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Frederick Sebastian
Mem. ASME
Department of Bioengineering,
Northeastern University,
Boston, MA 02120
e-mail: sebastian.f@northeastern.edu

Ana I. Vargas
Mem. ASME
Department of Bioengineering,
Northeastern University,
Boston, MA 02120
e-mail: vargas.an@northeastern.edu

Julia Clarin
Mem. ASME
Department of Bioengineering,
Northeastern University,
Boston, MA 02120
e-mail: clarin.j@northeastern.edu

Anthony Hurgoi
Department of Mechanical and
Industrial Engineering,
Northeastern University,
Boston, MA 02115
e-mail: hurgoi.a@northeastern.edu

Rouzbeh Amini[1]
Mem. ASME
Department of Bioengineering,
Northeastern University,
Boston, MA 02115;
Department of Mechanical and
Industrial Engineering,
Northeastern University,
Boston, MA 02115
e-mail: r.amini@northeastern.edu

Meta Data Analysis of Sex Distribution of Study Samples Reported in Summer Biomechanics, Bioengineering, and Biotransport Annual Conference Abstracts

The biased use of male subjects in biomedical research has created limitations, underscoring the importance of including women to enhance the outcomes of evidence-based medicine and to promote human health. While federal policies (e.g., the 1993 Revitalization Act and the 2016 Sex as a Biological Variable Act) have aimed to improve sex balance in studies funded by the National Institutes of Health (NIH), data on sex inclusivity in non-NIH funded research remain limited. The objective of this study was to analyze the trend of sex inclusion in abstracts submitted to the Summer Biomechanics, Bioengineering, & Biotransport Conference (SB^3C) over 7 years. We scored every abstract accepted to SB^3C, and the findings revealed that approximately 20% of total abstracts included sex-related information, and this trend remained stable. Surprisingly, there was no significant increase in abstracts, including both sexes and those with balanced female and male samples. The proportion of abstracts with balanced sexes was notably lower than those including both sexes. Additionally, we examined whether the exclusion of one sex from the corresponding studies was justified by the research questions. Female-only studies had a 50% justification rate, while male-only studies had only 2% justification. Disparity in sex inclusion in SB^3C abstracts was apparent, prompting us to encourage scientists to be more mindful of the sex of the research samples. Addressing sex inclusivity in biomechanics and mechanobiology research is essential for advancing medical knowledge and for promoting better healthcare outcomes for everyone. [DOI: 10.1115/1.4064032]

Introduction

For decades, the outcomes of biomedical research have been limited due to the exclusive use of male subjects. The inclusion of women as research subjects—both in hypothesis-driven investigations and in tool-development efforts—is vital to extend the impact of evidence-based medicine and to improve human health. It also ensures that generalized inferences about health and diseases can be made accurately. Certain areas of biomedical engineering suffer from extensive disparity between their effects on women and men, including but not limited to cardiovascular disease [1–3], biomechanical response to concussion [4–7], stroke [8–11], and motor vehicle crash injury outcomes [12–14].

In recent years, rules and regulations have been implemented to encourage higher recruitment of women and minorities in research studies. In the United States, title 42 U.S.C. § 289(a)(2) of federal statutes requires the NIH to ensure that women are included as subjects in clinical research. Additionally, in 1993, the NIH Revitalization Act was executed to further bridge the gap in sex inclusivity in research studies.

The title 42 U.S.C. § 289(a)(2) of federal statutes and the NIH Revitalization Act have proven effective to some extent with data showing that approximately 50% of participants in NIH-funded research studies are women [15]. However, data for studies not funded by NIH are not readily available. Some research has been done to assess the inclusivity of sexes in studies that also encompass animals and cells. For example, Shanksy et al. [16] called for a need in cultural shift to address sex and gender biases in neuroscience research that utilized male animals and participants predominantly. They stated that despite receiving NIH grants, awardees were not

