR covid OR pandemic)
Inequality	Comparator	AND (bias* OR disparit* OR disproportion* OR fewer OR gap OR "gender difference*" OR imbalance* OR inequalit* OR inequit* OR parity OR "sex difference*" OR skew* OR unequal)
Productivity	Outcome	AND (performan* OR publication* OR publish* OR productiv*)
Exclusion of biomedical studies	Population	AND NOT (experiment OR laboratory OR mortality OR surviv* OR *"acute respiratory"* OR *gis* OR *icu* OR *risk* OR *rna* OR *symptoms*)

Extracting variables

Effect size: We extracted values needed to calculate 115 effect sizes from 50 texts investigating the effect of the pandemic on academic research productivity between genders, before and during the pandemic. 11 measures of the effect sizes were already calculated within the articles (two lasso regression, two Somers' delta, two ordered logistic regression, one logistic regression and four mixed-effect models) and we recorded these as such. For the other 104 effect sizes, we entered summary data (N=101) or statistical inferences (N=3) into Campbell collaboration's effect size calculator (Wilson, 2019) to calculate a standardised mean difference (d) effect size. For effect sizes calculated using summary data, 83 relied on the proportion of raw numbers of female and male authors before and after the pandemic, and 18 on the mean changes and standard deviations or standard errors in research productivity changes during the pandemic for female and male researchers. For effect sizes calculated from reported statistical tests, one converted the f-test statistic and sample size from a general linear model investigating the effect of gender on perceived work production, one converted the chi-square comparing proportions of female and male academics that experienced productivity changes due to the pandemic, and one converted the p-values from a t-test comparing mean changes in research time due to the pandemic. Two effect sizes (Jemielniak, Sławska & Wilamowski, 2021; Stenson et al., 2022) were calculated using sample sizes obtained by personal correspondence. We calculated multiple effect sizes from one study if they were for different research fields or authorship positions. We set the sign for effect sizes as negative if the pandemic had reduced relative research productivity of women (increased gender gap) and positive if the pandemic had increased the relative research productivity of women (reduced gender gap). A subset of 59 effect sizes were double-checked by A.C., A.M. and D.L and inconsistencies were discussed to ensure repeatability. K.L. then extracted the remaining 56 effect sizes.

Variance: Of 9 effect sizes already calculated in the original studies, 6 provided variance as the standard error, which we squared to obtain the variance; and 3 provided the variance as 95% confidence intervals, which we divided by 1.96 and then squared (Nakagawa et al., 2022). For the other 101 effect sizes, variance was estimated in the Campbell collaboration calculator (Wilson, 2019) when calculating effect sizes.

Research productivity measure: We first recorded whether the change in research productivity was measured from survey responses (survey response studies, N=23 effect sizes) or from the number of articles submitted or published (article output studies, N=92). Survey studies measured change in research productivity during the pandemic for each gender based on academics self-reporting their gender and change in general productivity (N=11), number of submissions (n=5), research time (N=4), number of projects (N=1), burn-out (N=1), or job loss (N=1). As 5 survey-studies measured research productivity in the number of submissions, we included these studies in the articles submitted and published category. This resulted in 18 effect sizes from surveys measuring some aspect of research productivity, 49 effect sizes measuring numbers of article submissions, and 48 effect sizes measuring numbers of publications.

Research field: For the article studies (N=92), we recorded the research field sampled based on the description in the original studies as either medicine (N=38), Technology, Engineering, Mathematics, Chemistry and Physics (N=16), social sciences (N=14), biological sciences (N=16), or multidisciplinary (N=8), following the classification scheme of (Astegiano, Sebastián-González & Castanho, 2019).

Previous gender bias: For the article output studies with available data (N=84), we recorded the number of female and male authors before the pandemic in addition to the change in gender bias.

Authorship position: For the article output studies (N=92), we recorded whether first (N=44), middle (N=3), last (N=20), corresponding (N=12), or the total number of (N=13) authors were studied. We classified one effect size studying submitting authors, as studying corresponding authors (Fox et al., 2016) and two effect sizes studying sole authors as studying last authors (Moore & Griffin, 2006).

Analyses

We conducted all analyses in R 3.6.2 (R Core Team, 2022). We used the 'metafor' package 3.0.2 to fit models, and build funnel plots (Viechtbauer, 2010). We used 'orchaRd' 0.0.0.9000 to build orchard plots to visualise distribution of effect sizes (points) and their precision (point size), calculated as a function of standard error (Nakagawa et al., 2021).
We fitted separate models for each prediction. All models included the identity of the article the effect size was extracted from as a random effect to control for dependency in effect sizes obtained from the same study. We tested prediction 1a in a model investigating the overall effect size and we displayed this as an orchard plot. We then tested prediction 1b in a model investigating the method of measuring research productivity (survey responses, number of submissions and number of publications) as a moderator of effect size and displayed this as an orchard plot. We included the outlier (Jemielniak, Sławska & Wilamowski, 2021) in the funnel plot of article output studies because this effect size was obtained by personal correspondence clarifying the sample sizes used in the study, which we assume was verified. We tested prediction 2a in a model investigating research field as a moderator of effect size for article studies in a model and displayed this as an orchard plot. We tested in a model how previous gender bias in research productivity before the pandemic, as measured by the proportion of female authors, influenced effect size and displayed this as a line graph, grouped by research field. To test prediction 2b, we tested in a model authorship position as a moderator on effect size for publication studies. We tested for publication bias by performing a multilevel regression model (Nakagawa et al., 2022) which investigates whether small studies have large effect sizes,

including research productivity measure as a moderator and display this relationship in funnel plots. We tested for total heterogeneity (I^2) using the function 'i2_ml' in 'orchaRd'.

