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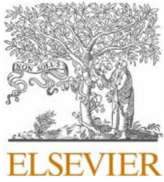

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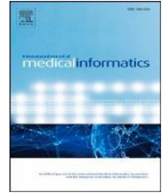

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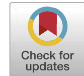

Interdisciplinary collaboration in critical care alarm research: A bibliometric analysis

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ABSTRACT

Background: Alarm fatigue in nurses is a major patient safety concern in the intensive care unit. This is caused by exposure to high rates of false and non-actionable alarms. Despite decades of research, the problem persists, leading to stress, burnout, and patient harm resulting from true missed events. While engineering approaches to reduce false alarms have spurred hope, they appear to lack collaboration between nurses and engineers to produce real-world solutions. The aim of this bibliometric analysis was to examine the relevant literature to quantify the level of authorial collaboration between nurses, physicians, and engineers.

Methods: We conducted a bibliometric analysis of articles on alarm fatigue and false alarm reduction strategies in critical care published between 2010 and 2022. Data were extracted at the article and author level. The percentages of author disciplines per publication were calculated by study design, journal subject area, and other article-level factors.

Results: A total of 155 articles with 583 unique authors were identified. While 31.73 % (n = 185) of the unique authors had a nursing background, publications using an engineering study design (n = 46), e.g., model development, had a very low involvement of nursing authors (mean proportion at 1.09 %). Observational studies (n = 58) and interventional studies (n = 33) had a higher mean involvement of 52.27 % and 47.75 %, respectively. Articles published in nursing journals (n = 32) had the highest mean proportion of nursing authors (80.32 %), while those published in engineering journals (n = 46) had the lowest (9.00 %), with 6 (13.04 %) articles having one or more nurses as co-authors.

Conclusion: Minimal involvement of nursing expertise in alarm research utilizing engineering methodologies may be one reason for the lack of successful, real-world solutions to ameliorate alarm fatigue. Fostering a

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collaborative, interdisciplinary research culture can promote a common publication culture across fields and may yield sustainable implementation of technological solutions in healthcare.

1. Introduction

Research on the phenomenon of 'alarm fatigue' dates back to the 1950s and has received increasing scientific attention from various disciplines in recent years. Alarm fatigue refers to the assimilation of clinical staff to alarms in the intensve care unit (ICU) [1–3]. It occurs when a large number of clinical alarms are either technically false (artifactual) or clinically irrelevant (non-actionable). As ICU staff become desensitized ("fatigued") to alarms, this can cause serious harm to both patients, due to missed true events, and to clinicians themselves. Among affected staff, nurses bear the greatest burden of persistent audiovisual overload [4,5] from spending most of their shift in close proximity to alarm sources, often resulting in stress and burnout [6,7]. Despite numerous attempts to reduce alarm fatigue, it remains a significant patient safety concern.

The negative implications for patient safety stem from various types of subpar alarm responses, including ignored alarms [8], delayed alarm responses [9], lowered alarm volume, or muted alarms [10]. In the past, these responses have had fatal consequences for patients as true alarms were unintentionally missed [4,11,12]. Most recently available data (2005 to 2012) reveal over 1640 in-hospital deaths related to alarms [10,13]. Since these data are over a decade old, it is plausible that alarm- related deaths have increased, given the persisting issue with limited interventions tested and implemented in clinical care [14]. In addition, patients are subjected to both psychological stress (e.g., fear, anxiety [15,16]) and physiological stress (e.g., increased heart rate and blood pressure, sleep deprivation, delirium [17,18]) due to alarm noise. Several patient safety organizations, such as The Joint Commission, have repeatedly issued warnings about this problem [1,2,19,20].

The persistence of this problem compromises nurses' efforts to ensure patient safety in high-pressure environments such as the ICU. From a cognitive standpoint, nurses operate in a constant cycle of assessing and rapidly responding to stimuli. They must prioritize critical interventions by quickly deciphering multiple alarms-a mental task that requires immediate decision-making. Alarm fatigue can blur the line between urgent signals and background noise, potentially causing critical delays. Juggling priorities such as patient safety, workflow, and satisfaction undermines nurses' ability to provide timely care [21,22]. To ensure that they can provide effective care without succumbing to cognitive overload, it is imperative to address and mitigate alarm fatigue.