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required to conduct the exact experiments they proposed; therefore, without official accountability measures in place, the usage of 50/50 female and male subjects depended entirely on the good-faith efforts by researchers. Bale et al. [17] provided an argument for the importance for investigators to use both sexes in their studies to enhance the quality of science along with the safety, and efficacy of treatments for human disorders. Bale et al. provided varying examples of animal and clinical studies that showed the significance of using sex as a biological variable, including research about hormones, neurodevelopment, and neuropsychiatric disorders. For example, Bale et al. argued that while both male and female may receive a neuropsychiatric diagnosis of the same condition, such as autism, it is important to note that the underlying mechanisms and manifestations of that condition can exhibit sex-specific variations. Shah et al. [18] discussed the differences in phenotypes acquired from cells of different sexes and how they impacted study outcomes. They also stated that the NIH-mandated enrollment of women in clinical trials did not extend to studies using animal samples; thus, the male-to-female bias in neuroscience research studies was approximately 5.5 to 1 in animal studies. Finally, Bach et al. [19] evaluated the macroscopic trends regarding sex sampling in abstracts presented at the annual meetings of the American Society of Biomechanics from a wide range of biomechanics research. With similar motivations, the purpose of this study was to examine the sex inclusions in the abstracts of the Summer Biomechanics, Bioengineering, & Biotransport Conference (SB^3C) from 2015, the inception year of the conference, to 2022 (sans 2018). With increasing awareness of the scientific community, we hypothesized that the proportion of research projects with both sexes included would have increased over the past 7 years.

Methods

To assess trends of sex inclusion in biomedical studies, we analyzed abstracts from 7 years of SB^3C proceedings. The abstracts from 2018 were omitted since the conference was jointly run with the World Congress of Biomechanics. Identification of sex in human or animal experimental studies was straightforward. To identify sex in computational and mathematical studies, we examined if the animal or human data/geometry used as input parameters and validation datasets were reported. Additionally, due to the significance of genes expressed on the sex chromosomes within cells and tissues [18], we assessed whether researchers reported the sex of their cellular/tissue samples and its pertinence to the research question.

All abstracts accepted to SB^3C were scored, with the title, applicable population, and study summary of each abstract meticulously recorded. Given the large number of abstracts ($n = \sim 600$/year), each year was assigned to an examiner. Since the total number of abstracts varied each year (refer to Appendix Table 1 for raw data), we analyzed the metric of interest as a proportion to the total number of abstracts submitted each year. For each abstract, we first examined if any information about sex was provided. If the answer was yes, we then identified if, only female, only male, or both sexes were included. If both sexes were included, we examined if a balanced number of both sexes were used. If sex was irrelevant to the study, e.g., a study solely focusing on a new meshing technique, it was not included in the "sex reported" group. It was determined that a study was "balanced" if each sex accounted for $50 \pm 10\%$ of the total study population. If only one sex was included, we examined if the study had a sex-specific and biologically relevant purpose (e.g., biomechanics of pregnancy [20–23] or prostate cancer [24]) and thus the reason for using only one sex was considered "justified." The flowchart of this process is summarized in Fig. 1. Once every abstract from each conference proceeding was analyzed, the examiners were randomly assigned a different year from their initial assignments, the process was repeated, and any discrepancies were rectified. A final review of all reported data in the studies that included sex was conducted by a single examiner (FS) to ensure the assessments were accurate.

Statistical analyses were performed in GraphPad Prism version 10.0.2 for Windows, GraphPad Software, Boston, MA. Chi-squared test for trend [25] was used to test whether there was a linear trend between two groups (e.g., female only abstracts and male only abstracts) and time (year). Poisson regression analysis was used to investigate the relationship between the proportion of abstracts of interest and the year the studies were published. A dispersion ratio was calculated (variance-to-mean ratio) to verify that the data were not overdispersed; therefore, confirming the Poisson regression model was appropriate for statistical analysis. Additionally, the Poisson regression model reports a pseudo-R^2 value, which represents the goodness-of-fit of the data. A p-value of less than

