

# 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

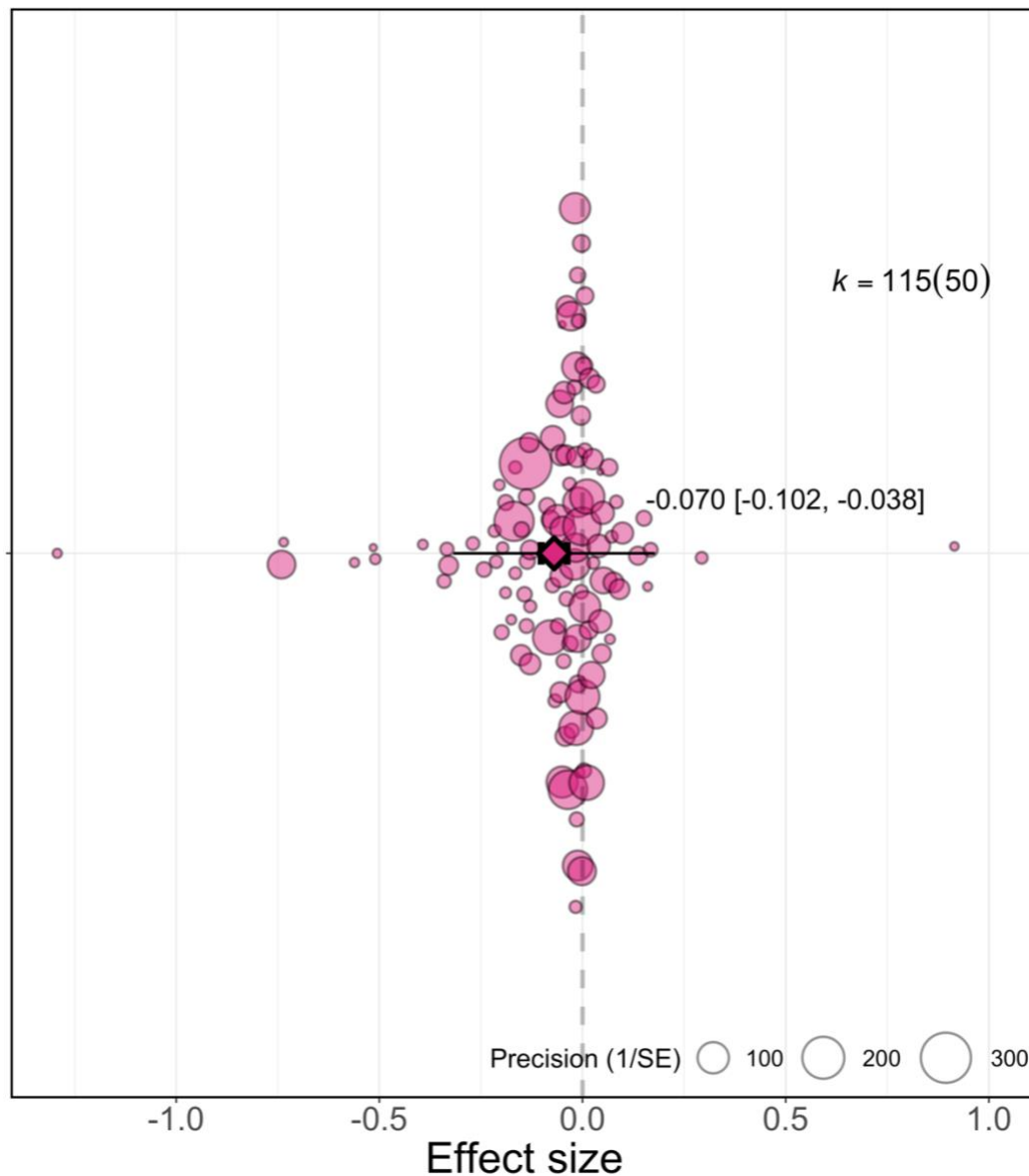
175 responses, numbers of submissions and numbers of publications, we investigated the influence  
176 this might have on the gender gap increase observed during the pandemic, but with no  
177 expectation of any differences (Prediction 1b). Second, we hypothesised that the pandemic has  
178 increased the gender gap differentially across research fields because of differences in working  
179 conditions and support structures in place (Hypothesis 2). We first explored variation in the  
180 gender gap increase across research fields (Prediction 2a) and then explored the interplay of  
181 research field according to the previous size of the gender gap. We predicted the gender gap is  
182 exacerbated in fields that already had a previously greater gender gap, as according to the  
183 proportion of female authors, because of less support available to women to balance the effects of  
184 the pandemic (Prediction 2b). Third, we hypothesised the disparity in favourable authorship  
185 positions has increased because female academics have been especially more limited in  
186 undertaking leading, but not supportive research roles in lockdown conditions (Hypothesis 3).  
187 We predicted that the pandemic has increased the gender gap more in first and last, rather than  
188 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.

