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Alarm Fatigue Across Critical Care Domains: Comparative Insights and Independent Predictors From a Cross-Sectional Multicenter Survey Study

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OBJECTIVES: Alarm fatigue, the desensitization to excessive false alarms, threatens patient safety and staff performance across critical care domains. It is unclear whether alarm fatigue differs between hospital departments. This study compared alarm fatigue among staff in the ICU, cardiac telemetry ward (CTW), and operating room (OR), and, secondarily, identified its independent determinants.

DESIGN: Cross-sectional, multicenter survey study.

SETTING: ICUs, a CTW, and ORs.

PATIENTS: A total of 514 healthcare professionals working in the ICU, CTW, and OR.

INTERVENTIONS: None.

MEASUREMENTS AND MAIN RESULTS: Alarm fatigue was assessed using the Dutch-translated Charité Alarm Fatigue Questionnaire, which includes alarm stress and alarm coping subscales. Participants also rated their self-perceived alarm fatigue on a 1–10 scale and the percentage of perceived false alarms. Telemetry staff reported the highest self-perceived alarm fatigue (B = 0.65; 95% CI, 0.06–1.24; $p = 0.032$) and perceived false alarms (B = 0.77; 95% CI, 0.23–1.30; $p = 0.005$), while OR staff reported the lowest (B = −1.01; 95% CI, −1.59 to −0.43; $p < 0.001$). Second, physicians (B = −0.13; 95% CI, −0.25 to −0.01; $p < 0.031$) and less experienced staff (< 3 mo; B = −0.34; 95% CI, −0.68 to −0.01; $p = 0.046$) reported lower alarm fatigue.

CONCLUSIONS: Alarm fatigue varied significantly across departments and professions, being highest in telemetry staff and lowest among physicians and less experienced personnel. Targeted department-specific interventions and longitudinal research are necessary to mitigate alarm fatigue and enhance patient safety.

KEYWORDS: alarm fatigue; cardiac telemetry ward; intensive care unit; operating room; patient safety

Continuous monitoring of a patient's vital functions is a crucial and standard practice in hospitals, especially in ICUs, cardiac telemetry wards (CTWs), and operating rooms (ORs). These settings rely on monitoring systems that generate visual and auditory alarms to alert staff to clinically relevant changes in patients or equipment.

However, empirical evidence has revealed that ICUs and ORs may generate up to 1000 alarms daily, with a false-positive rate ranging from 72% to 99% (1, 2). In this context, the term "false alarms" refers both to technically false alarms (e.g., signal artifacts or electrical noise) and to nonactionable alarms that reflect

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KEY POINTS

Question: Does alarm fatigue, as measured by the Charité Alarm Fatigue Questionnaire, differ between hospital departments? In addition, how does alarm fatigue vary across demographic and professional factors (age, sex, profession, and work experience)?

Findings: In this multicenter cross-sectional survey study of 514 healthcare professionals, alarm fatigue was highest among cardiac telemetry ward staff and lowest among operating room staff. Nurses and more experienced staff reported statistically significantly higher alarm fatigue than physicians and less experienced staff.

Meaning: Alarm fatigue varies by clinical setting and profession, indicating that targeted, department-specific interventions are needed to improve patient safety.

true parameter changes but do not require clinical intervention. Although these alarms play a crucial role in the early detection of clinical deterioration, an overabundance often results in desensitization, delayed responses, or missed alarms. Furthermore, a persistent overload of alarms increases the overall stress and burden on the medical team, potentially leading to burnout. Importantly, alarm fatigue reflects both alarm frequency and the cognitive load associated with continuous alarm exposure and decision-making demands (3–5). This phenomenon is known as alarm fatigue.

Recent evidence indicates that alarm fatigue remains highly prevalent in contemporary clinical practice, affecting over 60% of ICU nurses and continuing to be recognized as a major patient safety concern due to its association with delayed responses to critical alarms (6–8). This issue is further underscored by its consistent inclusion among the top 10 "Technology Hazards" identified by the Emergency Care Research Institute. Furthermore, data from the U.S. Food and Drug Administration reported approximately 566 patient fatalities between 2005 and 2008 linked to alarm-related incidents (9).

Although alarm fatigue is increasingly recognized as a patient safety issue, its prevalence and underlying determinants remain poorly defined in clinical environments. Most of the available literature has focused almost exclusively on nursing staff in ICUs, with limited comparative data from other settings, such as telemetry wards and ORs (10, 11). Furthermore, few studies have examined alarm fatigue in relation to demographic factors such as age, sex, professional role, and working experience.