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Additional information and declarations

Registration and protocol

This study was not registered.

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Competing interests

The authors declare there are no competing interests.

Author contributions

Adele Mennerat (AM) was involved in conceptualization, data extraction, methodology, analysis and reviewing and editing the manuscript draft.
Alecia J Carter (AJC) was involved in conceptualization, data extraction, methodology, analysis and reviewing and editing the manuscript draft.
Antica Culina (AC) was involved in conceptualization, data extraction, methodology, analysis and reviewing and editing the manuscript draft.
Dieter Lukas (DL) was involved in conceptualization, data extraction, methodology, analysis and reviewing and editing the manuscript draft.
Hannah Dugdale (HD) was involved in conceptualization, methodology, analysis and reviewing and editing the manuscript draft.
Kiran Lee (KL) was involved in conceptualization, data extraction, methodology, analysis, writing the first draft and reviewing and editing the draft.

Data availability

Data and materials to reproduce the meta-analysis can be found at Zenodo [DOI: 10.5281/zenodo.7382094](https://doi.org/10.5281/zenodo.7382094).

Supplementary information

Supplemental information is currently at the end of this document but can be separated if requested.

References

Abdellatif A, Gatto M. 2020. It's OK not to be OK: Shared reflections from two PhD parents in a time of pandemic. *Gender, Work & Organization* 27:723–733. DOI: 10.1111/gwao.12465.

Addessi E, Borgi M, Palagi E. 2012. Is Primatology an Equal-Opportunity Discipline? *PLOS ONE* 7:e30458. DOI: 10.1371/journal.pone.0030458.

Altan-Olcay Ö, Bergeron S. 2022. Care in times of the pandemic: Rethinking work meanings of work in the university. *Gender, Work & Organization*. DOI: 10.1111/gwao.12871.

Amano-Patiño N, Faraglia E, Giannitsarou C, Hasna Z. 2020b. The Unequal Effects of Covid-19 on Economists' Research Productivity. DOI: 10.17863/CAM.57979.

Anabaraonye N, Tsai CJ, Saeed H, Chino F, Ekpo E, Ahuja S, Garcia O, Miller RC. 2022. Impact of the early COVID-19 pandemic on gender participation in academic publishing in radiation oncology. *Advances in Radiation Oncology* 7:100845. DOI: 10.1016/j.adro.2021.100845.

Andersen JP, Nielsen MW, Simone NL, Lewiss RE, Jagsi R. 2020. COVID-19 medical papers have fewer women first authors than expected. *elife* 9. DOI: 10.7554/eLife.58807.

Anwer M. 2020. Academic labor and the global pandemic: Revisiting life-work balance under COVID-19. *Susan Bulkeley Butler Center for leadership excellence and advance working paper series* 3:5–13.

Armstrong MA, Jovanovic J. 2015. Starting at the crossroads: Intersectional approaches to institutionally supporting underrepresented minority women STEM faculty. *Journal of Women and Minorities in Science and Engineering* 21. DOI: 10.1615/JWomenMinorScienEng.2015011275.

Astegiano J, Sebastián-González E, Castanho CDT. 2019. Unravelling the gender productivity gap in science: a meta-analytical review. *Royal Society Open Science* 6. DOI: 10.1098/RSOS.181566.

Ayyala RS, Trout AT. 2022. Gender trends in authorship of Pediatric Radiology publications and impact of the COVID-19 pandemic. *Pediatric Radiology* 52:868–873. DOI: 10.1007/s00247-021-05213-6.

Babcock L, Peyser B, Vesterlund L, Weingart LR. 2022. Saying ‘no’ in science isn’t enough. *Nature*. DOI: 10.1038/d41586-022-03677-6.

Babcock L, Recalde MP, Vesterlund L, Weingart L. 2017. Gender differences in accepting and receiving requests for tasks with low promotability. *American Economic Review* 107:714–47. DOI: 10.1257/aer.20141734.

Barber BM, Jiang W, Morse A, Puri M, Tookes H, Werner IM. 2021. What explains differences in finance research productivity during the pandemic? *The Journal of Finance* 76:1655–1697. DOI: 10.1111/jofi.13028.

Bell ML, Fong KC. 2021. Gender differences in first and corresponding authorship in public health research submissions during the COVID-19 pandemic. *American Journal of Public Health* 111:159–163. DOI: 10.2105/AJPH.2020.305975.