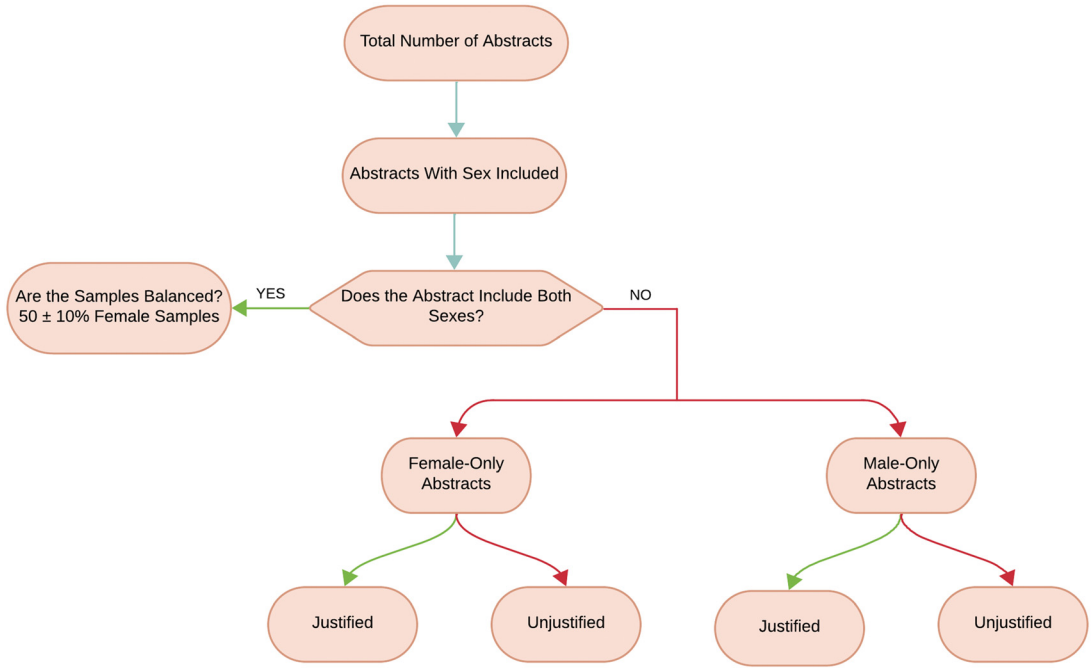

Fig. 1 Flowchart showing the process utilized to score every abstract submitted to SB^3C

0.05 was considered statistically significant for all tests. Normality was assessed using Shapiro–Wilk normality test prior to performing the comparison between the proportion of abstracts per year that included both sexes and those that included a balance sex sample using a t-test. If the data did not conform to a normal distribution, then a Mann–Whitney U test was performed to assess the difference between the proportions of abstracts. The process of checking for normality and then performing the appropriate t-test was repeated for the justification rate for female- and male-only abstracts over the years.

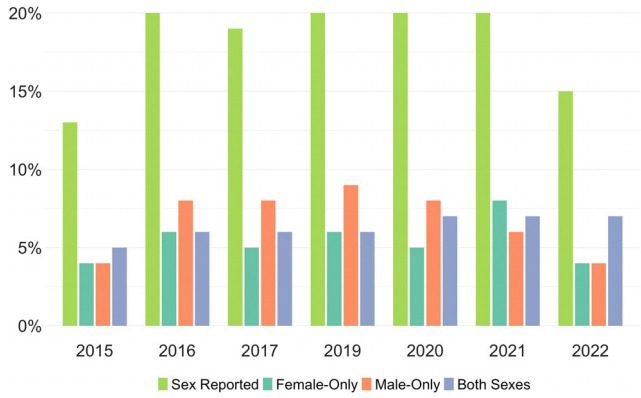

Fig. 2 Distribution of sex inclusion in SB^{3}C abstracts per year (for the raw data please refer to the Appendix)