To accurately measure alarm fatigue, a German questionnaire, the Charité Alarm Fatigue Questionnaire (CAFQa), which focuses on both nurses and physicians, was recently translated and validated in Dutch (12–14). The CAFQa demonstrates solid psychometric validity, focusing on stress responses and coping mechanisms associated with alarm fatigue.

The primary aim of this study is to compare alarm fatigue across different high-acuity hospital settings using the Dutch version of the CAFQa. In addition to assessing departmental differences, we aimed to explore how alarm fatigue varies across different subgroups based on demographic factors, professional roles, and levels of working experience.

MATERIALS AND METHODS

Study Design and Setting

A cross-sectional, multicenter survey study using the previously validated CAFQa was conducted among healthcare professionals working in the ICUs of eleven hospitals. Ten hospitals were part of the Intensive Care Units Zuid-Oost Nederland network in the southern Netherlands, including one academic center (Maastricht University Medical Center+ [MUMC+]) and nine general hospitals. In addition, one Belgian center, Jessa Hospital in Hasselt, participated in the study. At the MUMC+, the survey was also administered to nurses working on the CTW and to both nurses and physicians working in the operating room (OR). This study was reported in accordance with the Checklist for Reporting Of Survey Studies (CROSS) guideline.

Participants

Eligible participants included physicians and nursing staff from the ICU, CTW, and OR who were directly involved in patient care and exposed to clinical alarms on a daily basis. The survey was distributed electronically via institutional communication channels across

all participating hospitals and relevant departments, with a multidepartment approach for MUMC+ and a multicenter approach for the ICU. To enhance the response rate, reminders were circulated after 2 and 6 weeks. Participation was voluntary and anonymous. Ethical approval for the study, *Alarm Fatigue Across Critical Care Domains: Comparative Insights and Independent Predictors from a Cross-Sectional Multi-Center Survey Study,* was obtained from the Medical Ethics Commission of the MUMC+ (METC 2021-3060; approval date: December 27, 2021). All procedures were performed in accordance with the ethical standards of the responsible committee on human experimentation and with the Helsinki Declaration of 1975, as revised in 2013. Demographic variables (age, sex, profession, and work experience) were collected; sex was not recorded in two participating centers, resulting in missing data for this variable. Missing data were not imputed.

Charité Alarm Fatigue Questionnaire

Alarm fatigue was assessed using the Dutch-translated and previously validated CAFQa (14). The questionnaire comprises nine questions: the first five questions assessing alarm stress and the last four questions assessing alarm coping. A 5-point Likert scale (0 = strongly disagree to 4 = strongly agree) was used. Alarm stress items were positively worded, whereas alarm coping items were negatively worded and reverse-scored so that higher scores reflected poorer coping. Scores were averaged to obtain alarm stress, alarm coping, and total CAFQa scores. Item-level response distributions are provided in **Supplementary Figure 1** (https://links.lww.com/CCM/I96). Primary analyses were based on the validated domain scores. In this study, the primary outcome was the total CAFQa score, representing a multidimensional assessment of alarm fatigue. In this context, the term "alarm fatigue" refers to the multidimensional construct measured by the CAFQa. Two supplementary self-reported measures were included: a single-item rating of perceived alarm fatigue (1–10 scale) and the perceived false or nonactionable alarm rate. These measures captured complementary aspects of subjective alarm burden and were not considered interchangeable with the CAFQa score. The full wording and response options of these items are provided in **Appendix A** (https://links.lww.com/CCM/I96). Participant characteristics included age, sex, profession, and work experience (< 3 mo, 3–12 mo, and ≥ 1 yr). The English version of the CAFQa is presented in **Figure 1**.

Statistical Analysis

All analyses were performed using IBM SPSS Statistics version 28 (IBM Corp., Armonk, NY). Descriptive statistics summarized participant characteristics. Mean scores were calculated for self-reported (perceived) alarm fatigue, perceived false or nonactionable alarm rates, alarm stress, alarm coping, and total CAFQa scores.