There is an assumption that alarm fatigue can be solved using clinical interventions such as skin electrode changes or adjusting alarm settings. However, these interventions have had limited success in reducing the problem [14,23–25]. Studies suggest that algorithm deficiencies used in bedside monitors are a major contributor to the high rate of false alarms [3,8,26–28]. In view of these findings, some groups have applied engineering approaches (e.g., machine learning, signal processing) to mitigate false alarms [29–37]. Findings from these studies have spurred hope in alleviating the long-standing problem, but their limitations, such as missed true events, residual false positive alarms, and true non- actionable alarms, obstruct real-world improvements [29,30]. One potential explanation for this issue may be the lack of collaborative approaches between nurses and engineers (including informaticists, data scientists, etc.) when developing and testing alarm reduction strategies. Where nurses can provide contextualization of alarms and understanding of alarm workflows in clinical practice, engineers can develop methodological approaches for designing and improving alarm algorithms. We hypothesize that there is a disconnect between the respective involvement of these disciplines, in spite of their unique and important perspectives for developing clinically viable alarm systems.

We conducted a bibliometric analysis to investigate the authors' discipline by analysis category (e.g., study design, journal/conference subject area) in publications relating to false alarm reduction and alarm fatigue in ICU settings. Bibliometric analyses can unveil publication- related attributes and patterns associated with journals, authors, and articles in particular research areas, serving to examine the intellectual structure of a given field [38]. Measuring co-authorship based on author discipline can serve as a proxy for evaluating interdisciplinary collaboration in a field of study. Findings may uncover important gaps in collaboration, prompting future collaborations in the ICU alarm research field.

2. Methods

2.1. Study design and search strategy

We conducted a bibliometric analysis to review medical, engineering, nursing, interdisciplinary, and other articles reporting research in the field of alarm fatigue and false alarm reduction published across six databases (PubMed, CINAHL, EMBASE, Web of Science, IEEE Xplore, and Cochrane) between 2010 and 2022. The complete search strategy, including the search terms, is listed in **Appendix A**. We report in line with the Preferred Reporting Items for Systematic Reviews and Meta- Analyses (PRISMA) 2020 guidelines where applicable to bibliometric analyses [39]. The study protocol was prospectively registered on the International Prospective Register of Systematic Reviews (PROSPERO) under the identifying number CRD42022323984.

2.2. Eligibility criteria

Studies investigating alarm fatigue or alarm reduction in ICU settings (both adult and pediatric/neonatal) were considered for inclusion. All manuscripts except non-full-text records in the English language were considered for inclusion. The inclusion and exclusion criteria are listed in **Appendix B**.

2.3. Screening process and study selection

Publications were managed using EndNote20 (Clarivate, London, UK), where duplicate articles were removed, and the remaining records imported to Covidence systematic review software (Veritas Health Innovation, Melbourne, Australia). Possible articles were screened by two reviewers independently in line with the eligibility criteria. To ensure publications identified were of relevance to the topic and met the eligibility criteria, we screened the title and abstract of each publication. If deemed relevant, we reviewed the full-text version. Conflicts at each stage were solved by a third independent reviewer.

2.4. Data collection process and data items

We extracted the following data from each article: title, author, publication year, journal, study design, study setting, funding source, funding body, and journal/conference subject area (engineering/computer science, medicine, nursing, interdisciplinary, other) (see **Appendix C**). The data extraction template can be accessed on the Open Science Framework (see Data availability statement). A separate list of all authors was created. For each author, we extracted the full name, academic degrees, discipline (defined below), first affiliation listed, country of first affiliation listed, and second affiliation, if applicable (**Appendix C**). If a given author had more than two affiliations, only the primary affiliation was used for analysis. An author's discipline was categorized as either engineering (incl. computer science, data science), medicine, nursing, or other. Categorization was determined based on academic degrees listed either in the respective publication or, if not available, by internet search referring to academic, professional, or third-party websites (e.g., LinkedIn). If an author's discipline could not be determined due to a lack

of information, they were assigned the category of “other”. Each publication and each author were assigned a unique identifier (*publication_id* and *author_id*). For each author, all applicable *publication_id*’s were recorded to facilitate the analysis on a per-publication and per-author basis. The extracted data per publication and per author were harmonized by a second reviewer. Conflicts were resolved by a third reviewer.