Bell K, Green J. 2020. Premature evaluation? Some cautionary thoughts on global pandemics and scholarly publishing. *Critical Public Health* 30:379–383.

Biondi B, Barrett CB, Mazzocchi M, Ando A, Harvey D, Mallory M. 2021. Journal submissions, review and editorial decision patterns during initial COVID-19 restrictions. *Food Policy* 105:102167. DOI: 10.1016/j.foodpol.2021.102167.

Bol T, Vaan MD, Rijt AVD. 2018. The Matthew effect in science funding. *Proceedings of the National Academy of Sciences of the United States of America* 115:4887–4890. DOI: 10.1073/PNAS.1719557115/-/DCSUPPLEMENTAL.

Boncori I. 2020. The Never-ending Shift: A feminist reflection on living and organizing academic lives during the coronavirus pandemic. *Gender, Work & Organization* 27:677–682. DOI: 10.1111/gwao.12451.

Breuning M, Fattore C, Ramos J, Scalera J. 2021. The great equalizer? Gender, parenting, and scholarly productivity during the global pandemic. *PS: Political Science & Politics* 54:427–431. DOI: 10.1017/S1049096520002036.

Carli LL. 2020. Women, Gender equality and COVID-19. *Gender in Management: An International Journal*. DOI: 10.1108/GM-07-2020-0236.

Carlson DL, Petts RJ, Pepin JR. 2020. US Couples’ Divisions of Housework and Childcare during COVID-19 Pandemic. DOI: 10.31235/osf.io/jy8fn.

Chen T-HK, Seto KC. 2022. Gender and authorship patterns in urban land science. *Journal of Land Use Science* 17:245–261. DOI: 10.1080/1747423X.2021.2018515.

Clark D. 2020. Reflections on institutional equity for faculty in response to COVID-19. *Susan Bulkeley Butler Center for Leadership Excellence and ADVANCE Working Paper Series* 3.

Cook J, Gupta M, Nakayama J, El-Nashar S, Kesterson J, Wagner S. 2021. Gender differences in authorship of obstetrics and gynecology publications during the coronavirus disease 2019 pandemic. *American journal of obstetrics & gynecology MFM* 3. DOI: 10.1016/j.ajogmf.2020.100268.

Corbera E, Anguelovski I, Honey-Rosés J, Ruiz-Mallén I. 2020. Academia in the Time of COVID-19: Towards an Ethics of Care. *Planning Theory and Practice* 21:191–199. DOI: 10.1080/14649357.2020.1757891.

Cui R, Ding H, Zhu F. 2022. Gender inequality in research productivity during the COVID-19 pandemic. *Manufacturing & Service Operations Management* 24:707–726. DOI: 10.1287/msom.2021.0991.

Cushman M. 2020. Gender gap in women authors is not worse during COVID-19 pandemic: Results from Research and Practice in Thrombosis and Haemostasis. *Research and Practice in Thrombosis and Haemostasis* 4:672. DOI: 10.1002/rth2.12399.

Davies SW, Putnam HM, Ainsworth T, Baum JK, Bove CB, Crosby SC, Côté IM, Duplouy A, Fulweiler RW, Griffin AJ, Hanley TC, Hill T, Humanes A, Mangubhai S, Metaxas A, Parker LM, Rivera HE, Silbiger NJ, Smith NS, Spalding AK, Traylor-Knowles N, Weigel BL, Wright RM, Bates AE. 2021. Promoting inclusive metrics of success and impact to dismantle a discriminatory reward system in science. *PLOS Biology* 19:e3001282. DOI: 10.1371/journal.pbio.3001282.

Davis JC, Li EPH, Butterfield MS, DiLabio GA, Santhagunam N, Marcolin B. 2022. Are we failing female and racialized academics? A Canadian national survey examining the impacts of the COVID-19 pandemic on tenure and tenure-track faculty. *Gender, Work & Organization* 29:703–722. DOI: 10.1111/gwao.12811.

Day AE, Corbett P, Boyle J. 2020. Is there a gender gap in chemical sciences scholarly communication? †Electronic supplementary information (ESI) available: Total numbers, percentages, confidence intervals and significances for figures. See DOI: 10.1039/c9sc04090k. *Chemical Science* 11:2277–2301. DOI: 10.1039/c9sc04090k.

DeFilippis EM, Sinnenberg L, Mahmud N, Wood MJ, Hayes SN, Michos ED, Reza N. 2021. Gender differences in publication authorship during COVID-19: a bibliometric analysis of high-impact cardiology journals. *Journal of the American Heart Association* 10:e019005. DOI: 10.1161/JAHA.120.019005.

Deryugina T, Shurchkov O, Stearns JE. 2021. COVID-19 Disruptions Disproportionately Affect Female Academics. DOI: 10.1257/pandp.20211017.

Diaz JO, Gorgen ARH, da Silva AGT, de Oliveira Paludo A, de Oliveira RT, Rosito N, Barroso Jr U, Corbetta JP, Egaña P-JL, Tavares PM, Rosito TE. 2021. Burnout syndrome in pediatric urology: A perspective during the COVID-19 pandemic—Ibero-American survey. *Journal of Pediatric Urology* 17:402-e1. DOI: 10.1016/j.jpurol.2021.01.015.