Linear regression analyses compared outcomes between departments (ICU, telemetry ward, and OR), with ICU as the reference category. Univariate analyses assessed associations between outcomes and demographic/professional variables (age, sex, profession, experience), followed by multivariable models to identify independent determinants. Model assumptions and multicollinearity were checked. Results are presented as regression coefficients (β) with 95% CIs; p values of less than 0.05 were considered statistically significant.

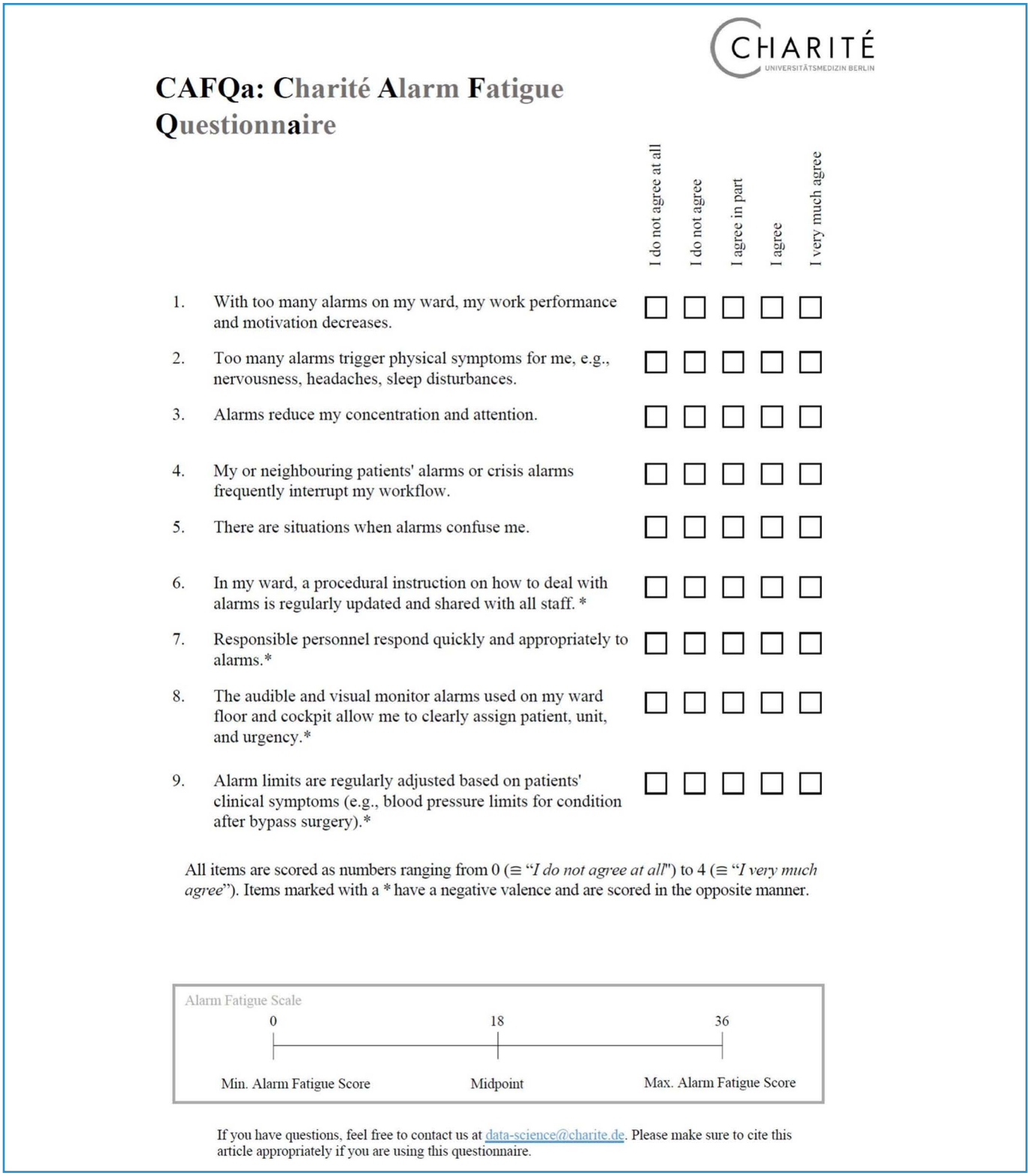
RESULTS

Baseline Characteristics

A total of 514 participants were included. Most respondents (n = 418, 81.3%) worked in the ICU, with smaller groups from the OR and CTW. The study population consisted predominantly of nurses, with physicians comprising about one-fifth of the sample. Participants were mostly female (62.3%), and the average age was approximately 42 years, with telemetry staff being younger than ICU and OR staff. Most respondents had more than 1 year of clinical experience, while the telemetry ward included a relatively higher proportion of less experienced staff (**Table 1**). A detailed overview per center and department is provided in **Supplementary Table 1** (https://links.lww.com/CCM/I96).