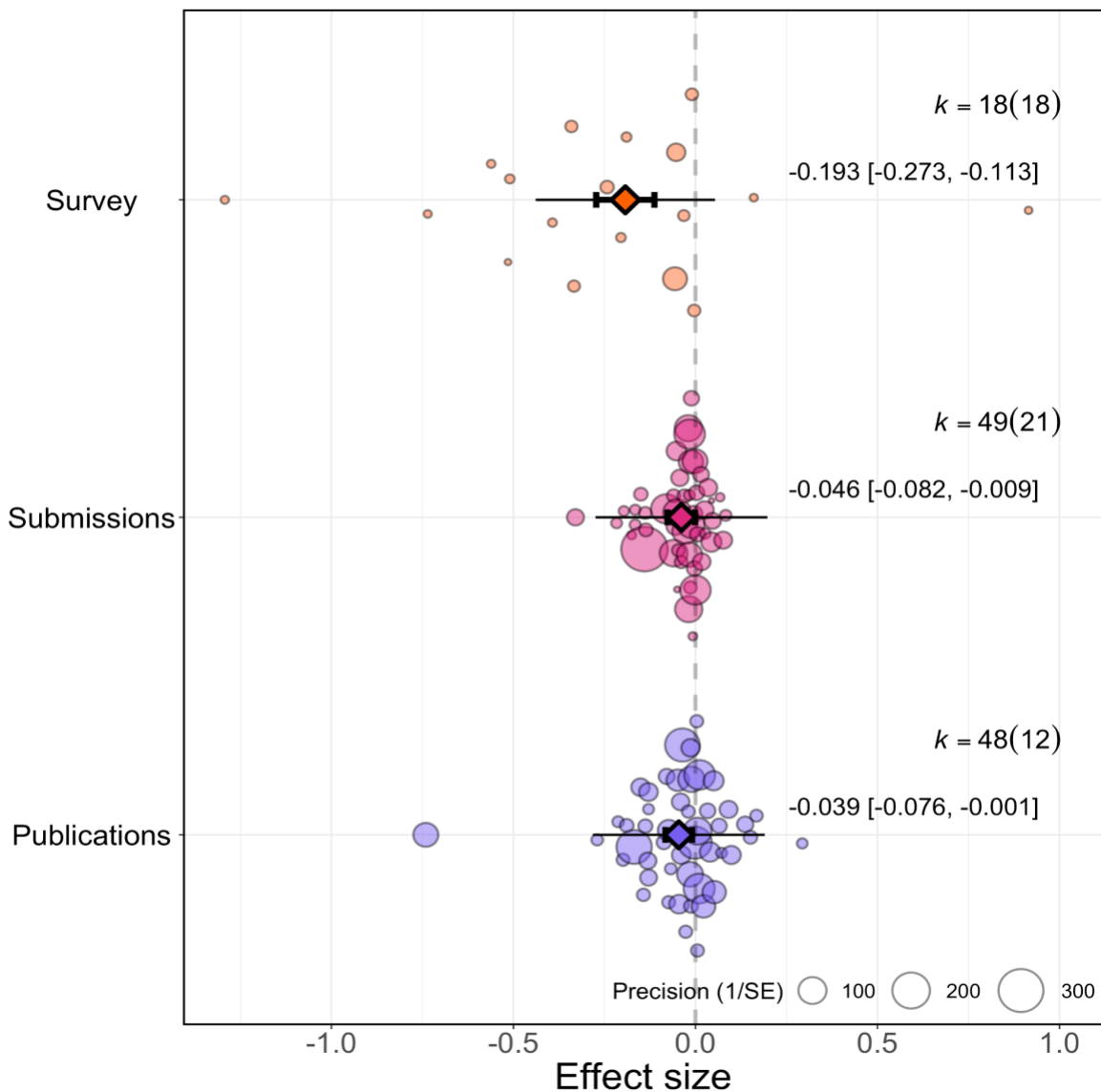


**Figure 1. Overall effect of the pandemic on academia's gender gap in productivity.** Orchard plot showing all 115 effect sizes (points) and their weight (point size), with the mean effect size (darker coloured point outlined black and vertically centred), the 95% confidence interval (horizontal thick 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?

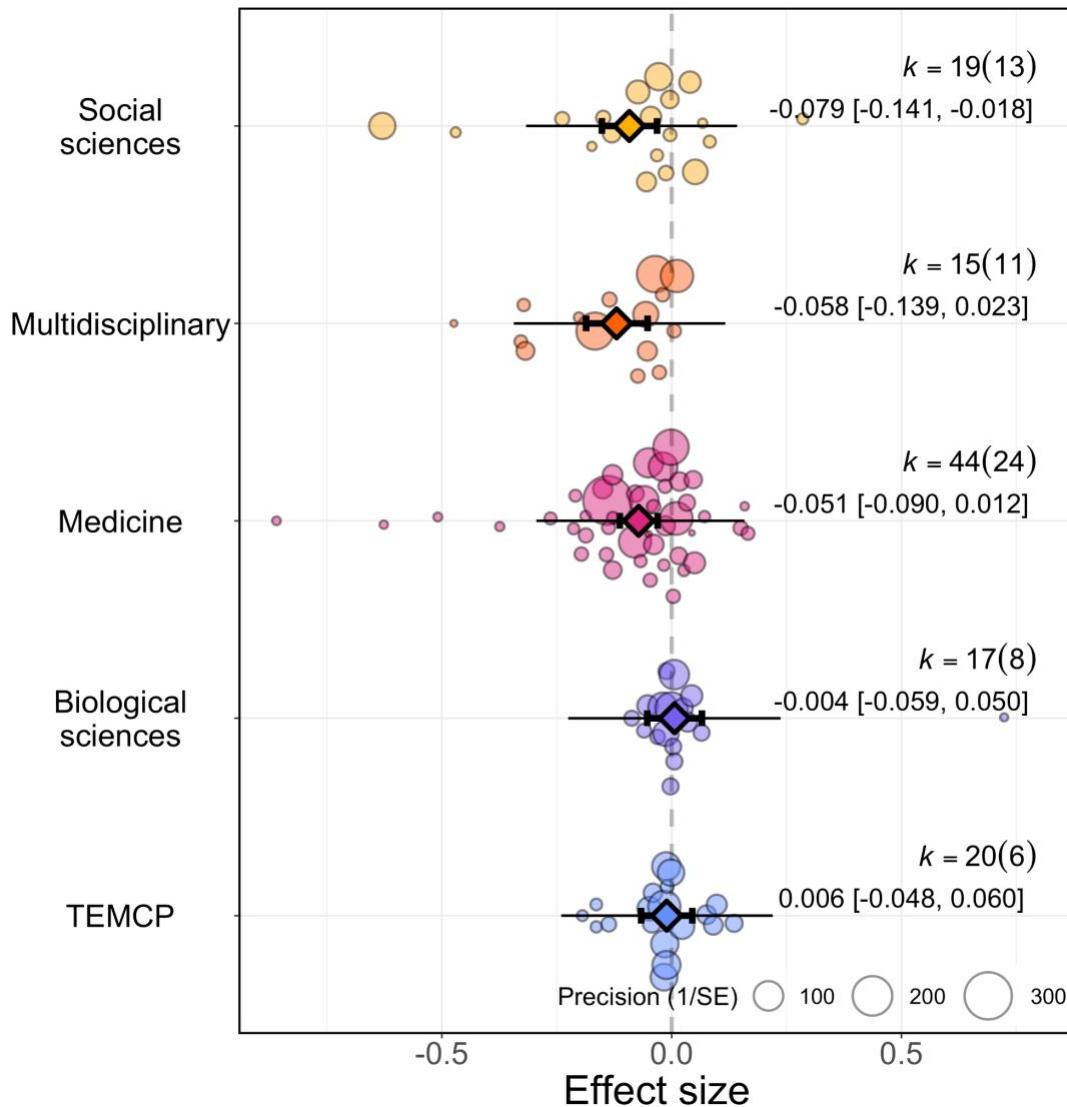
The degree of increase in the gender gap caused by the pandemic differed according to the type of research productivity measured (p-value= 0.0021, Fig. 2). Studies measuring changes to research productivity during the pandemic based on surveys detected a larger overall effect (-0.193, 95% CI= -0.235 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?