Docka-Filipek D, Stone LB. 2021. Twice a “housewife”: On academic precarity,“hysterical” women, faculty mental health, and service as gendered care work for the “university family” in pandemic times. *Gender, Work & Organization* 28:2158–2179. DOI: 10.1111/gwao.12723.

Ellinas EH, Ark TK, Kaljo K, Quinn KG, Krier CR, Farkas AH. 2021. Winners and Losers in Academic Productivity During the COVID-19 Pandemic: Is the Gender Gap Widening for Faculty? *Journal of women’s health (2002)*. DOI: 10.1089/jwh.2021.0321.

Else H. 2020. How a torrent of COVID science changed research publishing–in seven charts. *Nature* 588:553–554. DOI: 10.1038/d41586-020-03564-y.

Excess Beth [@El_Dritch]. 2020. Negligible number of submissions to the journal from women in the last month. Never seen anything like it. *Twitter*.

Fazackerley A. 2020. Women’s research plummets during lockdown - but articles from men increase. *The Guardian*.

Foo YZ, O’Dea RE, Koricheva J, Nakagawa S, Lagisz M. 2021. A practical guide to question formation, systematic searching and study screening for literature reviews in ecology and evolution. *Methods in Ecology and Evolution* 12:1705–1720. DOI: 10.1111/2041-210X.13654.

Forti LR, Solino LA, Szabo JK. 2021. Trade-off between urgency and reduced editorial capacity affect publication speed in ecological and medical journals during 2020. *Humanities and Social Sciences Communications* 8:1–9. DOI: 10.1057/s41599-021-00920-9.

Fortin J, Taylor DB. 2020. Florida State University Child Care Policy Draws Backlash. *The New York Times*.

Fox CW, Burns CS, Muncy AD, Meyer JA. 2016. Gender differences in patterns of authorship do not affect peer review outcomes at an ecology journal. *Functional Ecology* 30:126–139. DOI: 10.1111/1365-2435.12587.

Fox CW, Meyer J. 2021. The influence of the global COVID-19 pandemic on manuscript submissions and editor and reviewer performance at six ecology journals. *Functional Ecology* 35:4–10.

Fox CW, Paine CT. 2019. Gender differences in peer review outcomes and manuscript impact at six journals of ecology and evolution. *Ecology and Evolution* 9:3599–3619. DOI: 10.1002/ece3.4993.

Gao J, Yin Y, Myers KR, Lakhani KR, Wang D. 2021. Potentially long-lasting effects of the pandemic on scientists. *Nature communications* 12:1–6. DOI: 10.1038/s41467-021-26428-z.

Gayet-Ageron A, Ben Messaoud K, Richards M, Schroter S. 2021. Female authorship of covid-19 research in manuscripts submitted to 11 biomedical journals: cross sectional study. *BMJ (Clinical research ed.)* 375:n2288. DOI: 10.1136/bmj.n2288.

Gerding AB, Swan SJ, Brayer KA, Abdel-Rahman SM. 2021. Scholarly productivity in clinical pharmacology amid pandemic-related workforce disruptions: are men and women affected equally? *Clinical Pharmacology and Therapeutics* 110:841. DOI: 10.1002/cpt.2358.

Ghaffarizadeh SA, Ghaffarizadeh SA, Behbahani AH, Mehdizadeh M, Olechowski A. 2021. Life and work of researchers trapped in the COVID-19 pandemic vicious cycle. *bioRxiv*.

Grames EM, Stillman AN, Tingley MW, Elphick CS. 2019. An automated approach to identifying search terms for systematic reviews using keyword co-occurrence networks. *Methods in Ecology and Evolution* 10:1645–1654. DOI: 10.1111/2041-210X.13268.

Guarino CM, Borden VMH. 2017. Faculty Service Loads and Gender: Are Women Taking Care of the Academic Family? *Research in Higher Education* 58:672–694. DOI: 10.1007/s11162-017-9454-2.

Guintivano J, Dick D, Bulik CM. 2021. Psychiatric genomics research during the COVID-19 pandemic: A survey of Psychiatric Genomics Consortium researchers. *American Journal of Medical Genetics Part B: Neuropsychiatric Genetics* 186:40–49. DOI: 10.1002/ajmg.b.32838.

Guy B, Arthur B. 2020. Academic motherhood during COVID-19: Navigating our dual roles as educators and mothers. *Gender, Work & Organization* 27:887–899. DOI: 10.1111/gwao.12493.

Hagan AK, Topçuoğlu BD, Gregory ME, Barton HA, Schloss PD. 2020. Women Are Underrepresented and Receive Differential Outcomes at ASM Journals: a Six-Year Retrospective Analysis. *mBio* 11:e01680-20. DOI: 10.1128/mBio.01680-20.

Harris B, Sullivan AL, Embleton P, Shaver E, Nguyen T, Kim J, St. Clair K, Williams S. 2022. Exploratory Investigation of Gender Differences in School Psychology Publishing Before and During the Initial Phase of COVID-19. *Canadian Journal of School Psychology* 37:204–211. DOI: 10.1177/08295735221074473.

