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Impact of Alarm Management Training on Adult ICU Nurses' Knowledge, Behaviour, and Fatigue: A Quasi-Experimental Study

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ABSTRACT

Objective: Teaching effective alarm management behaviours to intensive care nurses and preventing alarm fatigue is essential for patient safety. In this context, demonstrating the effectiveness of training activities for nurses on effective alarm management can significantly contribute to ensuring patient safety. However, studies demonstrating the effectiveness of alarm management training activities are limited. Therefore, there is an emerging need to examine the effects of training interventions that can help nurses gain effective alarm management behaviours. The study aimed to assess the effect of alarm management training on the knowledge, behaviours and fatigue levels of ICU nurses.

Methods: This is a pretest- posttest, single-group, quasi-experimental study. The sample size was 19 nurses from two ICUs in a state hospital. Data were collected between 1 November 2021 and 20 March 2022 with the "Nurse Information Form," "Monitor Alarms Management Monitoring Form," "Monitor Alarm Management Knowledge Test," and "Alarm Fatigue Scale." Monitor alarm management training was given by presentation, case studies and reminder cards. The researcher monitored 322 alarms in the pretest and 199 in the posttest.

Results: At post- training, nurses' alarm response times ($p = 0.008$) and crisis alarms ($p = 0.032$) decreased statistically significantly compared to the pre-training. Post-training, nurses' customization of alarm ranges based on patients' clinical condition ($p = 0.001$) and performing skin cleaning ($p = 0.001$) increased statistically significantly compared to pre-training. The inappropriate behaviour of "silencing and muting the alarm" was never exhibited post-training. "No response to the alarm" behaviour decreased statistically significantly, and the rate of effective alarm management behaviours increased statistically significantly ($p = 0.016$). Nurses' monitor alarm management knowledge increased significantly ($p < 0.001$), while alarm fatigue scores decreased statistically significantly at posttest ($p < 0.001$).

Conclusions: The alarm management training intervention was significantly increased nurses' knowledge regarding effective alarm management, improved their behaviours and alarm fatigue scores, and patients' monitor alarm outputs. In conclusion, it can be suggested that training activities be focused on to teach intensive care nurses effective alarm management behaviours and reduce their alarm fatigue.

This study is based on data from the master's thesis of Dilanur KİBAR, supervised by Assoc. Prof. Dr. Aysel ÖZSABAN.

1 | Introduction

Intensive care units equipped with many medical devices to support the patients' organ functions [1]. These devices have alarm systems designed to make abnormal physiological conditions noticeable [2]. Alarm systems provide visual and audible warnings when deviations from the set value ranges occur [3]. The increasing number of clinical alarms from multiple medical devices, however, has become an important problem in intensive care units (ICU) [2, 4]. Bedside monitors, particularly those used in intensive care units, are among the devices that generate alarms most frequently [5–7]. But are crucial medical appliances that allow continuous and close monitoring of patients' vital signs, such as heart rate, blood pressure, respiration, and oxygen saturation. Alarms from these devices should be closely monitored, and effective alarm management strategies should be adopted [7, 8].

Alarm systems are precise but can sometimes cause false alarms in the absence of a real problem [9, 10]. Some studies in intensive care units found false alarm rates between 40% and 95% [4, 10, 11]. The high number of noncritical alarms reduces their reliability, and exposure to too many alarms may cause nurses to ignore the alarm system, respond slowly to repetitive alarms, reset alarms, set unsafe ranges, and mute alarms or even turn them off completely [4, 12, 13]. This may increase the risk of morbidity and mortality and thus endanger patient safety [8, 12–14]. Indeed, the U.S. Food and Drug Administration (FDA) determined that 237 deaths between 2002 and 2004 were caused by ignoring clinical alarms, and 566 patient deaths occurred due to clinical alarms between 2005 and 2008 [15]. From 2009 to 2012, 98 events, related to alarm systems were reported by Joint Commission International (JCI), with 81.7% of them resulting in death, 13.2% in partial loss of function, and 5.1% in unexpected additional events [15]. JCI published the National Patient Safety Goal in 2014 to improve the reliability of clinical alarm systems and set alarm management as the National Patient Safety Goal every year since 2014 [16].

Exposure to too many alarms causes emotional overload and alarm fatigue. Providing non-stop and intimate service to patients, intensive care nurses are particularly exposed to noise from alarms and have a higher risk of alarm fatigue [4, 9]. Also, noticing, recognising, evaluating and confirming an alarm further increases the nurses' workload, even if no other response is needed, causing stress [9, 14]. This is a matter of safety and quality as it complicates distinguishing between true and false alarms and is associated with alarm desensitisation [17]. As a matter of fact, intensive care nurses should accurately and holistically diagnose patients' clinical condition with bedside monitor alarms, make risk assessments, and try to solve the current problem by developing effective nursing practices [18]. Therefore, acquiring knowledge and behaviours about effective alarm management is an important requirement for intensive care nurses [3, 8, 11].