2.5. Data analysis

Each record was assigned to a group based on having either no or any number of nursing authors. Articles in the latter group were also grouped by having nurses as either first and/or last authors. We also calculated the percentage of each author group by discipline and journal/conference subject area per-publication and calculated the overall mean. For the per-author analysis, we conducted a descriptive analysis of author discipline by study design, journal/conference subject area, intensive care setting, country of first author, and year of publication. All analyses were performed using Google Sheets (Google, Menlo Park, CA, United States) and R (R Foundation for Statistical Computing, Vienna, Austria) [40].

2.6. Data availability

All data generated and/or analyzed during this study are included in this published article, its appendices, or the Open Science Framework repository (https://osf.io/kh4gj/?view_only%20=%2018a704b8385 b484dbb0fa5d3fda27828).

3. Results

3.1. Overview

3.1.1. Study selection

We identified 2,894 studies for screening, of which 1,067 (36.87 %) were duplicates and removed (Fig. 1). Of the remaining 1,827 records, 1,481 (81.06 %) were considered irrelevant after review of the abstract. A total of 338 full-text studies were assessed for eligibility, of which 183 (54.14 %) were excluded in the process. The remaining 155 articles were included in the final analysis.

3.1.2. Author discipline of included studies

The 155 included studies had a total of 773 authors; 583 were unique authors. Of the 583 unique authors, 185 (31.73 %) of the authors had a professional background in nursing, 177 (30.36 %) in engineering (e.g., computer science/data science), and 143 (24.53 %) in medicine. A total of 78 (13.38 %) were categorized as other, of which 32 (5.49 %) authors had unknown professional backgrounds. While 185 (31.73 %) of the unique authors had a nursing background, when the 155 articles we examined as the unit of analysis, 77 (49.68 %) of the articles had no nursing author (Table 1). A total of 58 (37.42 %) of the articles had a

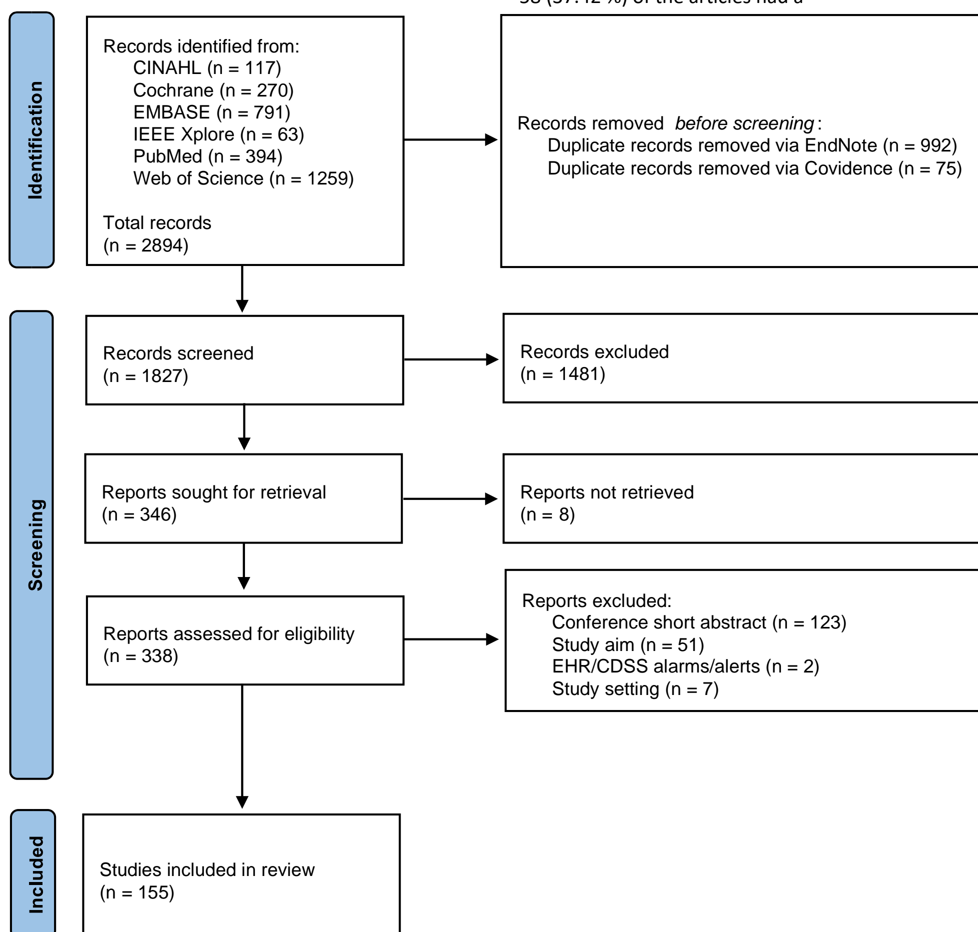

Fig. 1. PRISMA flow chart.