Interdepartmental Differences

Differences were observed between departments in alarm-related outcomes. Compared with ICU staff, telemetry ward staff reported higher self-perceived alarm fatigue (β = 0.65; 95% CI, 0.06–1.24) and a greater proportion of perceived false alarms (β = 0.77;



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CAFQa: Charité Alarm Fatigue Questionnaire

		I do not agree at all	I do not agree	I agree in part	I agree	I very much agree
1.	With too many alarms on my ward, my work performance and motivation decreases.	☐	☐	☐	☐	☐
2.	Too many alarms trigger physical symptoms for me, e.g., nervousness, headaches, sleep disturbances.	☐	☐	☐	☐	☐
3.	Alarms reduce my concentration and attention.	☐	☐	☐	☐	☐
4.	My or neighbouring patients' alarms or crisis alarms frequently interrupt my workflow.	☐	☐	☐	☐	☐
5.	There are situations when alarms confuse me.	☐	☐	☐	☐	☐
6.	In my ward, a procedural instruction on how to deal with alarms is regularly updated and shared with all staff. *	☐	☐	☐	☐	☐
7.	Responsible personnel respond quickly and appropriately to alarms.*	☐	☐	☐	☐	☐
8.	The audible and visual monitor alarms used on my ward floor and cockpit allow me to clearly assign patient, unit, and urgency.*	☐	☐	☐	☐	☐
9.	Alarm limits are regularly adjusted based on patients' clinical symptoms (e.g., blood pressure limits for condition after bypass surgery).*	☐	☐	☐	☐	☐

All items are scored as numbers ranging from 0 (≙ "*I do not agree at all*") to 4 (≙ "*I very much agree*"). Items marked with a * have a negative valence and are scored in the opposite manner.

Alarm Fatigue Scale

0 — 18 — 36

Min. Alarm Fatigue Score | Midpoint | Max. Alarm Fatigue Score

If you have questions, feel free to contact us at data-science@charite.de. Please make sure to cite this article appropriately if you are using this questionnaire.

Figure 1. English version of the Charité Alarm Fatigue Questionnaire (CAFQa). The questionnaire consists of nine items assessing alarm stress and alarm coping using a 5-point Likert scale (0 = strongly disagree to 4 = strongly agree). Items marked with an asterisk are reverse-scored.

TABLE 1.
Baseline Characteristics

Characteristics	Total Group	ICU	Telemetry Ward	Operating Room
Participants, *n*	542	446	47	49
Consent, *n* (%)	514 (94.8)	418 (93.7)	47 (100)	49 (100)
No consent, *n* (%)	28 (5.2)	28 (6.3)	0	0
Age, mean	41.70	43.42	33.29	39.78
Range	19–65	22–65	19–58	25–65
Sex, *n* (%)				
Male	147 (36.7)	116 (38.0)	11 (23.4)	20 (40.8)
Female	250 (62.3)	186 (61.0)	35 (74.5)	29 (59.2)
No sex specified	4 (1.0)	3 (1.0)	1 (2.1)	–
Missing sex[a]	113	113		
Profession, *n* (%)				
Nursing staff	402 (78.2)	333 (79.7)	47 (100)	22 (44.9)
Physician	112 (21.8)	85 (20.3)	0	27 (55.1)
Working experience				
> 1 yr, *n* (%)	461 (89.9)	379 (90.9)	33 (70.2)	49 (100)
3 mo to 1 yr, *n* (%)	39 (7.6)	29 (7.0)	10 (21.3)	0
< 3 mo, *n* (%)	13 (2.5)	9 (2.2)	4 (8.5)	0
Missing	1	1		

[a]Two centers (Catharina Hospital, Eindhoven, and Anna Hospital, Geldrop) did not collect data on sex.

95% CI, 0.23–1.30). They also showed slightly higher alarm stress and better coping (β = −0.17; 95% CI, −0.33 to −0.01).