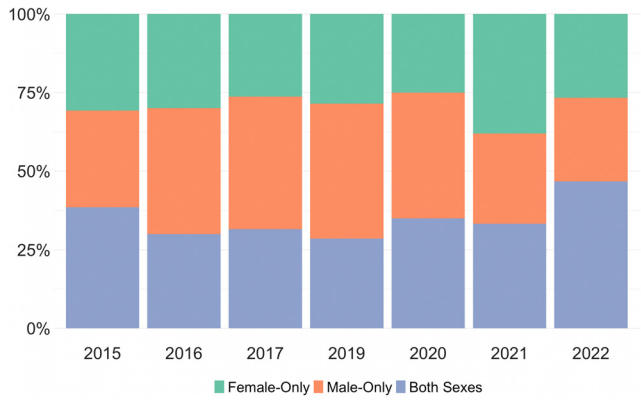

Fig. 3 Normalized distribution of sex groups per year. No significant difference was observed in the number of female- and male-only abstracts submitted each year.

Results

The overall proportion of abstracts with sex included stayed at approximately 20% for each year ($R^2 = 0.03$, $p = 0.76$; Fig. 2), suggesting that time did not influence the proportion of abstracts that included sex from the total number of abstracts. To better visualize the data from the abstracts that reported sex, a normalized distribution of female-only, male-only, and both sexes is provided in Fig. 3. It was determined that the proportion of female- and male-only abstracts submitted each year did not follow a linear trend (Chi-square for trend = 0.23, $p = 0.63$). As such, no linear relationship existed between female-only or male-only abstracts and the year of abstract submission.

Additionally, a Poisson distribution determined that the total proportion of abstracts that included both sexes did not increase over the years ($R^2 = 0.61$, $p = 0.59$). Likewise, of these abstracts, those with balanced sex groups did not increase significantly either ($R^2 = 0.40$, $p = 0.08$) as seen in Fig. 4. The proportion of balanced abstracts was significantly lower than the proportion of abstracts that included both sexes according to an unpaired, two-tailed t-test ($p < 0.001$). A Chi-square test for trend revealed that this difference remained the same across the years when the abstracts were submitted (Chi-square for trend = 0.02, $p = 0.89$).

Finally, the female- and male-only data were categorized for justification in each year. The percentage of justified versus unjustified abstracts was plotted using a waffle chart (Fig. 5). The proportion of female-only abstracts that were justified was significantly higher ($p < 0.001$) than the proportion of male-only abstracts that were justified according to an unpaired Mann–Whitney test. A Chi-square test for trend revealed that this difference significantly changed across the years when the abstract was submitted (Chi-square for trend = 6.97, $p = 0.01$).

Discussion

Inclusion of both sexes is critical in biomedical research. Evidence shows that disparity in the inclusion of women in research has led to uninformed decision-making and poor outcomes of evidence-based health care for women. Historically, most clinical