Table 1
Article-level factors and nursing authorship.

Analysis category	Total (%)	Article **with any** nursing author(s), n (%)	Article **without** nursing author(s), n (%)	Average proportion nursing authors, %
Overall # of articles	155 (100)	78 (50.32)	77 (49.68)	33.08
Nurse was first or last author	58 (37.42)	N/A	N/A	79.31

Study design				
Interventional	33 (21.29)	24 (15.48)	9 (5.81)	47.75
Modeling/engineering	50 (32.26)	2 (1.29)	48 (30.97)	1.09[†]
Observational	58 (37.42)	44 (28.39)	14 (9.03)	52.27
Other (e.g., comparative, review)	14 (9.03)	8 (5.16)	6 (3.87)	33.24
Journal/conference subject area				
Engineering	46 (29.68)	6 (3.87)	40 (25.81)	9.00
Medicine	64 (41.29)	36 (23.23)	28 (18.06)	31.73
Multidisciplinary	11 (7.10)	3 (1.94)	8 (5.16)	8.89
Nursing	32 (20.65)	32 (20.65)	0 (0.00)	80.32
Other	2 (1.29)	1 (0.65)	1 (0.65)	7.14
Intensive care setting				
Adult*	128 (82.58)	65 (41.94)	68 (43.87)	49.53
Pediatric/neonatal	27 (17.42)	13 (8.39)	9 (5.81)	17.20
Country of first author				
US	78 (50.32)	48 (30.97)	30 (19.35)	39.64
Non-US	77 (49.68)	30 (19.35)	47 (30.32)	31.77
Number of authors				
<5	73 (47.10)	31 (20.00)	42 (27.10)	27.75
5–10	80 (51.61)	46 (29.68)	34 (21.94)	31.53
>10	2 (1.29)	1 (0.65)	1 (0.65)	8.33
Year of publication				
2010–2015	43 (27.74)	18 (11.61)	25 (16.13)	25.98
2016–2022	112 (72.26)	60 (38.71)	52 (33.55)	36.75

* Including non-specified and other intensive care settings, considered adult if not specified as pediatric or neonatal intensive care setting.

† With n = 2, the percentages of those two publications were 14.29 % (2013) and 40.00 % (2019).

nurse as first or last author with a mean of 79.31 % nursing authors.

3.1.3. Study design of included studies

The study design with the highest representation were observational studies (n = 58, 37.42 %, Table 1). The second most common study design was modeling/engineering studies (n =50, 32.25 %), designed to examine engineering strategies to reduce false alarm rates (referring to technically incorrect alarms). This was followed by 33 (21.29 %) intervention studies, designed to reduce the number of alarms mostly by pre-post clinical interventions. The remaining studies were retrospective observational studies (n = 17, 10.97 %), or other study designs, including comparative studies and reviews (n = 14, 9.03 %).

3.1.4. Journal/conference subject area of included studies

Of the 155 publications included, 64 (41.29 %) were published in journals classified as medical journals. This was followed by 46 (29.68 %) studies published in engineering journals/conferences, then 32 (20.65 %) in nursing journals. The remaining 11 (7.10 %) were published in multidisciplinary journals or other journal/conference subject areas (n = 2, 1.29 %).

3.2. Author discipline by article-level factors

3.2.1. Author discipline per study design of included studies

Of the 50 included modeling/engineering studies on false alarm reduction, two publications had authors with a nursing background (Table 1). The average involvement of nursing authors across these 50 publications was at 1.09 % (Fig. 2). Engineering authors were most prevalent, with a mean of 75.34 % (Fig. 2). Compared to nursing authors, medical authors had a higher average involvement in modeling/ engineering studies at 16.03 % (Fig. 2).