The literature search based on the above information found limited international studies examining the effects of effective alarm management initiatives [2, 19–21]. The initiatives included changing the default settings of some parameters on the cardiac monitors and re-educating transplant/cardiac ICU bedside nurses on the appropriate use of the monitors [2], examining nurses' attitudes toward clinical alarm signals, assessing nurses' ability to discriminate audible alarm signals, and implementing a bundled set of best practices for monitor alarm reduction without undermining patient safety [19]. Other studies examined alarm management strategy interventions, including daily electrode change, elimination of nonactionable and duplicate alarms, adjustment of thresholds, alarm customization, and appropriate use of telemetry [20] and, determined the effectiveness of a training program on alarm fatigue awareness for telemetry unit nurses [21]. In Türkiye, only a few descriptive and methodological studies could be identified [11, 22, 23]. One of these studies aimed to adapt a scale [22], while one other study focused on diagnosing nurses' levels of alarm fatigue [23]. Yet another study aimed to analyse nurses' alarm management behaviours, concluding that nurses need training to improve their alarm management behaviours [11].

Alarm management interventions with nurses have positive effects on their alarm management behaviours and alarm fatigue. Training of nurses on effective alarm management may reduce alarm fatigue by improving alarm management knowledge, awareness, and behaviours. There is a need to develop training programs that can effectively enhance the alarm management processes of nurses in intensive care units, reduce alarm fatigue, and evaluate their effectiveness in clinical practice areas [24]. Interventional studies examining the impact of training on nurses' alarm management behaviours and levels of alarm fatigue have the potential to offer new insights into the literature. This study addresses a critical gap in alarm management research by examining the effects of both theoretical and practical training on nurses' alarm management knowledge, behaviour, and alarm fatigue. It is anticipated that the results of this study may lead to the development of alarm management training programs. This study aimed to assess the effect of alarm management training on the knowledge, behaviours and fatigue levels of ICU nurses.

2 | Methodology

2.1 | Study Design

This is a pretest- posttest, single-group, quasi-experimental study. It was conducted following the Transparent Reporting of Evaluations with Nonrandomized Designs (TREND) Checklist S1) [25].

2.2 | Settings

The internal intensive care unit (IICU) had a capacity of 10 beds, and the surgical intensive care unit (SICU) had a capacity of 8 beds. In both intensive care units, nurses work in two shifts, day (08.00–16.00) and night (16.00–08.00). The nurse/patient ratio in the day shift was 1:2 on weekdays, 1:2/3 on weekends, and 1:2/3 on night shifts. The units provided patient-centred care. The distance of the nurse station to patient beds was similar in both ICUs. There was a camera system and a central monitor system at each bedside. Bedside monitors were

installed at each bedside and were calibrated regularly. The units have no authorization or instructions regarding alarm management, and nurses are not given alarm management training.

2.3 | Sampling and Participants

The research was carried out in a state hospital, level 2, adult internal and surgical intensive care units between 1 November 2021 and 20 March 2022. The unattended observation method was adopted as the study aimed to monitor nurses' alarm responses in a naturalistic environment [26]. Since this method takes a long time and allows only a small number of individuals to be monitored, the study was planned to be conducted in two intensive care units [11]. The study population covered 29 nurses in these two intensive care units. It was determined that at least 18 nurses should be included according to the calculation made in the G*Power program based on the 95% confidence (1-α), 99% test power (1-β), and the effect size ($d = 1.104$) [27]. The inclusion criteria were (i) having at least 6 months of intensive care nursing experience for nurses to adapt to the practice environment, care processes, and the use of technological equipment, (ii) working both day and night shifts to allow evaluation of alarm management behaviours across different shifts and, (iii) volunteering to participate. Ten nurses were excluded from the universe because four worked only day shifts, three had less than 6 months of experience, two were on sick leave, and one had changed units (Figure 1). Nineteen nurses were included in the study, meeting the minimum sample size calculated. The post hoc power analysis results indicated a power of 99.9%.

2.4 | Data Collection Tools

Previous studies have developed monitoring tools specific to their purpose and scope to evaluate nurses' alarm management