OR staff reported lower self-perceived alarm fatigue (β = −1.01; 95% CI, −1.59 to −0.43), fewer perceived false alarms (β = −0.93; 95% CI, −1.45 to −0.41), and lower alarm stress, while coping was similar to ICU staff (**Table 2**, **Fig. 2**).

Despite differences in self-perceived alarm fatigue, total CAFQa scores did not differ between departments, suggesting the measures capture different aspects of alarm fatigue.

Determinants Associated With Alarm Fatigue—Univariable Analysis

Across the total population, older age was associated with poorer coping. Physicians reported lower alarm fatigue, fewer perceived false alarms, and less alarm-related stress than nurses (e.g., fatigue β = −0.15; 95% CI, −0.26 to −0.04). Participants with less than 3 months of experience reported lower self-perceived alarm fatigue (β = −1.86; 95% CI, −2.94 to −0.77) and better coping compared with those with at least 1 year of experience.

Within the ICU subgroup, similar patterns were observed: increasing age was associated with poorer coping, physicians perceived fewer false alarms, and the least experienced staff reported lower alarm fatigue (**Table 3**; **Supplementary Table 2**, https://links.lww.com/CCM/I96).

Determinants Associated With Alarm Fatigue—Multivariable Analysis

In multivariable analyses, older age was associated with slightly lower self-perceived alarm fatigue (β = −0.02; 95% CI, −0.03 to 0.00) but poorer coping (β = 0.01; 95% CI, 0.00–0.01). Physicians continued to report lower self-perceived alarm fatigue and stress than nurses (e.g., fatigue β = −0.83; 95% CI, −1.29 to −0.37).

Staff with less than three months of experience again showed lower alarm fatigue and better coping. Within the ICU subgroup, physicians perceived fewer false alarms and less stress, while older age remained

TABLE 2.
Interdepartmental Differences in Alarm Fatigue and Related Outcomes

Outcome	ICU, Reference (SD)	Telemetry (SD)	Operating Room (SD)	Comparison vs. ICU	Regression Coefficient, B	95% CI (Lower–Upper)	*p*
Self-reported alarm fatigue (1–10)	5.0 (2.0)	5.7 (2.0)	4.0 (1.7)	Telemetry	0.65	(0.06 to 1.24)	**0.032**
				OR	−1.01	(−1.59 to −0.43)	**< 0.001**
False alarms (1–10)	5.69 (1.68)	6.47 (1.69)	4.78 (2.07)	Telemetry	0.77	(0.23 to 1.30)	**0.005**
				OR	−0.93	(−1.45 to −0.41)	**< 0.001**
Charité Alarm Fatigue Questionnaire total	1.87 (0.50)	1.90 (0.55)	1.7 (0.4)	Telemetry	0.04	(−0.12 to 0.19)	0.640
				OR	−0.13	(−0.30 to 0.03)	0.119
Alarm stress	1.9 (0.7)	2.1 (0.8)	1.6 (0.6)	Telemetry	0.20	(−0.01 to 0.41)	0.065
				OR	−0.32	(−0.53 to −0.12)	**0.002**
Alarm coping	1.8 (0.5)	1.6 (0.5)	1.9 (0.5)	Telemetry	−0.17	(−0.33 to −0.01)	**0.035**
				OR	0.07	(−0.11 to 0.24)	0.453

OR = operating room.
All responses were based on complete answers from participants. Bold values indicate statistical significance ($p < 0.05$).

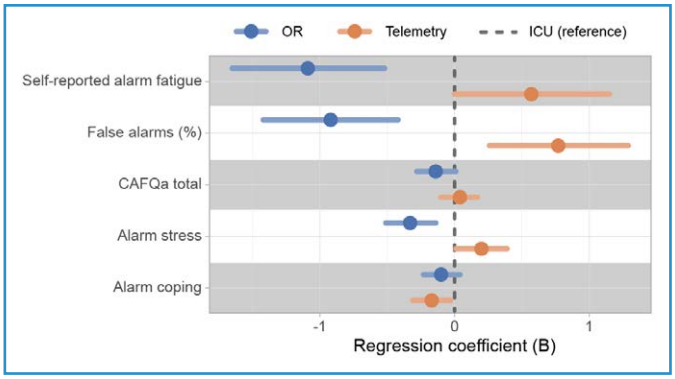


Figure 2. Regression coefficients (B) and 95% CIs for alarm-related outcomes comparing telemetry and operating room (OR) staff with ICU staff (reference group). CAFQa = Charité Alarm Fatigue Questionnaire.

associated with poorer coping. Staff with 3–12 months of experience demonstrated the most favorable coping profile (**Table 4**; **Supplementary Table 3**, https://links.lww.com/CCM/I96).