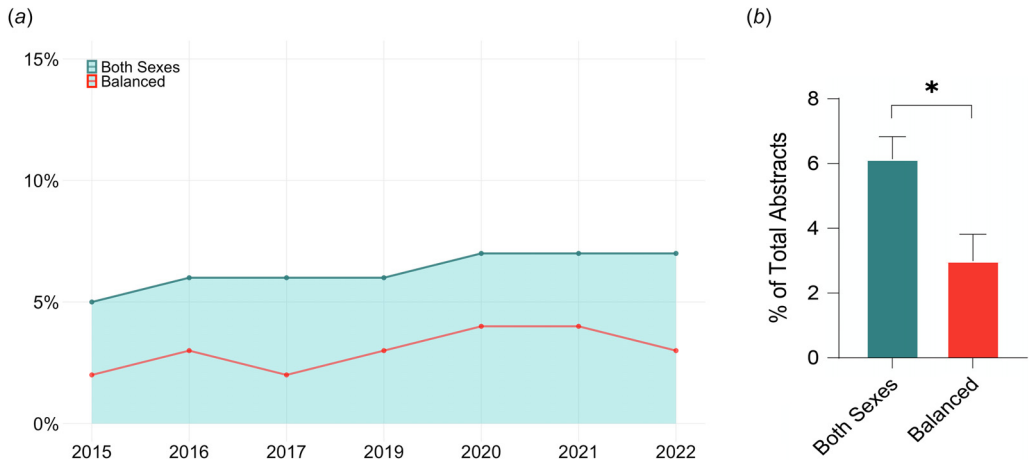

Fig. 4 (*a*) Trend of abstracts that includes both sexes and balanced inclusion of female and male sexes over the years. (*b*) Bar chart showing significant difference between proportion of abstracts including both sexes and those with balanced sexes over the years. Asterix indicates significant difference ($p < 0.05$, using an unpaired t-test).

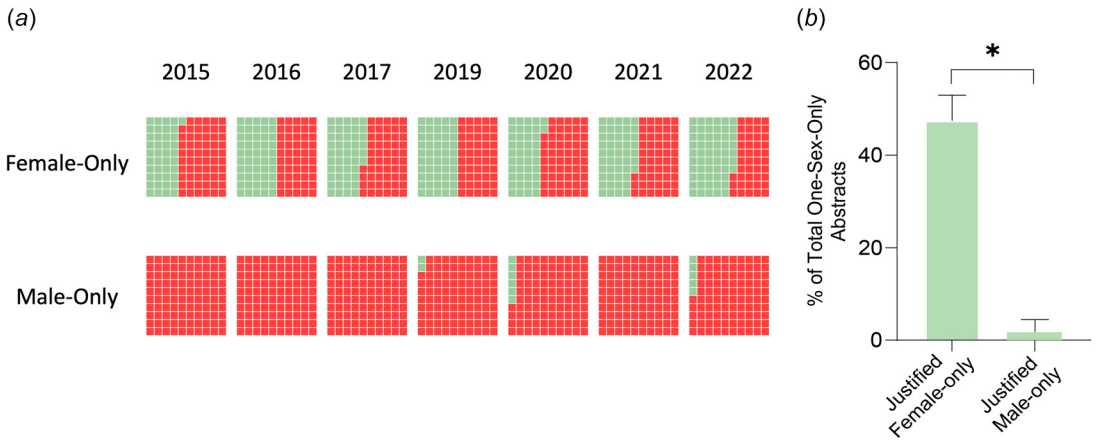

Fig. 5 (*a*) **Comparison of single-sex abstracts (light = justified; dark = unjustified). The reasons for the exclusion of the other sex were based on the research purposes in the "justified" category. (*b*) Bar chart showing significant difference between the proportion of justified female-only abstracts compared to justified male-only abstracts. Asterix indicates significant difference ($p < 0.05$, using an unpaired Mann–Whitney test).**

and nonclinical studies have failed to include a proportional number of female subjects, if any at all; yet these studies long served as a basis for our understanding of human physiology, disease, and treatment [26,27]. As a direct consequence, diseases that present differently in women are more commonly missed or misdiagnosed, and those that predominantly affect women are frequently understudied and undertreated.

Cardiovascular disease provides a clear example of such a disparity. For many years, cardiovascular disease was perceived as primarily affecting men [28], leading to clinical research and treatment approaches that heavily favored male participants. Women, specifically postmenopausal women, were underrepresented in cardiovascular research trials [29,30]. This skewed focus provided inconclusive results on how heart disease manifests in women and the unique risk factors they might face [31]. Consequently, symptoms and warning signs of heart disease in women were often overlooked or misdiagnosed, leading to delayed treatment and poorer health outcomes [32]. We used cardiovascular disease as an example because of its alignment with the interests of our research group; however, sex disparities have been evident in a myriad of other biomechanics-based research areas as discussed throughout this paper. Additionally, while the negative impact of sex bias in clinical research is detrimental, it is equally crucial to not overlook the significance of sex biases in preclinical research. For example, McMulkin et al. [33] assessed if muscle force estimates from an optimization-based model using a singular set of input parameters would correlate equally well with electromyography activity measured in female and male muscle activity. They found that using a generalized model parameter cannot be used for both sexes since the female and male muscle force estimates correlated better with their respective sexes. Preclinical studies such as that of McMulkin et al. provide the opportunity to mitigate the consequences in terms of both research efficacy and cost-effectiveness [33–35].