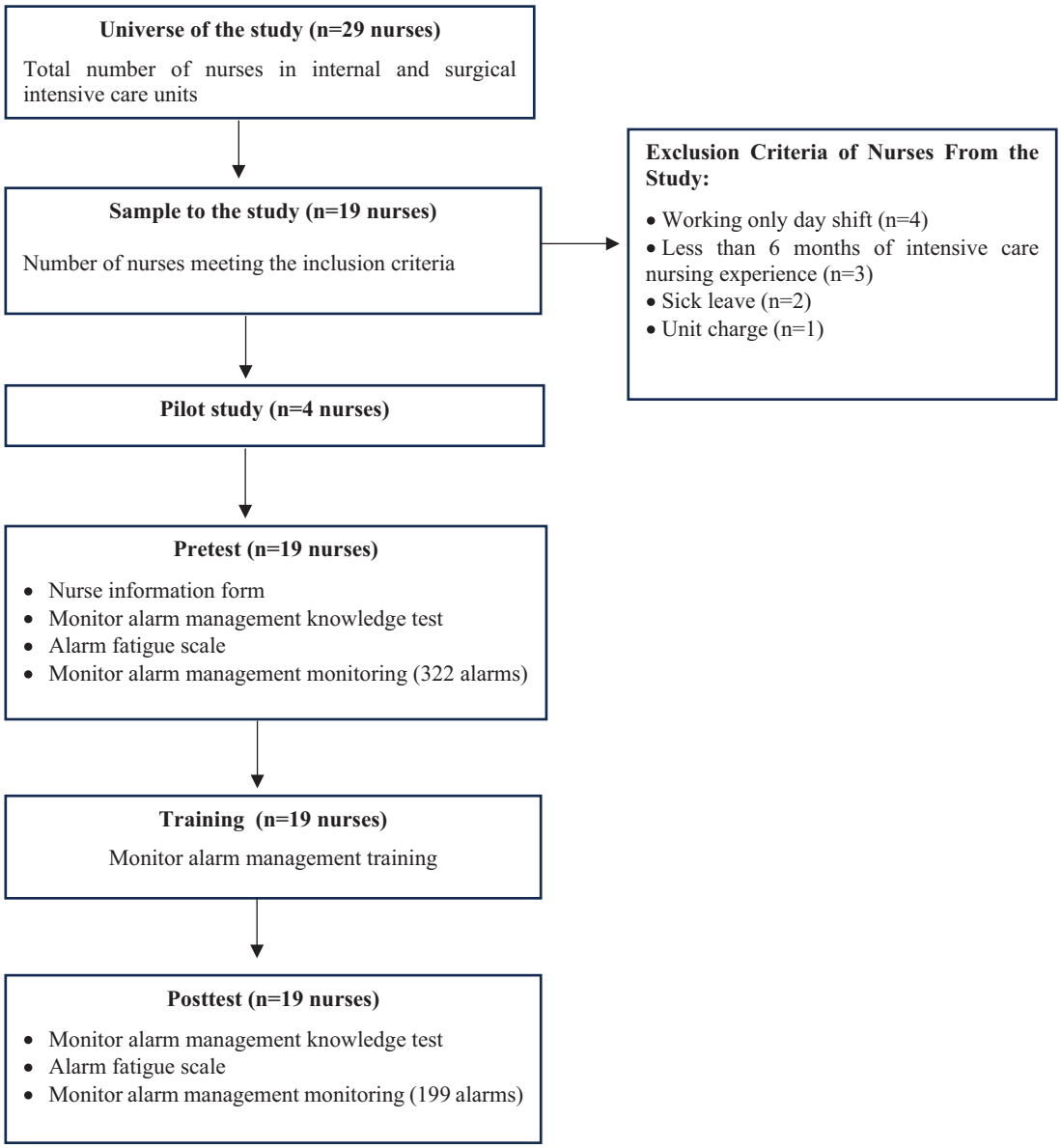

FIGURE 1 | Study design.

behaviours. In this study, original data collection tools aligned with the objectives and scope were developed by drawing upon forms used in previous research. The tools were finalised after receiving expert opinions and a pilot study. Moreover, it was aimed to prepare the Alarm Management Knowledge Test and Monitor Alarm Management Monitoring Form to be consistent with the training content. For this reason, the previous tools could not be used directly, but they were used as a source to develop new tools, with references made to relevant publications.

2.4.1 | Participants' Characteristics

Developed based on the literature [2, 4, 8], the nurse information form includes items on nurses' gender, age, education level, professional experience, intensive care experience, weekly working hours and whether they had an intensive care certificate and previously received training on monitor alarm management.

2.4.2 | Monitor Alarms Management Monitoring Form

Also developed by the researchers based on the literature work [11, 28, 29]. It was finalised with the opinions of 10 experts with a PhD degree in nursing, experience in intensive care nursing, and academic studies in the fields of intensive care nursing and nursing education. The form has nine sections, including (i) alarm time, (ii) alarm type, (iii) alarm value range, (iv) alarm speciality, (v) crisis alarms, (vi) alarm monitoring, (vii) alarm cause, (viii) alarm response time and (ix) alarm response (Data S2).

2.4.3 | Monitor Alarm Management Knowledge Test

As a result of the 10 experts (having the qualifications described above) opinions of the Monitor Alarm Management Knowledge Test, the content validity index score was calculated as 0.89. This knowledge test includes 20 questions with five answer options for the features that alarm systems should have, ECG electrodes, crisis alarms, alarm speciality, alarm reason, alarm response and alarm management applications. Each question in the knowledge test is scored 1 point, with the score range between 0 (lowest) and 20 (highest). The internal consistency of the test was calculated by Kuder–Richardson (KR-20) As a reliability assessment, the KR-20 coefficient was found to be 0.63. It was judged to be at an acceptable level of reliability [30]. Higher scores from the knowledge indicate higher levels of monitor alarm management knowledge (Data S2).

2.4.4 | Alarm Fatigue Scale

It was developed by Torabizadeh et al. [13] to assess alarm fatigue. The Turkish validity and reliability study was conducted by Kahraman [22]. The Turkish version of the scale has nine items, each scored reversely between 0 and 4. The sample items of the scale are as follows: "When alarms go off repeatedly, I become indifferent to them," "Alarm sounds make me nervous," and "I turn off the alarms at the beginning of every shift." The score range of the scale is between 0 (lowest) and 36 (highest). Higher scores from the scale indicate higher levels of alarm fatigue. The Cronbach's alpha value of the Turkish version of the scale was 0.8, and its validity and reliability were demonstrated [22]. The Cronbach's alpha value in our study was 0.7.

2.5 | Data Collection

The research was carried out in four phases: pilot study, pretest, training and posttest (Figure 1).