Among the observational (n = 58) and interventional (n = 33) studies, nursing involvement was higher with 44 (75.86 %) and 24 (72.72 %) publications having at least one nursing author, respectively (Table 1). On average, nursing authors made up 52.27 % to 47.75 %, respectively (Fig. 2). In these studies, engineering authors' average involvement was lower with 17.57 % to 14.77 % in non-modeling studies, similar to medical authors with 18.57 % and 26.14 %, respectively.

3.2.2. Author discipline per journal subject area of included studies

While all 32 articles published by nursing journals or conferences had at least one nurse co-author, 40 (86.96 %) of the 46 publications published by engineering journals or conferences did not have at least one nurse co-author (Table 1). While nursing journals had on average 80.32 % nursing co-authors, other professional groups were negligible (Fig. 3). Publications in engineering journals demonstrated the highest mean proportion of nursing authors (68.06%), reflecting strong interdisciplinary collaboration between nursing and engineering fields. The average proportion of medical authors was slightly higher at 13.89 %. Publications in medical journals were found to be most interdisciplinary and evenly weighted with a mean of 34.90 % medical authors, 23.03 % engineering authors, and 31.73 % nursing authors (Fig. 3). Given the considerable mean proportion of nursing authorship across all articles published in the medical field, a substantial proportion of articles – 28 of 64 publications (43.75 %) – did not include a single nursing author (Table 1). Multidisciplinary and all other journal/conference subject areas were neglected in further analysis due to the relatively low number of publications in these two categories (n = 13).

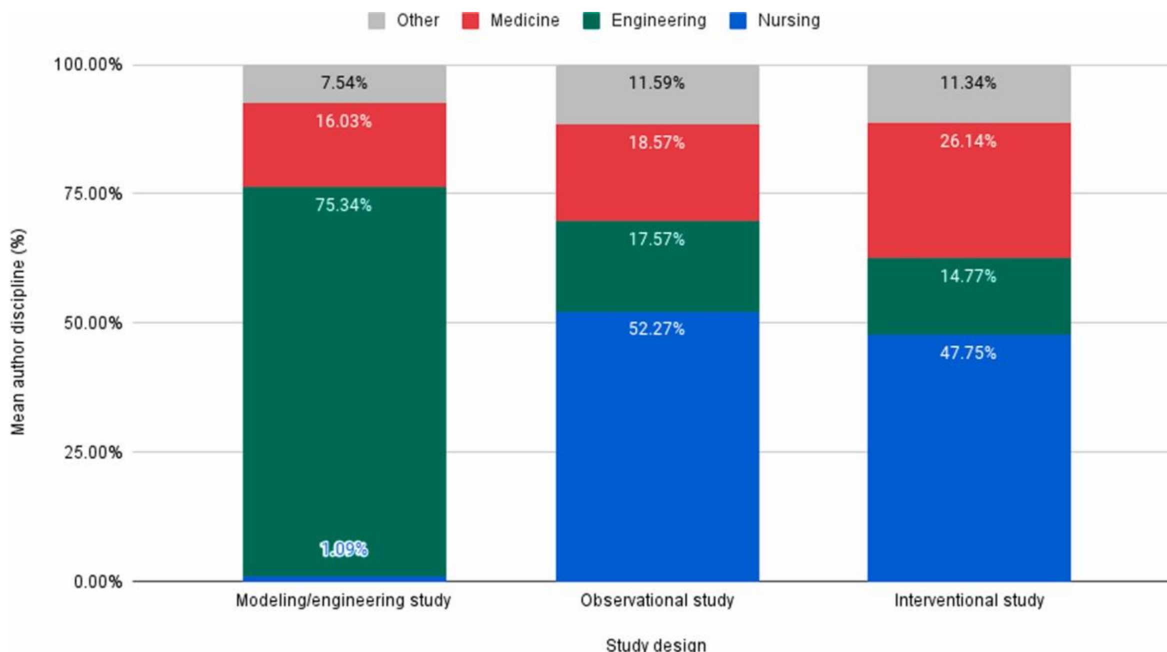

Fig. 2. Colored. Distribution of mean author discipline (%) by study design.