The lack of sex inclusion in research and clinical trials can largely be attributed to inequitable study design. However, it must be acknowledged that underlying political and socioeconomic factors have been inherently at play. For example, in 1977, the U.S. Food and Drug Administration issued guidelines that restricted women of childbearing potential from participating in early-phase drug trials [36]. The restriction arguably limited the potential for advancements in women's health until it was lifted in 1997. Over the 20-year period the restriction was in place, new prescription drugs continued to enter the market despite not being tested in a large population of women. In the 3 years following the lift of this restriction, eight of ten drugs withdrawn from the U.S. market were found to pose a significant risk to women, half of which were widely prescribed to both men and women [37]. For example, the drugs Seldane, Hismanal, and Propulsid were approved for treatment of hypertension and angina but were found to slow or completely stop the heart in a disproportionate population of women [38]. While this devastating oversight was extremely costly for the pharmaceutical industry and regulatory agencies, the true cost was imposed upon the women who suffered the long-term health consequences.

Considering the importance of inclusion of both sexes in biomedical research, the objective of this study was to obtain an overarching perspective of sex sampling in abstracts submitted to SB^3C over the years. Since its inception, SB^3C has been a flagship conference for the field of biomechanics and mechanobiology. In addition, the open access nature of their abstract repository made our investigation possible. We hypothesized that the proportion of SB^3C abstracts that included both sexes and those with balanced sex groups would increase over the years due to an increase in awareness of the scientific community. Our results from scoring every abstract accepted to SB^3C indicated that there was no significant increase in the inclusion of both sexes and in the proportion of balanced sexes. In addition, the proportion of balanced abstracts was significantly lower than expected. Ideally, all studies that included both sexes should have had a 100% rate of balanced groups. Yet, current results leave more to be desired. We acknowledge that health conditions can influence researchers' decisions when striving for a balanced sample population. For instance, a sample population with 65% male and 35% female could be reasonably balanced for a health condition that affect men more than women.

Additionally, it was hypothesized that the "justification" rate would be greater in female-only studies due to increased awareness and efforts to address women's health issues, including initiatives such as the U.S. Public Health Service Task Force on Women's Health Issues [39–41]. This initiative provided recommendations for deliberate focus on women's health issues and specific measures to tackle them. Some of the recommendations are outlined by Woods et al. [39], which include the establishment of programs to disseminate knowledge on sex and gender differences into research, the provision of treatment and services for diseases that affect women and children such as the human immunodeficiency virus, and the undertaking of research and evaluation specifically addressing conditions that are unique or more prevalent in women. Similarly, in her executive perspective, Nancy Lee [40] highlighted the Food and Drug Administration's mandate to incorporate data on the safety and efficacy of drugs and medical devices with consideration for sex. Our hypothesis was substantiated, as this analysis revealed the stark difference between the justifications of

female- and male-only studies over the years. Even though the proportion of female-only studies being justified is higher than the male-only studies, the need for more balanced studies in biomechanics is apparent. We wish to underscore the distinction between researchers adapting to the circumstances they encounter and researchers unintentionally overlooking the diversity of their sample groups. Acquiring high-quality human or animal samples always presents a challenge, and investigators might not have had the necessary resources to adequately plan for this factor in their experiments. Overall, in comparison to the study by Bach et al. [19], similarly we found no difference in the percentage of abstracts reporting sex over time. In contrast, we found no significant increasing trends for abstracts including both sexes, and abstracts having approximately balanced samples. This difference might be due to our approach in using a more stringent $50\pm10\%$ female to male ratio compared to their $50\pm20\%$.

