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Nurses' clinical alarm-related behaviors and influencing factors in China†

Original Article

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Abstract: **Objective:** To explore the nurses' behaviors regarding clinical alarms, analyze the related influencing factors, and provide rationales for alarm management.
Methods: A cross-sectional survey was conducted in China. The self-made questionnaire of nurses' clinical alarm-related knowledge, attitude, and behavior (NCAKAB) was used.
Results: The valid response rate was 98.66% ($n = 2368$). The average nurses' clinical alarm-related behaviors (NCAB) score was 65.14 ± 7.95 (out of 85). The dimension scores of NCAB from high to low were alarm learning (4.02 ± 0.85, out of 5), alarm response (27.99 ± 3.64, out of 35), alarm setting (19.24 ± 3.88, out of 25), alarm recognition (7.63 ± 1.68, out of 10) and alarm notification (6.25 ± 1.84, out of 10). There were significant differences in alarm behavior scores between nurses of different ages ($F = 4.619$, $P = 0.000$), nursing stints ($F = 9.564$, $P = 0.000$), professional titles ($F = 4.425$, $P = 0.004$), departments ($F = 9.166$, $P = 0.000$), and hospital levels ($t = 2.705$, $P = 0.007$). The study showed that nurses' total alarm behavior scores were positively correlated with the total alarm knowledge score ($r = 0.267$; $P < 0.001$) and the total alarm attitude score ($r = 438$; $P < 0.001$).
Conclusions: Nurses scored highest in alarm learning, followed by alarm response, alarm setting, alarm recognition, and alarm notification behavior. The factors that influenced alarm behavior included age, title, department, nursing stint, hospital level, professional title, alarm-related training, willingness to participate in alarm-related training, whether or not departments have improved alarm management over the last 3 years, and whether or not departments have formulated norms for alarm management. Nurses with higher scores for clinical alarm knowledge had higher correlating scores for alarm behavior; similarly, nurses with higher scores for clinical alarm attitude had higher scores for alarm-related behavior.

Keywords: *behavior • clinical alarm • factors • nurses • patient safety*

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1. Introduction

In clinical settings, an alarm is defined as a signal for notifying caregivers when a patient is in a potentially hazardous situation requiring immediate assistance.[1] Clinical alarms promote patient safety by alerting

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clinicians when there is an indication or change in a condition that requires a response. At certain time points, alarm-capable medical equipment has been widely used for patient care;[2] a patient might be connected to one or multiple alarming devices, including a cardiac monitor, ventilator, or medication pump.[3] The use of clinical alarms, which promote patient safety by alerting potentially hazardous situations, is steadily increasing. However, repeated false alarms may lead to desensitization of staff to alarms, which presents potential hazards to patients and reduces their trust in alarms. In 2013, the Joint Commission issued a sentinel event alert for 98 reported alarm-related events, 80 of which resulted in death. While multiple contributing factors were identified for each event, alarm fatigue was the most common contributing factor.[4] Alarm fatigue from frequent, false, or unnecessary sounding causes inappropriate or wrong behavior by the nurses. Previous research indicates that more than half of nurses believe that frequent false alarms reduce trust in alarms, leading nurses to inappropriately disable alarms.[5] According to the life cycle of alarms,[6] it refers to the process which begins with alarm generation to dispose of the patient's condition, and then eliminate the alarm. An alarm life cycle includes four important links: alarm generation, alarm transmission, alarm recognition, and alarm response. Nurses, as major operators of medical equipment, should be informed of proper alarm-related behaviors to ensure patient safety. According to the alarm life cycle, the alarm-related behaviors of nurses mainly refer to the behaviors of nurses in alarm setting, alarm notification, alarm recognition, and alarm response of medical equipment in clinical work, especially in the use of medical equipment, as well as learning alarm-related knowledge, acquiring the skills through training, alarm management, and so on.[7]

One study has reported that too many false alarms can disrupt daily nursing duties and foster distrust.[8] In this study, 150–350 alarms per day for patients (80%–90%) were non-actionable. In general, false alarms cause high levels of frustration, aggression, and misconduct,[9] and clinical nurses become susceptible to the consequences of "wolf coming," which ultimately leaves the patients in jeopardy.