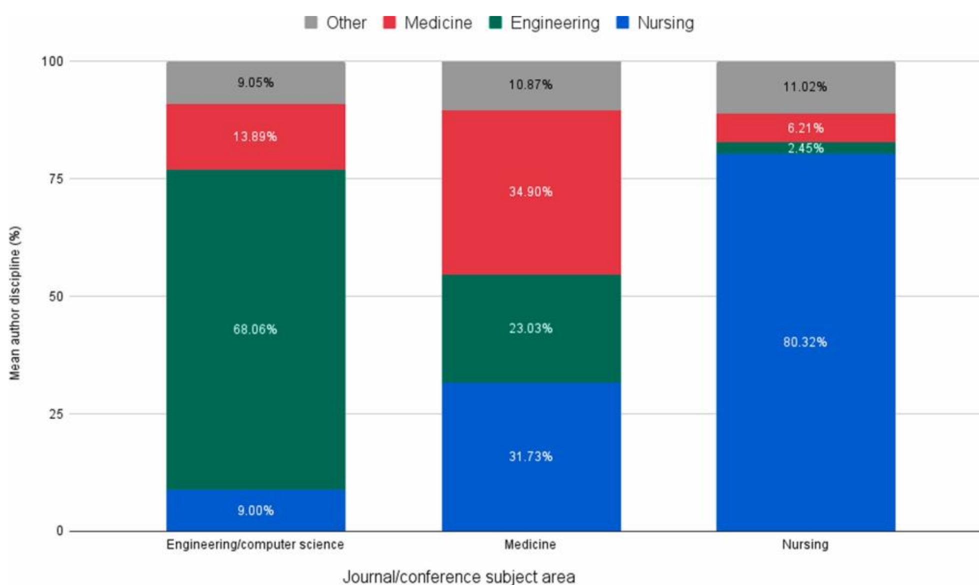

Fig. 3. Colored. Distribution of mean author discipline (%) by journal/conference subject area.

3.3. Other article-level factors

The average involvement of nursing authors varied considerably depending on the ICU setting. In adult ICU settings, their involvement was 49.53 % while in pediatric and neonatal intensive care settings it was 17.20 % (Table 1). Furthermore, when we examined the affiliation of the first author by country, the proportion of articles with at least one nursing author published with a US-affiliation was higher (30.97 %) than non-US-based publications (19.35 %, Table 1). Regarding the author group size, of the 73 articles with fewer than five authors, 31 studies (42.47 %) had at least one nursing author. Articles with larger numbers of co-authors (5 to 10 authors, n = 80), had a higher proportion of articles with one or more nursing authors, accounting for 57.50 % (n = 46). More recent articles, published in the second half of the review window (between 2016 and 2022), showed higher involvement of nursing co-authors at 36.75 %, compared to 25.98 % in articles published between 2010 and 2015.

3.4. Publishing patterns by study design

We grouped the number of publications per journal subject area by study design. It illuminates substantial differences in the types of studies published by certain journals and conference proceedings: Modeling studies were mostly published by engineering journals. Observational studies were mostly published by nursing and medical journals, similar to interventional studies, which were mostly clinical pre-/post studies (Fig. 4).