One of the limitations of our analysis is the assumption that the SB^3C abstracts encompass all the information of the full study. The papers that result from the abstracts might include a larger and more comprehensive subject population that has not been described in the abstracts due to space constraints. It is worth noting that prior studies have identified sex biases even in the analysis of full manuscripts within the field of biomedical engineering. For example, Lamia et al. [42], investigated sex bias in finite element analysis in hip arthroplasty by identifying which sex (female versus male) characteristic were used more prevalently in the models submitted to the PubMed database from 1984 to 2019. They found that male subjects or characteristics were modeled more often than females despite the increased number of studies that include female geometrics over the years. Additionally, many studies included both sexes, but the abstracts did not include the number of male and female subjects, thus skewing the "balanced" assessment. We did not track the gender of corresponding authors to assess its correlation with sex bias in their studies since we did not want to assume the gender of the authors solely from their names. However, Xiao et al. [43] investigated the correlation between the gender of authors and the prevalence of sex bias. They mitigated the issue of misgendering authors by utilizing an R Studio (R Core Team)-based package that identified the gender of authors based on the provided name and country within a confidence interval of 95%. Their study showed that sex bias is prevalent regardless of the gender of the author in surgical research. Additionally, for the purposes of this study, we considered the use of "gender" and "sex" in the abstracts to refer to the binary biological sexes (female and male) unless the study specifically examined sociological gender roles. We did not encounter any abstract focusing on gender roles in our SB^3C analyses; however, the effects of gender and sex in certain fields such as motor vehicle crash have been previously explored [44]. We also recognize that our use of "women" and "men" ostracizes nonbinary individuals from our analysis. However, within the current scientific context, we believe this terminology is appropriate to elucidate the necessary information for the scope of this study.

In summary, our analysis revealed a concerning disparity in the usage of female and male samples in research studies. We encourage scientists to be mindful of sex (i.e., the biological differences between females and males) and gender (i.e., the socially constructed identity of the individuals) inclusion to ensure the full benefit of biomedical research. Furthermore, Arnegard et al. [45] have presented the beneficial effects of initiatives such as the Sex as a Biological Variable policy by the NIH throughout the research and healthcare enterprise. Consequently, we advocate for the implementation and integration of systematic policies that foster the inclusion of balanced sample diversity into biomechanics and mechanobiology research. SB^3C and similar conferences should establish policies requiring authors to disclose the gender composition of their study samples, including justifications for any imbalance. Additionally, publicly collecting and sharing data on authors' genders and attendees' gender distribution would further enhance analyses and provide a more comprehensive database to examine the sex bias in conferences like SB^3C.

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Funding Data

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Data Availability Statement

The datasets generated and supporting the findings of this article are obtainable from the corresponding author upon reasonable request.

Appendix

In adherence to our commitment to developing an educational component and to broaden the impact of our work, as shown in our previous publications [23,46–48], we have included a homework problem with an additional table (Table 1) on the step-by-step breakdown and methodology employed to achieve the results presented in this paper. This problem is appropriate for any undergraduate or graduate student with basic knowledge of statistics.

Problem-Table 1 includes data for the total number of abstracts for each year along with the corresponding count of abstracts, in which sex-related data are available. Within the subset of abstracts that include sex details, the table further differentiates between those involving both sexes, balanced (as described in the methods section), only males, and only females. To complete this problem, refer to the most recent year of the SB^3C or an equivalent conference and fill in the information in the last row of Table 1. Identify how the data you have collected compare with those presented in the rest of Table 1.

Table 1 Raw data for the distribution of sex inclusion in SB^3C abstracts per year with a blank column for the homework problem

Year	Total abstracts	Sex reported	Both sexes included	Balanced	Only male	Only female
2015	665	87	31	15	29	27
2016	663	135	41	23	54	40
2017	595	113	35	11	50	28
2019	617	126	37	18	54	35
2020	660	131	45	27	53	33
2021	548	111	36	23	32	43
2022	515	78	36	15	20	22
Current year						

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