DISCUSSION

In this multi-center study, we assessed alarm fatigue among healthcare staff across critical care domains using the validated Dutch version of the CAFQa (14). A key finding is the discrepancy between the CAFQa total score and the single-item self-perceived alarm fatigue rating across departments. Although the single-item measure suggested differences in perceived alarm fatigue, the multidimensional CAFQa score did not. This indicates that the validated CAFQa did not detect interdepartmental differences, whereas the single-item measure suggested differences in perceived alarm fatigue. As these instruments assess related, but distinct, aspects of alarm fatigue, this discrepancy should be interpreted cautiously and warrants further investigation. However, alarm fatigue varied across departments, professional roles, age, and experience, indicating that it is context-dependent and influenced by both individual and workplace factors.

The observed interdepartmental differences highlight the contextual and organizational factors shaping alarm fatigue. Previous studies have mainly focused on ICUs or single departments, limiting insight into how clinical environments differ (15). Differences may reflect staffing ratios and monitoring characteristics, with telemetry wards having lower staff-to-patient ratios and greater susceptibility to artifacts and broader

TABLE 3.

Determinants Associated With Alarm Fatigue and Related Outcomes in the Total Population (Univariable Linear Regression)

Determinant	Self-Reported Alarm Fatigue, Regression Coefficient, B (95% CI), *p*	Perceived False Alarms, Regression Coefficient, B (95% CI), *p*	Charité Alarm Fatigue Questionnaire Total, Regression Coefficient, B (95% CI), *p*	Alarm Stress, Regression Coefficient, B (95% CI), *p*	Alarm Coping, Regression Coefficient, B (95% CI), *p*
Age, yr	−0.01 (−0.03 to 0.01), 0.266	−0.01 (−0.02 to 0.01), 0.464	0.01 (0.00 to 0.01), **0.016**	0.00 (0.00 to 0.01), 0.339	0.01 (0.00 to 0.01), **< 0.001**
Sex					
Female (reference)	–	–	–	–	–
Male	−0.03 (−0.41 to 0.36), 0.898	−0.01 (−0.35 to 0.34), 0.971	0.04 (−0.06 to 0.14), 0.454	−0.01 (−0.15 to 0.13), 0.901	0.09 (−0.01 to 0.19), 0.075
Profession					
Nurse (reference)	–	–	–	–	–
Physician	−0.77 (−1.18 to −0.36), **< 0.001**	−0.86 (−1.26 to −0.47), **< 0.001**	−0.15 (−0.26 to −0.04), **0.006**	−0.22 (−0.36 to −0.07), **0.004**	−0.06 (−0.17 to 0.05), 0.296
Work experience					
≥ 1 yr (reference)	–	–	–	–	–
< 3 mo	−1.86 (−2.94 to −0.77), **< 0.001**	−1.18 (−2.35 to −0.01), **0.049**	−0.39 (−0.66 to −0.11), **0.006**	−0.33 (−0.72 to 0.06), 0.099	−0.45 (−0.73 to −0.17), **0.002**
3–12 mo	−0.14 (−0.78 to 0.51), 0.671	−0.36 (−1.00 to 0.28), 0.272	−0.18 (−0.34 to −0.02), **0.031**	−0.08 (−0.31 to 0.15), 0.512	−0.30 (−0.46 to −0.13), **< 0.001**

Bold values indicate statistical significance ($p < 0.05$). Dashes represent reference category.

TABLE 4.

Determinants Associated With Alarm Fatigue and Related Outcomes in the Total Population (Multivariable Linear Regression)