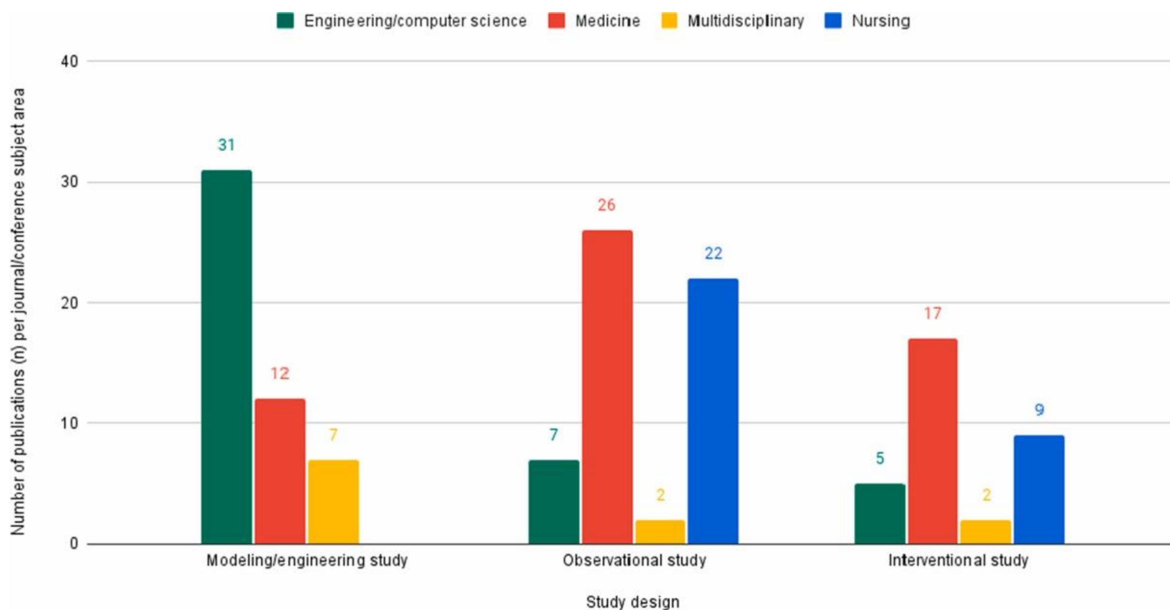

Fig. 4. Colored. Number of publications (n) per journal/conference subject area by study design.

4. Discussion

This bibliometric analysis evaluated 155 publications about alarm fatigue and false alarm reduction strategies in ICU settings, co-authored by 583 unique authors. The analysis revealed substantial shortcomings in the involvement of nursing domain experts in engineering publications. Out of 50 publications with an engineering study design, only two included one or more nursing authors. The mean involvement of nurse co-authors in this subset of publications was 1.09 %. When stratified by journal or conference subject area, 13.04 % (n = 6 of n = 46) of articles published in engineering journals or conference proceedings included one or more nurses as co-authors. In contrast, all 32 nursing journals or conference publications had at least one nurse as an author, with an average proportion of nursing authors of 80.32 %. Although one-third of the unique authors had a nursing background, half (n = 77, 49.69 %) of the 155 articles did not include any nursing authors. This points to a lack of collaboration between nurses and engineers with regard to the socio- technical problem of alarm fatigue.

There is evidence to suggest that interdisciplinary collaboration can notably impact finding practical solutions and increasing the chance of sustainable and translatable research findings [41–43]. This review's results demonstrated that only one third of false alarm reduction studies included nurses as authors for a problem that is intrinsically tied to their practice. While some may argue that studies utilizing an engineering methodology (e.g., model development) do not necessitate domain expertise, design failures of alarm systems created without input from clinical end-users are a real concern. Without a thorough appraisal of the end-user interaction, they can even pose a significant risk to patient safety. While nurses have historically been underrepresented in research and system design, it is important to involve them for ensuring holistic and patient-centered solutions that align with real-world healthcare workflows and needs.

What can nurses do to address this issue? It is crucial to acknowledge that reducing alarm rates through traditional clinical interventions may only have a limited impact in the context of alarm research. This is because algorithm design flaws in bedside monitors are the primary cause of false and non-actionable alarms [3,8,26,27,36,44]. Nursing scientists should collaborate with engineers who can design models for false alarm reduction, as well as possess the expertise to develop and test these models. Nurses can contribute by annotating alarm data, such as stratifying alarm actionability, pointing out algorithm deficiencies, and integrating their knowledge of real-world alarm workflows. This would address an important limitation of engineering studies, such as reducing missed true events and true non-actionable alarms. As nursing academia shifts towards more technological literacy and the application of quantitative methods (e.g., machine learning) [45], collaborating with computer scientists becomes increasingly feasible and attractive.

What actions can engineers take to facilitate fruitful collaborations with domain disciplines? It is important to recognize that interdisciplinary issues necessitate cognitive diversity [46] for finding a solution. To avert design failures, it is imperative to be inclusive of experts in a given application context. “Datathons” (short for data hackathons) taking place around the world can serve as a starting point for meeting domain experts, grouping research interests, and building interdisciplinary teams [47,48]. Beyond collaborating with other specialists, established frameworks for implementing technological innovations in healthcare, such as the CFIR (Consolidated Framework for Implementation Research) [49] or the NASSS (non-adoption, abandonment, scale-up, spread, sustainability) framework [50], offer guidance in considering critical *meta*-level aspects (e.g., the adopters, the organization, and the wider system) at each phase to enhance likelihood of clinical adoption.