2.5.1 | Pilot Study

To test the applicability of the data collection tools and to check the interobserver agreement, a second observer, who was outside the sample, was trained by the researcher on the purpose, content and data collection tools of the research. For this, four nurses in the sample group were monitored simultaneously by two observers for the same situation ($n =$ total 62 alarms). Kappa statistic was then used to examine the interobserver agreement and was found to be very good (between 0.967 and 1) for this study. Since no changes were made in the data collection tools and application of the research, the data obtained from the pilot study were included in the analysis of the main study.

2.5.2 | Pretest Phase

The Nurse Information Form was applied to the nurses. Their alarm management behaviours were monitored in the patient monitoring room. The observed nurse's management behaviours for the patient's monitor alarms were recorded using the Monitor Alarms Management Monitoring Form every time an alert occurred, utilising the unattended observation method. The observed nurse was continuously monitored during the times they were at the patient's bedside. The observer researcher (DK) took breaks during the nurse's meal/rest times. Thus, every moment of being at the patient's bedside throughout the entire shift could be observed. In previous studies, nurses' alarm management behaviours were monitored across various shifts, including weekdays, weekends, day, evening, and night shifts. It was determined that there was no standard for planning the monitoring, and the plans were made according to the purpose and scope of the relevant research [11, 31]. In this study, each nurse was observed during six shifts in the pretest for a total of 48 h, including between 08.00 and 16.00, 16.00–24.00 and 24.00–08.00 h on weekdays and weekends. This approach allowed for repeated monitoring across different shifts. As a criterion, the nurses had to care for two or three patients on the day they were observed. If any situations outside the routines occurred in the clinic, observation was cancelled for that day.

In this study, nurses were aware that monitoring would be done throughout the applicable shift. Observations were conducted

multiple times throughout the shift to minimize behavioural changes in nurses due to observation. Selecting the most appropriate response behaviour among nurses' varied responses to different alarms specific to an actual clinical situation minimised the likelihood of behaviours being affected by observation. Alarm response involves evaluating the nurses' alarm management process, not through a single intervention but through repeated assessments. In addition, to avoid affecting their monitor alarm management behaviour, the nurses were informed that they were not expected to make any special behavioural changes during the care process but to continue routine care. The researchers did not give feedback during the observation process in order not to affect the alarm management behaviours of the nurses and not to cause any interruption in the care process. Additionally, the observations were conducted in the patient monitoring room, where images and sounds from the cameras were transmitted and the monitor system was utilized, without any interaction with the nurse or the patient at the bedside. During observation, the time (seconds) for the nurse to come to the patient after the onset of the alarm was measured using a stopwatch. Alarm management behaviours were monitored in real time, and the Monitor Alarms Management Monitoring Form was recorded. After observations were completed, the Monitor Alarm Management Knowledge Test and Alarm Fatigue Scale were administered to the nurses as a pretest.

2.5.3 | Providing Monitor Alarm Management Training

Monitor alarm management training included theoretical training, practical training and the use of reminder cards. Training content and materials prepared in line with the literature [2, 4, 11, 14, 15, 17, 20, 32–34] were applied after they were finalised in line with the opinions of the ten experts. Theoretical and practical training was conducted in two sessions, each taking an average of 2 h, in an environment reserved for training in the intensive care unit, with face-to-face presentation and question-answer method. Immediately after the theoretical training, practical training on setting alarm parameter value ranges and sound levels on the bedside monitor used in the clinic and possible responses in case of an alarm was provided using sample cases prepared in line with the nursing process. To ensure the permanence of the information conveyed in the training, the presentation was shared with the nurses electronically and by printouts. In addition, reminder cards containing basic information about alarm management were attached next to patient monitors in a way that nurses could easily see and read, allowing them to remember the information presented on monitor alarm management (File S3).

2.5.4 | Posttest Phase

After the training was completed, the Monitor Alarms Management Knowledge Test was administered to the nurses as a posttest. The posttest was administered immediately after training to control exposure to in-service trainings that may affect the evaluation of the effectiveness of Alarm Management Training, to maintain in the posttest the working conditions and clinical processes in the pre-test and to take into account the possible loss of subjects due to nurses in the sample group leaving the clinic or hospital for any reason. As in the pretest, nurses' alarm management behaviours were recorded with the Monitor Alarm Management Monitoring Form using the unattended observation method, following the same monitoring principles. Each nurse was observed during six shifts in the posttest for a total of 48 h, including between 08.00 and 16.00, 16.00–24.00 and 24.00–08.00 h on weekdays and weekends in the study. Upon completion of the observation, the Alarm Fatigue Scale was applied to the nurses as a posttest.

2.6 | Data Analysis

Data were analysed with the IBM Statistical Package for the Social Sciences V23. Conformity to the normal distribution was evaluated using the Shapiro–Wilk test. A paired two-sample *t*-test was used to compare nurses' knowledge scores and alarm fatigue before and after the training. The chi-square test was used to compare the findings regarding alarm characteristics and alarm management behaviours before and after training. The Pearson correlation coefficient was used to examine the relationship between normally distributed data. The McNemar test was used to compare the findings regarding customising alarm value ranges to the patient's clinical condition. Kappa statistics were used to examine the interobserver agreement. Descriptive data were presented as mean ± standard deviation (Mean ± SD) and categorical data as frequency. The significance level was accepted as $p < 0.05$.