Determinant	Self-Reported Alarm Fatigue, Regression Coefficient, B (95% CI), *p*	Perceived False Alarms, Regression Coefficient, B (95% CI), *p*	Charité Alarm Fatigue Questionnaire Total, Regression Coefficient, B (95% CI), *p*	Alarm Stress, Regression Coefficient, B (95% CI), *p*	Alarm Coping, Regression Coefficient, B (95% CI), *p*
Age, yr	−0.02 (−0.03 to 0.00), 0.089	−0.01 (−0.03 to 0.00), 0.063	0.00 (0.00 to 0.01), 0.260	0.00 (−0.01 to 0.01), 0.735	0.01 (0.00 to 0.01), **0.034**
Sex					
Female (reference)	–	–	–	–	–
Male	0.12 (−0.27 to 0.52), 0.538	0.13 (−0.22 to 0.48), 0.468	0.03 (−0.07 to 0.13), 0.542	0.01 (−0.13 to 0.15), 0.894	0.05 (−0.05 to 0.15), 0.324
Profession					
Nurse (reference)	–	–	–	–	–
Physician	−0.83 (−1.29 to −0.37), **< 0.001**	−0.85 (−1.26 to −0.45), **< 0.001**	−0.13 (−0.25 to −0.01), **0.031**	−0.22 (−0.39 to −0.06), **0.009**	−0.01 (−0.13 to 0.11), 0.910
Work experience					
≥ 1 yr (reference)	–	–	–	–	–
< 3 mo	−1.83 (−3.16 to −0.50), **0.007**	−1.06 (−2.24 to 0.12), 0.078	−0.34 (−0.68 to −0.01), **0.046**	−0.21 (−0.69 to 0.27), 0.389	−0.49 (−0.84 to −0.15), **0.005**
3–12 mo	0.20 (−0.58 to 0.99), 0.609	−0.45 (−1.15 to 0.25), 0.204	−0.14 (−0.34 to 0.06), 0.156	−0.07 (−0.35 to 0.22), 0.646	−0.22 (−0.43 to −0.02), **0.032**

Bold values indicate statistical significance ($p < 0.05$). Dashes represent reference category.

monitoring indications, potentially increasing nonactionable alarms (16, 17). In contrast, OR staff reported the lowest self-perceived alarm fatigue, likely reflecting a more controlled environment with direct patient monitoring and immediate response capability. The perceived false alarm rate in ICU staff (56.9 ± 16.8%) was lower than previously reported (72–99%) (2, 18). This may reflect increased awareness and prioritization of alarm management (19). Potential strategies to reduce alarm burden include optimizing alarm settings, staff education, and critical evaluation of monitoring indications.

Professional role influenced alarm fatigue, highlighting the importance of task distribution and workflow. Nursing staff experienced significantly higher self-perceived alarm fatigue scores than physicians. Interestingly, this pattern is inconsistent with that of one of the few studies comparing nurses and physicians. A recent study conducted in Lebanon reported a slightly higher level of alarm fatigue in physicians than in nurses (20). A possible explanation could be found in cultural differences and organizational structure. In this study, the nursing staff was responsible for continuous monitoring and alerting the physician when necessary. Consequently, nurses are more frequently exposed to nonactionable alarms, which could potentially increase their perception of alarm fatigue. In contrast, physicians may predominantly respond to clinically significant alarms, shaping a different subjective experience of alarm burden. These role-based differences suggest that alarm fatigue is not only a function of alarm frequency but also of alarm relevance and the user's perceived responsibility.

Working experience emerged as a determinant associated with alarm fatigue, with a trend suggesting that more experienced staff members are more vulnerable to alarm fatigue. This could potentially be explained by increased responsibility, cumulative stress, and the expectation that experienced staff members act as primary responders. This contrasts with recent studies that have reported less alarm fatigue among experienced staff, likely reflecting better coping strategies and adaptation to higher alarm frequencies (12, 21). A key difference is that these studies defined working experience in years, whereas our study classified staff with more than one year of working experience as 'experienced.'

The present observation that older staff members reported slightly lower self-perceived alarm fatigue, but demonstrated poorer coping skills, should be interpreted with caution, given the modest effect sizes. Furthermore, this observation appears to differ from previous evidence suggesting that alarm fatigue decreases with age (22). A key difference is that the previous study included only nurses, whereas our cohort comprised both nurses and physicians. Furthermore, that study did not distinguish between the different components of alarm fatigue, such as coping. It remains plausible that age interacts with years of experience and professional role; for instance, nurses are more likely to work independently at a younger age than are physicians. Sex was not significantly associated with any component of alarm fatigue in the total population or the ICU subgroup. The existing literature on sex differences in alarm fatigue is inconsistent, with studies reporting conflicting results (20). This suggests that any sex-related patterns, if present, may be context-dependent or influenced by other variables such as professional role and experience.