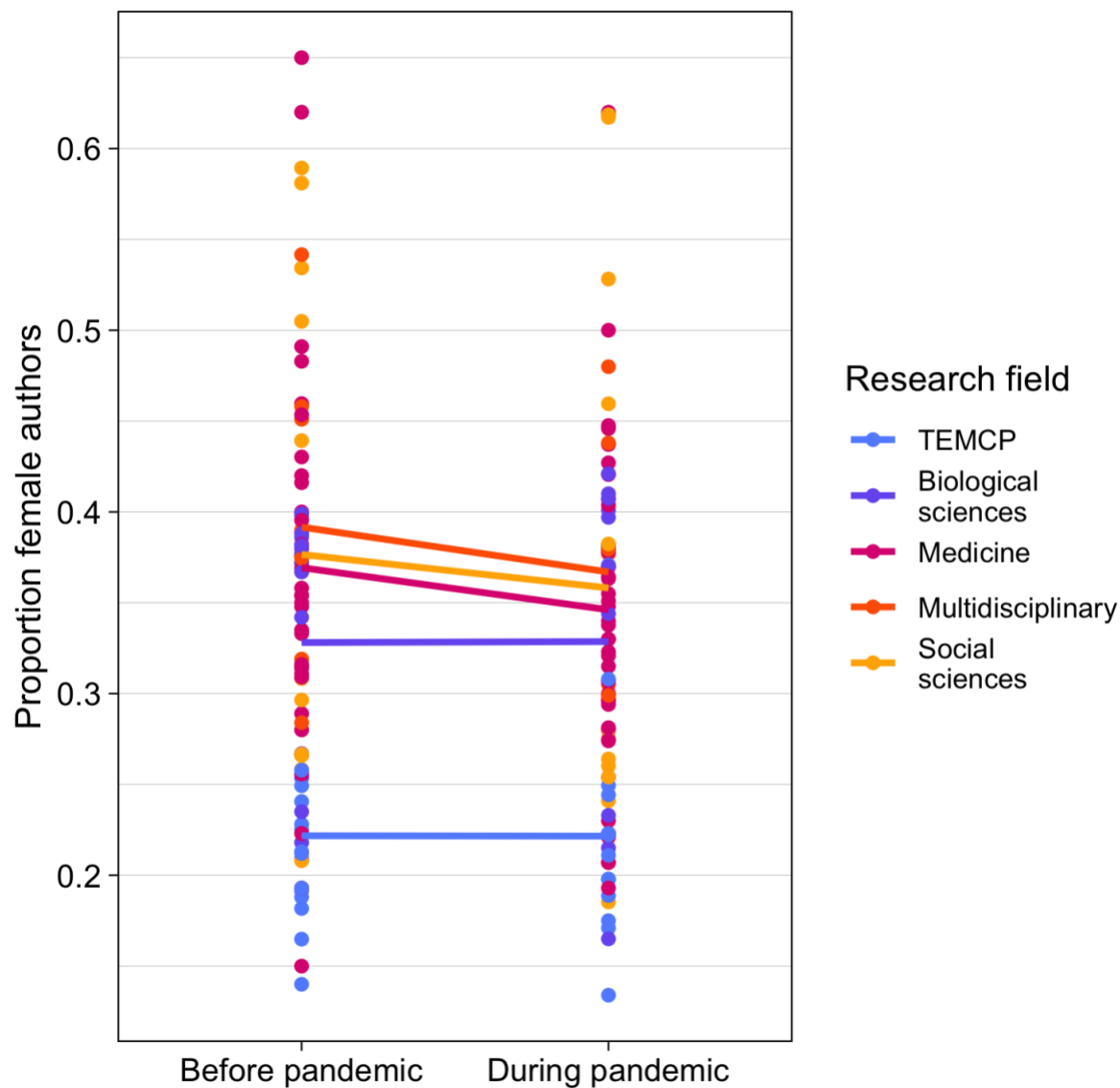
We found little evidence of a significant differential impact of research fields on the reported effect sizes (QM (df=4)= 6.341, p-value= 0.175, Fig. 3). When considering research fields individually, social sciences showed the greatest increases in the academic productivity gender gap during the pandemic (-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= -0.059 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 ( $QM(df = 1) = 11.0156$ ,  $p\text{-value} = 0.0009$ ). 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%).