2.7 | Ethical Considerations

Ethics Committee Approval (Date: 30.06.2021 Number: 24237859-591) and institutional permissions were obtained. Verbal and written consents were received for participation in the study from the ICU nurses who were planned to be included in the study after explaining to them the purpose, content and scope of the study. Permission to use the Alarm Fatigue Scale was obtained by the author from the researchers who developed and adapted the scale (File S4). The Alarm Management Knowledge Test and Monitor Alarm Management Monitoring Form were developed within the scope of this study by the researchers. The principles of the Declaration of Helsinki were followed during all phases of the study.

3 | Results

All the nurses participating in this study were women; their mean age was 34.8 ± 6.8 years, 78.9% had a bachelor's degree, and 57.9% had 2–5 years of experience in the intensive care unit. 73.7% of ICU nurses worked in the internal intensive care unit, 57.9% worked a total of 40–48 h a week, 31.6% had an intensive care nursing certificate, and none had previously received alarm management training (Table 1).

In this study, 322 alarms were observed in the pretest and 199 in the posttest. Most alarms occurred between 08.00 and 16.00

TABLE 1 | Findings on the individual and professional characteristics of nurses ($n = 19$).

Variables		*n*	%
Gender	Female	19	100.0
Age	**Mean ± SD**		
	34.8 ± 6.8		
Education level	High school	1	5.3
	Associate degree	3	15.8
	Bachelor's degree	15	78.9
Professional experience (year)	2–5 year	3	15.8
	6–10 year	6	31.6
	11–20 year	8	42.1
	21 year and above	2	10.5
Intensive care nursing experience	6 month −1 year	3	15.8
	2–5 year	11	57.9
	6–10 year	4	21.0
	11 year and above	1	5.3
Unit	Internal ICU	14	73.7
	Surgical ICU	5	26.3
Weekly total working hours	40–48 h	11	57.9
	49–56 h	8	42.1
Intensive care certificate	Yes	6	31.6
	No	13	68.4
Previous monitor alarm management training	No	19	100
Total		**19**	**100.0**

Abbreviation: SD, Standard deviation.

shifts on weekdays and weekends, and the most frequent ones were oxygen saturation (27.3%, 33.2%, respectively) and respiratory alarms (26.3%, 26.1%, respectively) in the pre- training and post-training. The false alarm rate was 37.9% in the pre-training and 33.2% in the post-training. There was no statistically significant difference between the pre-training and post-training in alarm time, alarm type and alarm speciality distributions ($p = 0.686$, $p = 0.367$, $p = 0.243$, respectively). The crisis alarm rates were 18% in the pre-training, compared to 11.1% post-training, with a statistically significant difference found between them ($p = 0.032$). As for the causes of alarms, "change in the patient's health status" was the most common, at 38.2% pre-training and 45.7% post-training. No statistically significant difference was found pre-training and post-training for the distribution of alarm causes ($p = 0.116$) (Table 2).

In this study, the nurses' attempts to customise the alarm value ranges according to the clinical condition of the patient and to perform appropriate skin cleaning increased statistically ($p = 0.001$, $p = 0.001$, respectively), and the response times to the alarm decreased statistically ($p = 0.008$) in the posttest. There was no statistically significant difference in "Electrode change during the shift" and "responding to alarm with monitoring or intervention" practices in the posttest compared to the pretest ($p = 0.435$, $p = 0.314$, respectively). The most common type of alarm response in the pretest and posttest was "patient monitoring." A statistically significant difference was found in "checking and restoring mechanical ventilator connections" and "silencing and muting the alarm" behaviours between the pretest and posttest ($p = 0.016$, Table 3). Nurses' monitor alarm management knowledge increased significantly ($p < 0.001$), while alarm fatigue scores decreased statistically significantly ($p < 0.001$) at posttest (Table 4, Figure 2).

4 | Discussion

Nineteen nurses' knowledge, behaviours, and fatigue related to monitor alarm management were assessed in this observational study, and the findings were discussed within this context. Despite the small sample size, alarm management behaviours were assessed in a neutral environment with a total of 521 alarms, including 322 observed in the pretest and 199 in the posttest. The high number of monitored alarms supports the validity and reliability of the findings.

4.1 | Nurses' Monitor Alarm Management Knowledge

Nurses need to increase their awareness of monitor alarms and be informed about how to implement evidence-based practices in alarm management [8]. However, all the ICU nurses in the sample of this study stated that they had not received alarm management training previously, similar to the literature [2, 11, 35]. In this study, the nurses' knowledge level increased significantly in the posttest after the training. This finding of the study showed that the training programme had an effective content and method in increasing the nurses' alarm management knowledge levels. These findings supported previous studies showing that alarm management training was useful in increasing knowledge [6, 18, 26]. Nurses' alarm management is not only limited to increasing their level of knowledge, but also has the potential to improve patient safety and care outcomes and reduce alarm fatigue by transforming their behaviours in diagnosing alarms and taking effective interventions [35, 36]. In this context, the findings obtained were discussed in terms of how nurses' increased knowledge levels were reflected in effective alarm management behaviours and alarm fatigue levels.

4.2 | Nurses' Monitor Alarm Management Behaviours

Monitor alarm management is vital for recognizing alarms and responding appropriately to the specific needs of the individual [18]. Alarms primarily occurred during the day shift in both observation periods in this study. This finding supports the most frequently reported reasons for alarms in this study and previous research [11, 28], including patients' health status, treatment and care interventions, and patients' movements in their beds. This highlights the importance of individualized

TABLE 2 | Comparison of findings on monitor alarm management before and after training alarm features.