Herman E, Nicholas D, Watkinson A, Rodríguez-Bravo B, Abrizah A, Boukacem-Zeghmouri C, Jamali HR, Sims D, Allard S, Tenopir C, Xu J, Świgoń M, Serbina G, Cannon LP. 2021. The impact of the pandemic on early career researchers: what we already know from the internationally published literature. *El Profesional de la Información* 30. DOI: 10.3145/epi.2021.mar.08.

Hoggarth JA, Batty S, Bondura V, Creamer E, Ebert CE, Green-Mink K, Kieffer C, Miller H, Ngonadi C, Pilaar Birch SE, others. 2021. Impacts of the COVID-19 pandemic on women and early career archaeologists. *Heritage* 4:1681–1702. DOI: 10.3390/heritage4030093.

Horbach SPJM. 2020. Pandemic publishing: Medical journals strongly speed up their publication process for COVID-19. *Quantitative Science Studies* 1:1056–1067. DOI: 10.1162/QSS_A_00076.

Huang J, Gates AJ, Sinatra R, Barabási A-L. 2020. Historical comparison of gender inequality in scientific careers across countries and disciplines. *Proceedings of the National Academy of Sciences* 117:4609–4616. DOI: 10.1073/PNAS.1914221117.

Ipe TS, Goel R, Howes L, Bakhtary S. 2021. The impact of COVID-19 on academic productivity by female physicians and researchers in transfusion medicine. *Transfusion* 61:1690–1693. DOI: 10.1111/trf.16306.

James A, Chisnall R, Plank MJ. 2019. Gender and societies: a grassroots approach to women in science. *Royal Society open science* 6. DOI: 10.1098/RSOS.190633.

Jemielniak D, Sławska A, Wilamowski M. 2021. COVID-19 effect on the gender gap in academic publishing. *Journal of Information Science*:01655515211068168. DOI: 10.1177/01655515211068168.

Kaatz A, Gutierrez B, Carnes M. 2014. Threats to objectivity in peer review: the case of gender. *Trends in pharmacological sciences* 35:371–373. DOI: 10.1016/j.tips.2014.06.005.

King MM, Frederickson ME. 2021. The Pandemic Penalty: The Gendered Effects of COVID-19 on Scientific Productivity: *Socius*. DOI: 10.1177/23780231211006977.

Kozlowski D, Larivière V, Sugimoto CR, Monroe-White T. 2022. Intersectional inequalities in science. *Proceedings of the National Academy of Sciences* 119:e2113067119. DOI: 10.1073/pnas.2113067119.

Krukowski RA, Jagsi R, Cardel MI. 2021. Academic productivity differences by gender and child age in science, technology, engineering, mathematics, and medicine faculty during the COVID-19 pandemic. *Journal of Women's Health* 30:341–347. DOI: 10.1089/jwh.2020.8710.

Landis J, Koch G. 1977. The measurement of observer agreement for categorical data. *Biometrics* 33:159–174. DOI: 10.2307/2529310.

Langin K. 2019. Women of color face double dose of bias. *Science (New York, N.Y.)* 364:921–922. DOI: 10.1126/science.364.6444.921.

Larivière V, Ni C, Gingras Y, Cronin B, Sugimoto CR. 2013. Bibliometrics: Global gender disparities in science. *Nature* 504:211–213. DOI: 10.1038/504211a.

Lerchenmüller C, Schmallenbach L, Jena AB, Lerchenmueller MJ. 2021. Longitudinal analyses of gender differences in first authorship publications related to COVID-19. *BMJ open* 11:e045176. DOI: 10.1136/bmjopen-2020-045176.

Livoreil B, Glanville J, Haddaway NR, Bayliss H, Bethel A, Lachapelle FF de, Robalino S, Savilaakso S, Zhou W, Petrokofsky G, Frampton G. 2017. Systematic searching for environmental evidence using multiple tools and sources. *Environmental Evidence 2017 6:1* 6:1–14. DOI: 10.1186/S13750-017-0099-6.

Macaluso B, Larivière V, Sugimoto T, Sugimoto CR. 2016. Is Science Built on the Shoulders of Women? A Study of Gender Differences in Contributorship. *Academic Medicine* 91:1136–1142. DOI: 10.1097/ACM.0000000000001261.

Madsen EB, Nielsen MW, Bjørnholm J, Jagsi R, Andersen JP. 2022. Author-level data confirm the widening gender gap in publishing rates during COVID-19. *eLife* 11:e76559. DOI: 10.7554/eLife.76559.

Maguire R, Hynes S, Seebacher B, Block VJ, Zackowski KM, Jonsdottir J, Finlayson M, Plummer P, Freeman J, Giesser B, others. 2021. Research interrupted: The impact of the COVID-19 pandemic on multiple sclerosis research in the field of rehabilitation and quality of life. *Multiple Sclerosis Journal–Experimental, Translational and Clinical* 7:20552173211038030. DOI: 10.1177/20552173211038030.