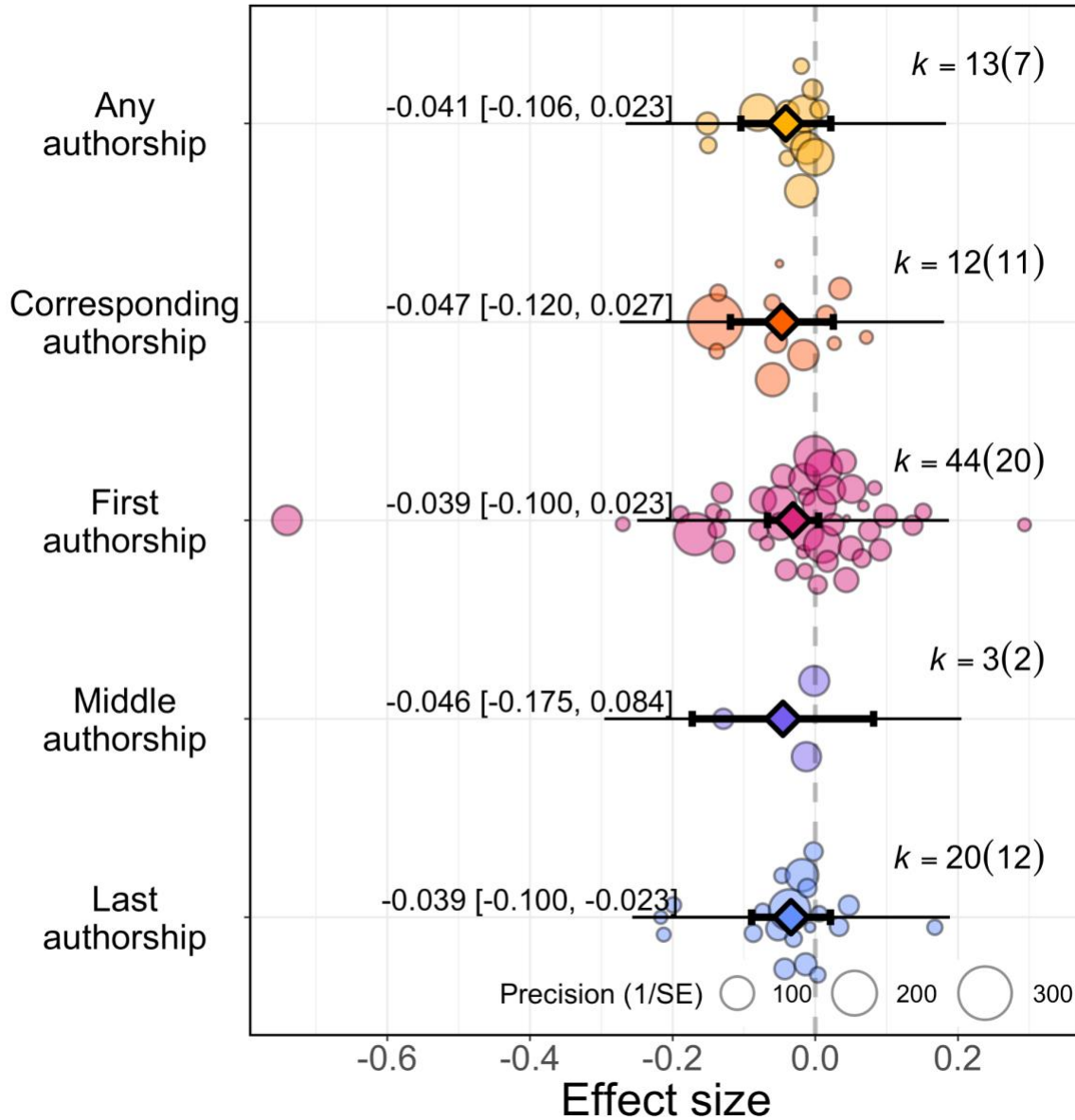


**Figure 4. Research field influence on academia's gender gap in submissions and publications during the pandemic.** Line plot of gender gap in authorship before and during the pandemic, grouped by research field. Points show gender gap as the proportion of female authors publishing and submitting before 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.

277 3a: Has the pandemic affected women more in their ability to lead rather  
278 than support research?