Variables	Pretest ($n = 322$) n (%)	Posttest ($n = 199$) n (%)	Test	p-value	Effect size (%95 CI)
Number of alarms	322	199			
Alarm time					
Weekday (08.00–16.00)	57 (17.7)	40 (20.1)	3.090	0.686	0.08 [0; 0.12]
Weekday (16.00–24.00)	49 (15.2)	32 (16.1)			
Weekday (24.00–08.00)	56 (17.4)	34 (17.1)			
Weekend (08.00–16.00)	54 (16.7)	40 (20.1)			
Weekend (16.00–24.00)	53 (16.5)	24 (12)			
Weekend (24.00–08.00)	53 (16.5)	29 (14.6)			
Alarm type					
Pulse	87 (27)	42 (21.1)	3.165	0.367	0.08 [0; 0.15]
Respiratory	85 (26.3)	52 (26.1)			
Blood pressure	62 (19.2)	39 (19.6)			
Oxygen saturation	88 (27.3)	66 (33.2)			
Alarm speciality					
True alarm	200 (62.1)	133 (66.8)	1.363	0.243	0.05 [0; 0.14]
False alarm	122 (37.9)	66 (33.2)			
Crisis alarms					
Crisis alarm (Ventricular bradycardia, ventricular fibrillation, ventricular tachycardia, asystole)	58 (18.0)	22 (11.1)	4.580	**0.032**	0.09 [0; 0.18]
Not a crisis alarm	264 (82)	177 (88.9)			
Alarm cause					
Change in the patient's health status	123 (38.2)	91 (45.7)	8.832	0.116	0.13 [0.04; 0.22]
Movement of the patient in bed	55 (17.1)	38 (19.1)			
Treatment and care intervention (endotracheal asp., hygiene applications, inhaled medicine administration etc.)	72 (22.3)	33 (16.6)			
Weaning from mechanical ventilator	8 (2.5)	9 (4.5)			
Contact and transmission problems	37 (11.5)	19 (9.6)			
Inappropriate device alarm	27 (8.4)	9 (4.5)			

Note: Chi-square test, effect size index w [%95 Confidence interval]. Bold values indicate statistically significant results ($p < 0.05$).

nursing care in assessing alarms, evaluating risky situations, and implementing appropriate interventions. Moreover, it suggests that more attention should be given to alarm management during day shifts, considering the influence of external factors on alarm outputs.

In the study, respiratory and oxygen saturation alarms occurred more frequently. On the other hand, previous studies have reported that nurses often skip respiratory evaluation when assessing vital signs [37, 38]. The initial indicator of clinical deterioration is a decline in respiration. Additionally, deterioration in respiratory function in intensive care unit patients signals high-risk problems that may be life-threatening and requires a rapid and timely response, which highlights. Furthermore, respiratory and oxygen saturation alarm rates are expected to be high simultaneously as an indicator of respiratory function. Oxygen saturation measurement can be easily affected by many factors such as the movement of the probes used in oxygen saturation measurement, the disturbance in the patient's peripheral circulation, the change in body temperature and tracheal aspiration procedure. Therefore, respiratory alarms should be closely monitored for patient safety, the aspiration time should be kept shorter than 15 s, oxygenation should be supported before and after aspiration, thermoregulation should be provided to reduce contact conduction problems, and oxygen saturation probes should be placed correctly [39–41]. Lastly, missed respiratory evaluations are related to nurses' attitudes and behaviours regarding vital signs monitoring [37, 38]. In this context, nurses' vital signs monitoring knowledge, behaviour and attitude should be included as part of alarm management training.

TABLE 3 | Comparison of findings on monitor alarm management behaviours before and after training.

Variables	Pretest ($n = 103$) n (%)	Posttest ($n = 103$) n (%)	p-value	Effect size (%95 CI)
Customization of alarm value ranges in shift to patient clinical situation				
Yes	18 (17.5)	42 (40.8)	**0.001**[a]	0.909 [0.321; 2.756][1]
No	85 (82.5)	61 (59.2)		

	Pretest ($n = 322$) n (%)	Postest ($n = 199$) n (%)	Test	p-value	
Status of alarm sounds					
Open	321 (99.7)	198 (99.5)	—	1000[b]	
Close	1 (0.3)	1 (0.5)			
Status of skin cleaning during the shift					
Yes	103 (32)	92 (46.2)	10.654	**0.001**[c]	0.14 [0.06; 0.23][2]
No	219 (68)	107 (53.8)			
Electrode change status in shift					
Yes	136 (42.2)	91 (45.7)	0.610	0.435[c]	0.03 [0; 0.12][2]
No	186 (57.8)	108 (54.3)			