McHugh ML. 2012. Interrater reliability: the kappa statistic. *Biochemia Medica* 22:276. DOI: 10.11613/BM.2012.031.

Mihaljević H, Tullney M, Santamaría L, Steinfeldt C. 2019. Reflections on Gender Analyses of Bibliographic Corpora. *Frontiers in Big Data* 2. DOI: 10.3389/fdata.2019.00029.

Minello A, Martucci S, Manzo LK. 2021. The pandemic and the academic mothers: present hardships and future perspectives. *European Societies* 23:S82–S94. DOI: 10.1080/14616696.2020.1809690.

Mitchell SM, Hesli VL. 2013. Women don't ask? Women don't say no? Bargaining and service in the political science profession. *PS: Political Science & Politics* 46:355–369. DOI: 10.1017/S1049096513000073.

Moher D, Liberati A, Tetzlaff J, Altman DG, Group TP. 2009. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *PLOS Medicine* 6:e1000097. DOI: 10.1371/JOURNAL.PMED.1000097.

Moore MT, Griffin BW. 2006. Identification of factors that influence authorship name placement and decisions to collaborate in peer-reviewed, education-related publications. *Studies in Educational Evaluation* 32:125–135. DOI: 10.1016/j.stueduc.2006.04.004.

Morgan AC, LaBerge N, Larremore DB, Galesic M, Brand JE, Clauset A. 2022. Socioeconomic roots of academic faculty. *Nature Human Behaviour*:1–9. DOI: 10.1038/s41562-022-01425-4.

Muric G, Lerman K, Ferrara E, others. 2021. Gender disparity in the authorship of biomedical research publications during the COVID-19 pandemic: retrospective observational study. *Journal of medical Internet research* 23:e25379. DOI: 10.2196/25379.

Murray D, Siler K, Larivière V, Chan WM, Collings AM, Raymond J, Sugimoto CR. 2019. Author-reviewer homophily in peer review. *BioRxiv*:400515.

Myers KR, Tham WY, Yin Y, Cohodes N, Thursby JG, Thursby MC, Schiffer P, Walsh JT, Lakhani KR, Wang D. 2020. Unequal effects of the COVID-19 pandemic on scientists. *Nature human behaviour* 4:880–883. DOI: 10.1038/s41562-020-0921-y.

Nakagawa S, Lagisz M, Jennions MD, Koricheva J, Noble DWA, Parker TH, Sánchez-Tójar A, Yang Y, O’Dea RE. 2022. Methods for testing publication bias in ecological and evolutionary meta-analyses. *Methods in Ecology and Evolution* 13:4–21. DOI: 10.1111/2041-210X.13724.

Nakagawa S, Lagisz M, O’Dea RE, Rutkowska J, Yang Y, Noble DWA, Senior AM. 2021. The orchard plot: Cultivating a forest plot for use in ecology, evolution, and beyond. In: *Research Synthesis Methods*. John Wiley and Sons Ltd, 4–12. DOI: 10.1002/jrsm.1424.

Nash M, Churchill B. 2020. Caring during COVID-19: A gendered analysis of Australian university responses to managing remote working and caring responsibilities. *Gender, Work & Organization* 27:833–846. DOI: 10.1111/gwao.12484.

National Academies of Sciences E. 2021. *The Impact of COVID-19 on the Careers of Women in Academic Sciences, Engineering, and Medicine*. DOI: 10.17226/26061.

Nguyen AX, Trinh X-V, Kurian J, Wu AY. 2021. Impact of COVID-19 on longitudinal ophthalmology authorship gender trends. *Graefe’s Archive for Clinical and Experimental Ophthalmology* 259:733–744. DOI: 10.1007/s00417-021-05085-4.

O’Meara K, Kuvaeva A, Nyunt G. 2017. Constrained choices: A view of campus service inequality from annual faculty reports. *The Journal of Higher Education* 88:672–700. DOI: 10.1080/00221546.2016.1257312.

O'Meara KA, Kuvaeva A, Nyunt G, Waugaman C, Jackson R. 2017. Asked More Often: Gender Differences in Faculty Workload in Research Universities and the Work Interactions That Shape Them. *American Educational Research Journal* 54:1154–1186. DOI: 10.3102/0002831217716767.

Ouzzani M, Hammady H, Fedorowicz Z, Elmagarmid A. 2016. Rayyan—a web and mobile app for systematic reviews. *Systematic Reviews 2016 5:1* 5:1–10. DOI: 10.1186/S13643-016-0384-4.

Plaunova A, Heller SL, Babb JS, Heffernan CC. 2021. Impact of COVID-19 on radiology faculty-an exacerbation of gender differences in unpaid home duties and professional productivity. *Academic Radiology* 28:1185–1190. DOI: 10.1016/j.acra.2021.05.004.

Porter SR. 2007. A closer look at faculty service: What affects participation on committees? *The Journal of Higher Education* 78:523–541. DOI: 10.1353/jhe.2007.0027.

Powell K. 2016. Does it take too long to publish research? *Nature* 530:148–151. DOI: 10.1038/530148a.