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

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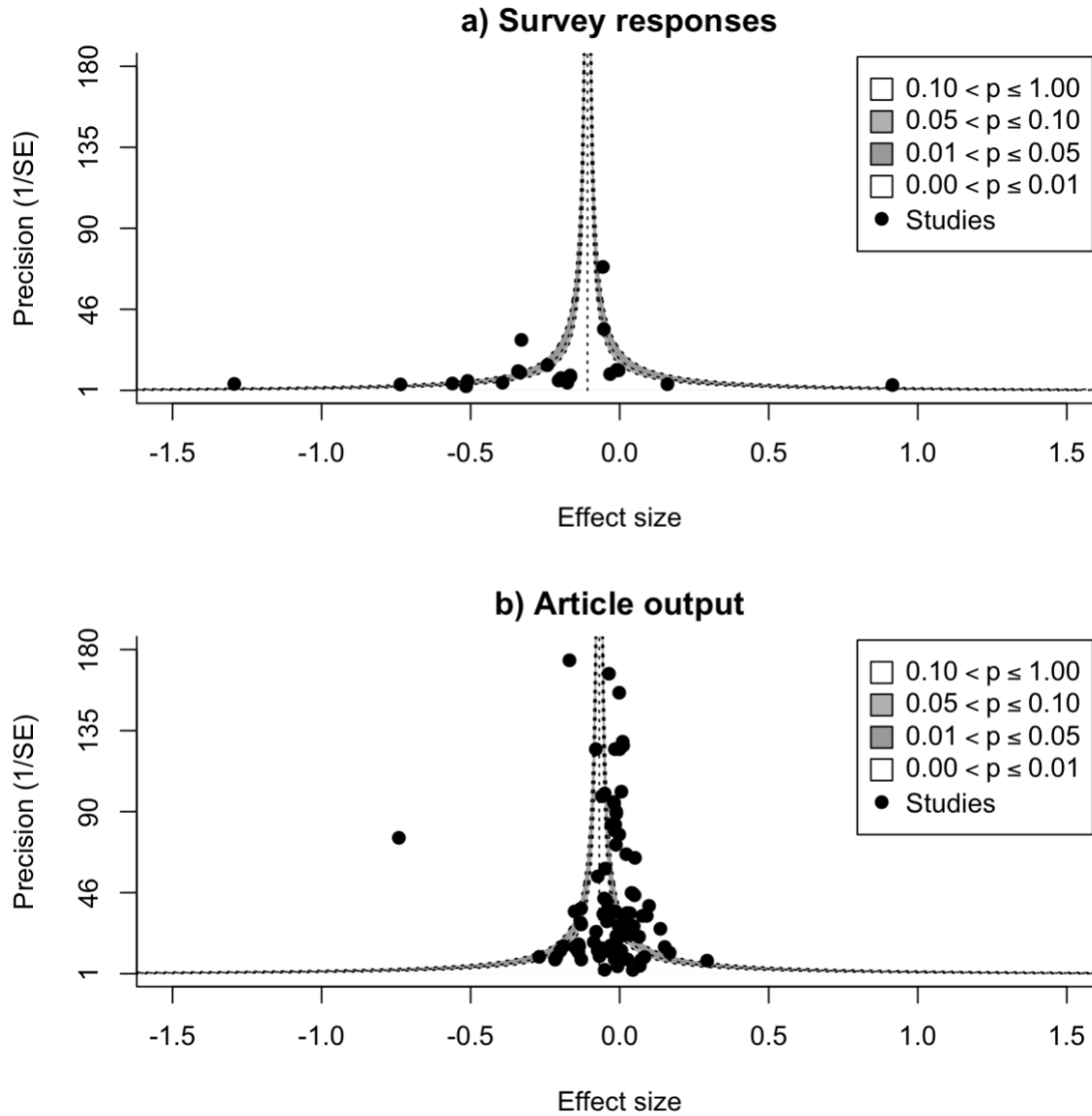


**Figure 5. Authorship position and academia's gender gap during the pandemic.** Orchard plot comparing the distribution of effect sizes (points) and their weight (point sizes), depending on the authorship position sampled in publication studies, for which the mean effect size (darker coloured points 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.



293 Is there evidence of publication bias?

294 We found no evidence of publication bias based on our multilevel meta-regression, suggesting  
295 small studies with large effect sizes did not skew our model (Article-output studies: slope= -  
296 0.026, 95% CI= [-0.061- 0.009], SE=0.018, p=0.140; Survey-response studies: slope= -0.190,  
297 95% CI= [-0.286- -0.095], SE=0.049, p<0.001). A visual inspection of the funnel plots (Fig. 6)  
298 similarly did not indicate any suggestion of publication bias.  
299



**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 ( $-0.04 \times 34.0\% = -1.4\%$ ). 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 <i>"acute respiratory"</i> OR <i>gis</i> OR <i>icu</i> OR <i>risk</i> OR <i>rna</i> OR <i>symptoms</i> )



## 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,

551 including research productivity measure as a moderator and display this relationship in funnel  
552 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.7409165](https://doi.org/10.5281/zenodo.7409165).

## Supplementary information

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

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## 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 )

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

Term	Strength	Rank ascending
child	4257	2063
regression	4335	2064
survey	4367	2065
<b><i>acute respiratory</i></b>	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
<i>icu</i>	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
<i>iga</i>	8235	2099
hospital	8318	2100
work	8319	2101
covid-19 pandemic	8377	2102
<i>gis</i>	8489	2103

severe	8518	2104
time	8831	2105
infection	8914	2106
<i>rna</i>	10303	2107
outcome	10461	2108
review	11869	2109
coronavirus	12243	2110
stem	12316	2111
<i>risk</i>	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