Our study has several strengths. For instance, the use of linear regression enabled estimation of effect sizes with 95% CIs and identification of independent determinants of alarm fatigue as measured by the CAFQa. By applying both univariate and multivariable models, we examined subgroup differences across age, experience, profession, and sex, an approach rarely used in alarm fatigue research. We used the previously validated CAFQa questionnaire, assessing alarm stress and coping, and included both physicians and nurses (14). Additional self-reported nonvalidated measures, such as self-perceived alarm fatigue and perceived false or nonactionable alarm rates, provided complementary insight into subjective alarm burden, but are subject to perception bias and potential circularity. Consequently, clinicians experiencing greater alarm fatigue may perceive a higher proportion of alarms as nonactionable, rather than perceived false alarm rates necessarily contributing to alarm fatigue. Future studies should combine these measures with objective alarm data and longitudinal designs to better establish the direction of these relationships. The multicenter ICU design with a large sample size further enhanced generalizability and external validity.

This study also has several limitations. Although a priori use in study design is encouraged, here the CROSS guideline has been applied retrospectively to improve the completeness and transparency of reporting. Its

cross-sectional design precludes causal inference; repeated measurements after targeted interventions (e.g., alarm management training or system-based filtering) are warranted. Unmeasured confounders such as workload, staffing ratios, and burnout may have influenced results. Work experience was categorized rather than measured continuously, limiting precision. In particular, the greater than or equal to 1 year category likely includes clinicians with a wide range of experience levels, which may reduce interpretability and obscure potential differences between subgroups. This may partly explain inconsistencies with previous studies (22). Therefore, these findings should be considered hypothesis-generating rather than evidence that limited clinical experience is protective against alarm fatigue, and require confirmation in longitudinal studies accounting for organizational and individual confounders (e.g., workload, burnout, staffing ratios, and ward culture). An important limitation is the imbalance in sample size between departments, with the majority of participants originating from ICU settings, while telemetry and OR groups were substantially smaller. In particular, the predominance of ICU providers may have resulted in a skewed sample, such that observed associations, especially those related to professional experience and demographic factors, may primarily reflect ICU-specific conditions. Although nonresponse bias cannot be excluded due to the anonymous design, opposing mechanisms may influence participation. Clinicians with higher alarm fatigue may be either more or less likely to respond. In the absence of clear evidence for selective participation, and given the multicenter distribution across professional groups, the findings are unlikely to substantially overestimate alarm fatigue and may represent a conservative estimate. These considerations also apply to the multivariable analyses, and the identified associations should therefore be interpreted with caution, as they may not fully reflect the underlying population. In addition, sex data were unavailable for 113 participants (22%) because two participating centers did not collect this variable; as this missingness was center-specific rather than random and no imputation was performed, sex-related findings should be interpreted with caution. Furthermore, telemetry and OR participants were recruited from a single center, whereas ICU participants were drawn from multiple hospitals. This may introduce center-level effects, such as local organizational culture, monitoring practices, or alarm management strategies, which could have influenced the observed differences. As a result, findings related to telemetry and OR settings should be interpreted with caution, as they may not be fully representative of these environments in other institutions. Furthermore, as this study was conducted within the Dutch healthcare system, differences in monitoring practices, staffing models, and alarm management protocols may limit the generalizability of these findings to other healthcare systems. At the time of the study, only German and Dutch versions of the CAFQa were available; however, the recent availability of an English version may support future international validation of these findings. Due to the single-center design of these groups and their limited sample size, clustering by hospital was not formally accounted for in the analyses.

Finally, future studies should investigate the impact of technical infrastructure and contextual/organizational factors (e.g., single- vs. multiple-bed rooms, smartphone-based alarm distribution, alarm settings, and alarm load per bed per hour) on alarm fatigue across departments and hospitals.

CONCLUSIONS

Alarm fatigue varies across hospital departments and professions, with CTW personnel, nursing staff, younger personnel, and more experienced staff exhibiting greater vulnerability. Overall, these findings contribute to the growing body of knowledge on alarm fatigue and highlight that it affects individuals differently depending on their workspace and professional role. These results suggest that interventions to reduce alarm fatigue may benefit from considering contextual and professional differences, although it remains unclear whether such interventions should be department-specific or broadly applied. Longitudinal research is needed to determine the most effective strategies to reduce alarm fatigue and enhance patient safety.

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The Alarm Fatigue Study Group members are listed in the Appendix section.

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APPENDIX

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