There are already lighthouse projects for this type of collaborative approach, one example of which was recently published [30]. The study tested a new alarm for ventricular tachycardia (VT) created by a biomedical engineering team. Five nurse scientists with hospital-based ECG monitoring expertise annotated potential VT alarms, demonstrating the possibility and rationality of including nurses in this line of work [30]. Positive side effects of these collaborative efforts involve utilizing a shared language, allowing authors from all contributing disciplines to communicate their discoveries to a broader range of readers and potentially increasing the readership of academic journals.

Further work involves assessing interdisciplinary collaboration in other fields. It is suspected that alarm research serves as a proxy for many areas of siloed research that do not involve all experts. Following successful implementation of models to reduce false alarms, research teams can measure alarm fatigue in nurses longitudinally to assess the effectiveness of the implementation [51]. Future publications in this research area should employ a team science approach to ensure broad adoption of solutions [41], regardless of study design.

There are major limitations to this study. It may be positively biased towards medical and nursing publications as non-full-text conference papers were excluded. Engineering publishing practices rely heavily on conference abstracts with fewer original journal articles (as compared to nursing/medical publishing), which probably resulted in the exclusion of many engineering conference abstracts. As the trend was evident, we did not modify our eligibility criteria to include such publication types. Our analysis disregarded any journal guideline restrictions that limit author count. We only encompassed articles that explicitly stated they were conducted in an ICU

setting. Thus, we might have missed other pertinent publications that did not explicitly state ICU settings. The author annotation relied on some tertiary sources, which could potentially result in inaccuracies regarding an author's discipline. Unique authors may have had varying academic degrees or affiliations during different periods. As each author had only one unique entry in the data collection table, we obtained only the most up-to-date information from publications or online sources. Finally, we excluded non-English records due to the reviewers' language proficiencies.

5. Conclusions

This bibliometric analysis quantified the diversity of authors by discipline in critical care alarm research and demonstrated minimal involvement of nurses in publications using an engineering methodology. Involving all stakeholders in interdisciplinary research, including clinical end-users, at all stages is paramount to success. It has the potential to reduce system design failures, increase user acceptance, and improve patient safety. Inclusive research offers a promising path towards developing solutions to long-standing problems, such as alarm fatigue. Interdisciplinary events (e.g., hackathons) can serve as a starting point for engaging all relevant parties, but systemic measures are needed to lower the barriers to participatory research, e.g., for clinically employed nurses.

Using alarm research as a motif, cognitive diversity in science represents an important strategy for producing sustainable solutions to other multifaceted challenges in healthcare. Democratizing stakeholder engagement will not only create a common language, but also make research more equitable and inclusive. **Summary table**.

What was already known on the topic	What this study added to our knowledge
Constant exposure to clinical alarms in intensive care units, most of which are false or non-actionable, leads to alarm fatigue.	Most false and non-actionable alarms are due to algorithm deficiencies and require the expertise of domain experts in engineering, medicine, and nursing to resolve.
Alarm fatigue primarily affects nursing staff and can result in the assimilation of alarms into a nurse's workflow. Consequences include unsafe alarm adjustments, delayed or missed alarm responses, and missed true events.	Publications in this research area lack interdisciplinary collaboration between engineering, medical, and nursing authors.
Alarm fatigue is a threat to staff well- being and a risk to patient safety. Decades of research have not been able to produce clinically viable solutions.	Enforcing cognitive diversity in future research may lead to more successful, real-world solutions to reducing alarm fatigue.

CRediT authorship contribution statement

Louis Agha-Mir-Salim: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Lucas McCullum:** Investigation, Visualization, Writing – review & editing. **Enrico Dahnert:** ¨ Investigation, Writing – review & editing. **Yanick-Daniel Scheel:** Investigation, Writing – review & editing. **Ainsley Wilson:** Investigation, Writing – review & editing. **Marianne Carpio:** Investigation, Writing – review & editing. **Carmen Chan:** Investigation, Writing – review & editing. **Claudia Lo:** Investigation, Writing – review & editing. **Lindsay Maher:** Investigation, Writing – review & editing. **Corinna Dressler:** Methodology, Writing – review & editing. **Felix Balzer:** Supervision, Writing – review & editing. **Leo Anthony Celi:** Conceptualization, Supervision, Writing – review & editing. **Akira-Sebastian Poncette:** Resources, Supervision, Writing – review & editing. **Michele M. Pelter:** Supervision, Validation, Writing – review & editing.

Declaration of Competing Interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijmedinf.2023.105285.

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