	Pretest (Mean ± SD)	Posttest (Mean ± SD)	Test	p-value	
Alarma response time (Minute)	7.30 ± 1.24	5.78 ± 1.74	2.992	**0.008**[d]	1.00 [0.03; 1.95][3]
Alarm response					
There is monitoring or intervention	282 (87.6)	180 (90.5)	1.012	0.314[c]	0.04 [0; 0.13][2]
No monitoring or intervention	40 (12.4)	19 (9.5)			
Alarm response type					
Observing the patient	70 (21.7)	41 (20.6)	21.786	**0.016**[c]	0.20 [0.04–0.25][2]
Report the situation to the doctor	32 (9.9)	20 (10.1)			
Ensuring the patient's position change	33 (10.3)	28 (14.1)			
Readjustment of alarm value ranges	40 (12.4)	16 (8)			
Checking and restorig mechanical ventilator connections	20 (6.2)[x]	27 (13.6)[y]			
Resolving contact and transmission problems	29 (9)	18 (9)			
Check device settings	8 (2.5)	1 (0.5)			
Informing the technical support alarm	6 (1.9)	2 (1)			
Silenncing and muting alarm	9 (2.8)[x]	0 (0)[y]			
No response the alarm	40 (12.4)	19 (9.5)			
Other (CPR, endotracheal asp., intraoral asp.)	35 (10.9)	27 (13.6)			

Note: Bold values indicate statistically significant results ($p < 0.05$). x, y: there is no difference between groups with the same letter in each line.
[a]McNemar test.
[b]Fisher's Exact test.
[c]Chi-Square test.
[d]Dependent t test.
[1]OR [%95 Confidence interval].
[2]effect size index w [%95 Confidence interval].
[3]Cohen's d [%95 Confidence interval].

TABLE 4 | Comparison of nurses' pretest and posttest monitor alarm management knowledge score and alarm fatigue level ($n = 19$).

Variables	Pre-training (Mean ± SD)	Post-training (Mean ± SD)	r(p)	Test	*p*-value	Cohen's d (%95 CI)
Monitor alarm management knowledge score	17.05 ± 2.30	19.37 ± 0.83	0.659 (0.002)	−5.434	**< 0.001**	1.03 [0.05; 1.98]
Alarm fatigue scale	12.16 ± 4.34	10.00 ± 3.16	0.954 (< 0.001)	6.119	**< 0.001**	0.43 [−0.49; 1.33]

Note: Paired two sample t test, r: Pearson correlation coefficient, mean ± standard deviation, Cohen's d [%95 Confidence interval]. Bold values indicate statistically significant results ($p < 0.05$).

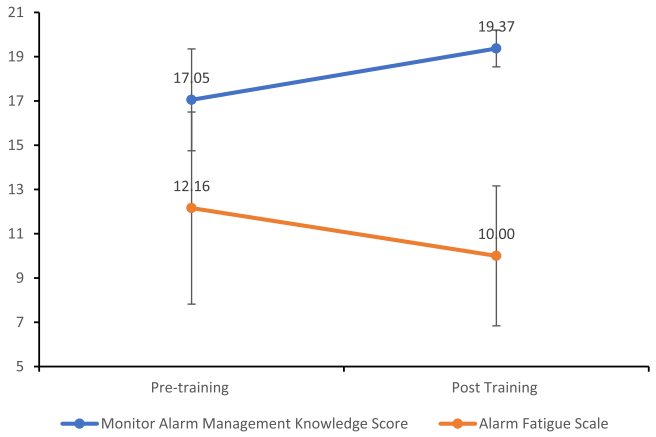

FIGURE 2 | Nurses' pretest and posttest monitor alarm management knowledge score and alarm fatigue levels.

Pulse alarms are potentially crisis alarms (ventricular bradycardia, ventricular fibrillation, ventricular tachycardia and asystole) and may indicate a significant risk that may threaten the patient's life. If crisis alarms are not recognised and intervened timely, patients may suffer irreversible consequences and may even be lost [40, 42]. Blood pressure assessment also provides basic data about the patient's circulatory system health [43]. We think the pulse and blood pressure alarms in this study are caused by changes in the patient's health status, treatment and care interventions, and patient movements in the bed. In managing pulse alarms, it is recommended that ECG electrodes be changed daily after skin care and as needed and that circulation monitoring should be done individually [9, 17, 27]. In managing blood pressure alarms, it may be recommended to have the arm at heart level and choose the appropriate extremity and cuff [19, 20].

The false alarm rate was found to be 37.9% in the pre- training in our study, consistent with the literature [4, 10, 11]. The rate of false and crisis alarms decreased in the post- training in our study. These findings supported the expected effect of alarm management training in raising awareness and teaching behaviours for effective alarm management. The alarm value ranges were customised according to the patient's clinical condition, the rate of skin cleansing increased significantly, and the electrode replacement rate improved in the post- training. These findings are very important in that they show that individualised alarm management strategies reduce false alarms and crisis alarms, thus drawing attention to early warnings. ICU nurses should take responsibility for setting the value ranges of alarm parameters and adjust the value ranges of alarm parameters [9, 44, 45] and aim to reduce contact and conduction problems [17, 46, 47] with proper skin cleaning and electrode replacement in each shift. To achieve this, ICU nurses should be trained accordingly, and their practices monitored to reduce false and crisis alarms.

Previous studies have demonstrated that nurses may choose to disable alarms because of the high number of alerts that do not require intervention [8, 48]. Failure to respond to the alarm may threaten patient safety, increasing morbidity and mortality [8, 12]. In this study, "no response to alarm," an inappropriate alarm management behaviour, was one of the most common response types in the pre-training. In the study of Ergezen and Kol [11], "silencing the alarm," another inappropriate alarm management behaviour, was the most common type of alarm response. In our study, "silencing and muting the alarm" behaviour as an inappropriate alarm response was not exhibited on any occasion in the post-training, while "no response to alarm" behaviour decreased significantly, and the rate of effective alarm management behaviours increased compared to the pre-training. These results were critical in demonstrating the effectiveness of alarm management training. Silencing and deactivating alarms or not responding to alarms may delay or prevent diagnosing alarms and making necessary interventions. These behaviours may be related to nurses' negative attitudes towards alarms. The alarm management training appears to positively impact affective learning, not only by increasing knowledge but also by fostering positive attitudes.