Quak E, Girault G, Thenint MA, Weyts K, Lequesne J, Lasnon C. 2021. Author Gender Inequality in Medical Imaging Journals and the COVID-19 Pandemic. *Radiology* 300:E301–E307. DOI: 10.1148/radiol.2021204417.

R Core Team. 2022. *R: A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing.

Reuben E, Sapienza P, Zingales L. 2014. How stereotypes impair women's careers in science. *Proceedings of the National Academy of Sciences* 111:4403–4408. DOI: 10.1073/pnas.1314788111.

Ribarovska AK, Hutchinson MR, Pittman QJ, Pariante C, Spencer SJ. 2021. Gender inequality in publishing during the COVID-19 pandemic. *Brain, behavior, and immunity* 91:1. DOI: 10.1016/j.bbi.2020.11.022.

Rodríguez-Rivero R, Yáñez S, Fernández-Aller C, Carrasco-Gallego R. 2020. Is it time for a revolution in work–life balance? Reflections from Spain. *Sustainability* 12:9563. DOI: 10.3390/su12229563.

Romano N. 2021. Assessing the gender gap in academia. *Nature Italy 2021*. DOI: 10.1038/d43978-021-00037-2.

Safdar B, Naveed S, Chaudhary AMD, Saboor S, Zeshan M, Khosa F. 2021. Gender Disparity in Grants and Awards at the National Institute of Health. *Cureus* 13. DOI: 10.7759/CUREUS.14644.

Schiebinger L, Gilmartin SK. 2010. Housework is an academic issue. *Academe* 96:39–44.

Schiebinger LL, Henderson AD, Gilmartin SK. 2008. *Dual-career academic couples: What universities need to know*. Michelle R. Clayman institute for gender research, Stanford University.

Shalaby M, Allam N, Buttorff GJ. 2021. Leveling the field: Gender inequity in academia during COVID-19. *PS: Political Science & Politics* 54:661–667. DOI: 10.1017/S1049096521000615.

Shandera S, Matsick JL, Hunter DR, Leblond L. 2021. RASE: Modeling cumulative disadvantage due to marginalized group status in academia. *PLOS ONE* 16:e0260567. DOI: 10.1371/journal.pone.0260567.

Shen H. 2013. Inequality quantified: Mind the gender gap. *Nature* 495:22–24. DOI: 10.1038/495022A.

Squazzoni F, Bravo G, Grimaldo F, García-Costa D, Farjam M, Mehmani B. 2021. Gender gap in journal submissions and peer review during the first wave of the COVID-19 pandemic. A study on 2329 Elsevier journals. *PloS one* 16:e0257919. DOI: 10.1371/journal.pone.0257919.

Staniscuaski F, Kmetzsch L, Soletti RC, Reichert F, Zandonà E, Ludwig ZM, Lima EF, Neumann A, Schwartz IV, Mello-Carpes PB, others. 2021. Gender, race and parenthood impact academic productivity during the COVID-19 pandemic: from survey to action. *Frontiers in psychology* 12:663252. DOI: 10.3389/fpsyg.2021.663252.

Stenson MC, Fleming JK, Johnson SL, Caputo JL, Spillios KE, Mel AE. 2022. Impact of COVID-19 on access to laboratories and human participants: exercise science faculty perspectives. *Advances in Physiology Education* 46:211–218. DOI: 10.1152/advan.00146.2021.

Valentova JV, Otta E, Silva ML, McElligott AG. 2017. Underrepresentation of women in the senior levels of Brazilian science. *PeerJ* 5. DOI: 10.7717/PEERJ.4000.

Viechtbauer W. 2010. Conducting Meta-Analyses in R with the metafor Package. *Journal of Statistical Software* 36:1–48. DOI: 10.18637/JSS.V036.I03.

van der Wal JEM, Thorogood R, Horrocks NPC. 2021. Collaboration enhances career progression in academic science, especially for female researchers. *Proceedings of the Royal Society B: Biological Sciences* 288:20210219. DOI: 10.1098/rspb.2021.0219.

Wehner MR, Li Y, Nead KT. 2020. Comparison of the proportions of female and male corresponding authors in preprint research repositories before and during the COVID-19 pandemic. *JAMA network open* 3:e2020335–e2020335. DOI: 10.1001/jamanetworkopen.2020.20335.

West JD, Jacquet J, King MM, Correll SJ, Bergstrom CT. 2013. The Role of Gender in Scholarly Authorship. *PLOS ONE* 8:e66212. DOI: 10.1371/journal.pone.0066212.

Williams II WA, Li A, Goodman DM, Ross LF. 2021. Impact of the coronavirus disease 2019 pandemic on authorship gender in the Journal of Pediatrics: disproportionate productivity by international male researchers. *The Journal of Pediatrics* 231:50–54. DOI: 10.1016/j.jpeds.2020.12.032.

Wilson DB. 2019. Practical Meta-Analysis Effect Size Calculator [Online calculator.

Wooden P, Hanson B. 2022. Effects of the COVID-19 Pandemic on Authors and Reviewers of American Geophysical Union Journals. *Earth and Space Science* 9:e2021EA002050. DOI: 10.1029/2021EA002050.