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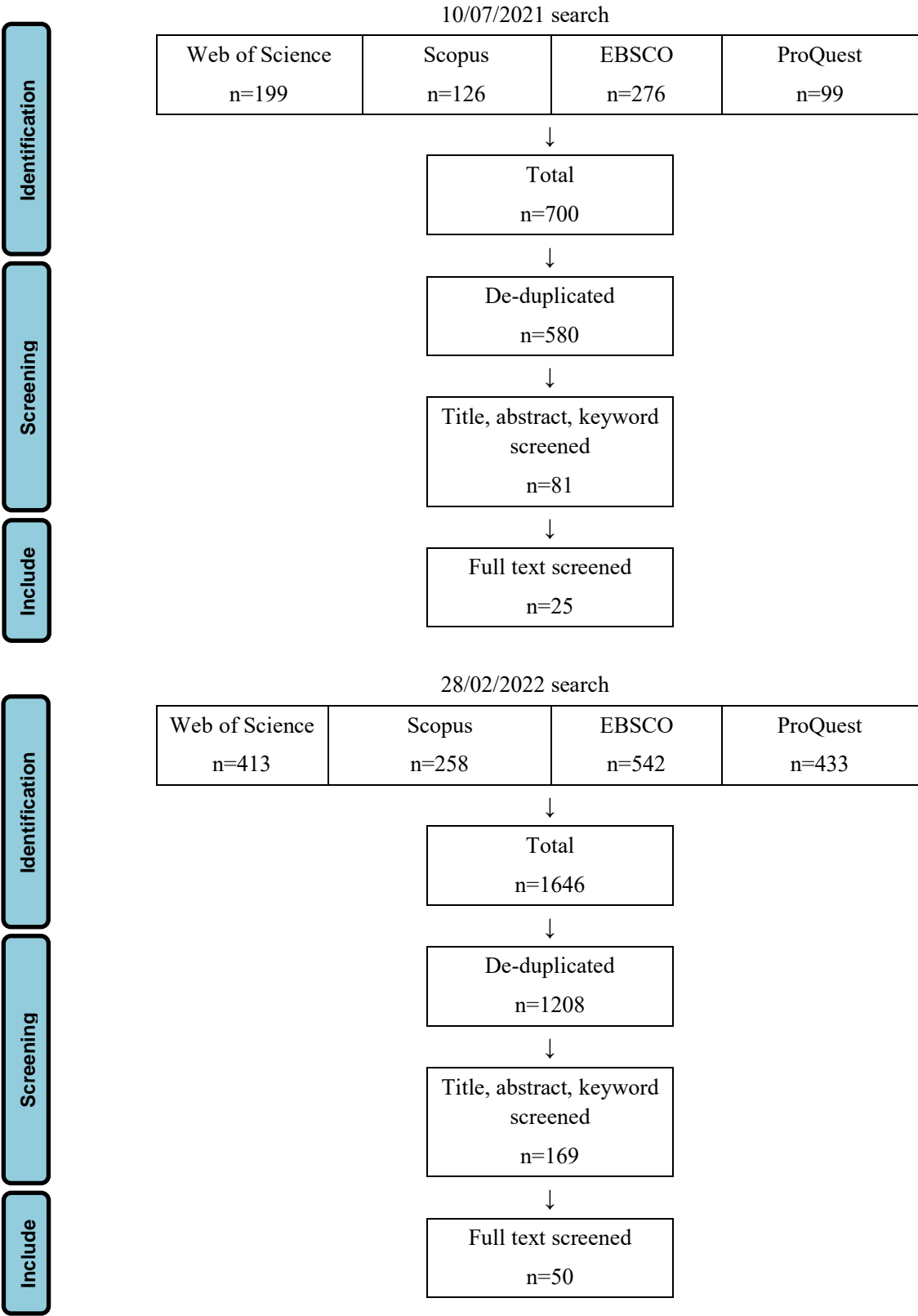
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**Table S3. Flowchart of questions used for initial screen of title, abstract and key-words.**

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.

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



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