4.3 | Nurses' Alarm Fatigue

Reducing alarm response times is critical in managing risky situations in the intensive care unit and ensuring patient safety [49, 50]. In this study, the mean response time to alarms in the pretest was found to be 7.30 min. In a study examining the effects on alarm fatigue and patient safety, nurses' mean response time to alarms was 9 min [34]. In some previous studies [34, 51], alarm response time was considered equal to alarm fatigue, stating that alarm fatigue levels increased as the alarm response time increased. Due to exposure to numerous alarms, nurses become desensitised to them and experience alarm fatigue [23, 52]. Nurses may leave alarms unanswered as a result of desensitisation [49, 50]. In this study, the nurses' response time to the alarm and the level of alarm fatigue in the posttest decreased significantly compared to the pretest. Consistent with the literature [8, 48, 53, 54], it was concluded that trainings to provide effective alarm management behaviours to reduce nurses' alarm response time and alarm fatigue levels would be a useful approach. This finding indicates a

significant improvement in nurses' alarm management behaviours post-training. We believe this is the improvement results from the increased control over alarms achieved by nurses whose knowledge levels were enhanced through alarm management training, allowing them to understand and respond to alarms more appropriately. The training was effective in promoting better alarm management behaviours, which helps reduce alarm fatigue. Reduced alarm fatigue is not only a nursing outcome but also a patient safety issue that can significantly affect patient outcomes by reducing the number of alarms that are missed or ignored and delayed response. Alarm fatigue should be regarded as an indicator reflecting whether effective alarm management is taking place.

5 | Limitations

The most important limitations of this study was the small sample included 19 nurses working in two intensive care units with no control group utilized, making the results not generalizable to all ICUs. It is recommended that future studies be conducted with larger sample groups and research designs with high evidence power. Another limitation of the study was that only monitor alarms were considered in alarm monitoring and that it did not include alarms related to other devices, such as mechanical ventilators or infusion pumps. Testing interventions that include alarm management training and strategies for all alarm systems and devices may be recommended. In addition, despite all the precautions taken, nurses' monitor alarm management behaviours may have been influenced to some extent by the observation as an inevitable limitation in observational studies. It may be recommended to use methods to minimise the effect of observation on nurses' behaviour and, if possible, to use blinding when the design of the study allows. Finally, the effectiveness of the training was evaluated immediately after the training, and a follow-up assessment was not made, which was another limitation. Therefore, the monitoring of long-term effects should be made in future studies.

6 | Conclusions

The current study contributes evidence supporting that the training provided to nurses regarding monitoring alarm management in intensive care units positively impacts nurses' knowledge and behaviours and is effective in reducing alarm fatigue. The information obtained indicate that, while alarms are intended to facilitate monitoring, decision-making, and intervention by highlighting important changes in the patient's condition, inappropriate alarm responses can compromise patient safety. To bridge the gap between theoretical knowledge and practical application in alarm management to practice, the importance of the education of nurses, who are in a key position within the healthcare team in alarm management, should be recognised. With alarm management training, nurses can recognise, prioritise and intervene in critical situations in a timely manner, improve patient outcomes by reducing unnecessary time losses due to false alarms, and increase efficiency by reducing alarm fatigue. In this regard, monitoring the long-term results of alarm management training for nurses, patients and the institution is recommended.

This study was conducted with nurses in two intensive care units, and its findings align with existing literature. Consequently, the structured and comprehensive monitor alarm management training including theoretical content, case studies and reminder cards is recommended as an effective tool in creating a safe intensive care environment. Healthcare administrators should invest resources to identify and address the alarm management training needs of intensive care nurses. Providing in-service training on monitor alarm management and regularly updating and repeating this training based on the literature and the specific monitors and medical device alarm systems used, establishing policies for alarm management through a multidisciplinary approach, periodically auditing compliance with these policies, and conducting regular meetings to develop for addressing alarm management issues can be recommended. For evidence-based alarm management institution-specific alarm management protocols should be developed using existing literature and guidelines, and the calibration and maintenance of medical devices should be ensured. Further studies with different and larger sample groups and different research designs can be recommended. Additionally, the long-term effects of monitor alarm management training can be demonstrated through long-term observations conducted after the training period.

Author Contributions

Dilanur Kibar: conceptualization, methodology, data curation, writing – original draft preparation, visualization, investigation, supervision, writing – reviewing and editing. **Aysel Özsaban:** conceptualization, methodology, data curation, writing – original draft preparation, visualization, investigation, supervision, writing – reviewing and editing.

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Ethics Statement

The study was approved by the Karadeniz Technical University Medicine Faculty Scientific Researchs Ethical Committe (Date: 30.06.2021 Number: 24237859-591/2021-207). The approval and permission of the subjects, who participated in the study, were obtained before the initiation of our study. The confidentiality and anonymity of findings were preserved. The principles of the Declaration of Helsinki were followed during all phases of the study.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.