Yildirim TM, Eslen-Ziya H. 2021. The differential impact of COVID-19 on the work conditions of women and men academics during the lockdown. *Gender, Work & Organization* 28:243–249. DOI: 10.1111/gwao.12529.

Zeng XHT, Duch J, Sales-Pardo M, Moreira JAG, Radicchi F, Ribeiro HV, Woodruff TK, Amaral LAN. 2016. Differences in Collaboration Patterns across Discipline, Career Stage, and Gender. *PLOS Biology* 14:e1002573. DOI: 10.1371/journal.pbio.1002573.

Supplementary materials

Table S1. Naive Boolean search string used in initial literature search. Wildcards (*) were used to return results containing different word endings. Texts were limited to those since 2020. Search was conducted on 10/07/2021.

Concept group (PICO)	Terms
Academia (population)	(academi* OR author* OR database* OR journal* OR research OR scien*)
Gender (population)	AND (female* OR gender OR male* OR men OR women)
Pandemic (intervention)	AND (coronavirus OR covid OR pandemic)
Inequality (comparator)	AND (bias* OR disparit* OR disproportion* OR fewer OR gap OR "gender difference*" OR imbalance* OR inequalit* OR inequit* OR parity OR "sex difference*" OR skew* OR unequal)
Productivity (outcome)	AND (performan* OR publication* OR publish* OR productiv*)
Exclusion of biomedical studies (population)	AND NOT (surviv* OR experiment OR laboratory)

Table S2. Top 60 strongest terms in the term co-occurrence matrix and their rank in ascending order. Terms in bold were included in the AND NOT operator concept group excluding biomedical studies.

Term	Strength	Rank ascending
child	4257	2063
regression	4335	2064
survey	4367	2065
acute respiratory	4427	2066
embase	4637	2067
databases	4646	2068
death	4664	2069
knowledge	4764	2070
hip	4918	2071
mortality	5000	2072
female	5065	2073
rights reserved	5257	2074
city	5504	2075
information	5700	2076
symptom	6108	2077
sars-cov-2	6112	2078
sars-cov	6185	2079
coronavirus disease 2019	6397	2080
systematic review	6506	2081

rest	6578	2082
science	6659	2083
distance	6679	2084
literature	6816	2085
database	6916	2086
medical	7023	2087
icu	7170	2088
affect	7297	2089
control	7386	2090
population	7418	2091
women	7422	2092
bias	7665	2093
gender	7693	2094
male	7977	2095
coronavirus disease	8009	2096
article	8135	2097
virus disease	8230	2098
iga	8235	2099
hospital	8318	2100
work	8319	2101
covid-19 pandemic	8377	2102
gis	8489	2103

severe	8518	2104
time	8831	2105
infection	8914	2106
rna	10303	2107
outcome	10461	2108
review	11869	2109
coronavirus	12243	2110
stem	12316	2111
risk	12776	2112
analysis	13610	2113
research	13737	2114
virus	13835	2115
pandemic	14212	2116
author	14333	2117
car	15893	2118
over	15964	2119
health	16176	2120
covid-19	21088	2121
age	21194	2122
covid	21330	2123

Table S3. Flowchart of questions used for initial screen of title, abstract and key-words. Any 'No' answer meant that the article was excluded. 'Yes' AND/OR 'Maybe' answers to all of the below meant that the articles were included. Reports such as reviews or comments that may contain secondary data investigating our PICO framework were included. Articles that lacked a formal abstract but had a title or informal abstract suggesting at least 3 of the above questions were answered with a ‘yes’.

1) Population: Is there suggestion the article investigates academia/ research/academics/journals?	Note: If the population is not narrowed to academia/research/academics/journals, but the study considers the effect on ‘work’ or ‘work productivity’ at a broad level, and looks like it has enough power to subdivide effects on different workplaces such as academia, then include. Some academic fields such as those within medicine and engineering are dominated by a practical/applied/professional/labour component. Explicit reference to only investigating the professional/practical/labour context of these fields are excluded. If no reference is made to whether the academic field is investigated in a research or professional capacity, we include.
2) Intervention: Is there suggestion the article investigates the effect of the pandemic?	
3) Comparison: Is there suggestion the article investigates pre-pandemic?	Note: Often titles and abstracts do not have dates and will not refer explicitly to pre-pandemic data being included. If there is suggestion the ‘effect of the pandemic’ (or similar) is considered, we are generous and assume a comparison with pre-pandemic data is included.
4) Outcome: Is there suggestion the article investigates the effect on gender in productivity/publication/submission/authorship numbers?	Note for gender: If there is no reference to investigating the effect of gender or sex, but does refer to investigating broader sociodemographic or socioeconomic factors, then include because gender may be investigated in the full text. Note for productivity: If there is no direct reference to publication or submission numbers, but does refer to, ‘productivity’ or ‘output’ in a research context, then include because publication or submission metrics may be included in the full text.

Figure S1. PRISMA flow diagram for number of records included at each stage in first and iterated search.