In the United States, the Emergency Care Research Institute has listed alarms among the top three Health Technology Hazards for several consecutive years.[10] In China, item nine of the Patient Safety Goals of the China Hospital Association (2019/2020 Edition) is strengthening medical equipment safety and alarm management, which highlights the importance of clinical alarm management. However, few studies have analyzed the alarm-related behaviors of nurses and the related influencing factors, which can provide rationales for clinic alarm management.

2. Methods

2.1. Study design

A cross-sectional survey was conducted.

2.2. The questionnaire

The behavior of nurses regarding clinical alarms was measured through a self-made questionnaire[11]: questionnaire of nurses' clinical alarm-related knowledge, attitude, and behavior (NCAKAB). The questionnaire was based on the KAP model, We developed an item pool based on "the life cycle of an alarm" theory, literature reviews, and in-depth interviews. Then a two-round of expert consultation was conducted using the Delphi process and 450 clinical nurses were surveyed. The final questionnaire consisted of 40 items (total score = 152) and 3 dimensions: knowledge dimensions with 12 items, attitude dimensions with 11 items, behavior dimensions with 17 items. For knowledge dimensions (total score = 12), which are multiple choice, 1 point is calculated for each correct answer. For the attitude dimensions (total score = 17) and behavior dimensions (total score = 85), the answer options are set according to Likert's five-level scoring method. According to the degree of approval (strongly disagree = 1, disagree = 2, general = 3, agree = 4, strongly agree = 5) and the frequency of behavior (never do like this = 1, normally don't do like this = 2, occasionally do like this = 3, often do like this = 4, always do like this = 5), and there are some reverse entries. Higher scores indicate better performance of the nurses.

The *Cronbach's* α coefficient, split-half reliability, and test-retest reliability were 0.884, 0.993, and 0.876 respectively. The *Cronbach's* α coefficient for the three dimensions of knowledge, attitude, and behavior is between 0.739 and 0.920. The item level content validity index (*I-CVI*) ranged from 0.818 to 1.000, and the scale level (*S-CVI*) was 0.850, indicating that the questionnaire contents are reasonable. To assess the structural validity, an exploratory factor analysis is used to extract eight common factors with eigenvalues > 1, the cumulative contribution rate is 58.86%. The questionnaire has good reliability and validity, which is suitable for the evaluation of nurses' knowledge, attitudes, and behavior regarding clinical alarms.

2.3. Participants

To determine the number of participants required, we used previously published data and formulas.[12] The pre-survey resulted in a standard deviation (SD) of 13.02 with an allowable error of 0.6, $a = 0.05$, $u0.05/2 = 1.96$, which suggested that we needed at least 1809 samples.

In June 2018, we recruited 2400 nurses from 10 different hospitals (total: 9600 nurses) One grade-3 general hospital and one grade-2 general hospital in the east, west, south, north, and middle regions of Hunan province, China were selected respectively. Thus, the 10 hospitals were selected to conduct the sampling method. A multi-stage cluster random sampling method was used and one nurse was selected randomly from every four nurses in each interval.

Registered nurses who enrolled in the study met the following criteria: (1) practicing at a clinical department; (2) nursing stint > 1 year; c) registered status; (3) provided informed consent. The exclusion criteria included refresher nurses and those working at non-clinical nursing units. It took 6–10 min for each respondent to complete the questionnaire.

The study protocol was executed by three graduate students of the Nursing College and five nurses with master's degrees. Data were collected by mobile phone with a customized electronic data collection form.

2.4. Data analysis

Software SPSS18.0 was utilized for statistical analyses. Statistical descriptions of measurement data were expressed as mean ± SD. The inter-group comparison was made by *Wilcoxon's* rank-sum test of two independent samples. The utilization rate and composition ratio of counting data were described, and the comparison was made by the Chi-square test. Pearson correlation analysis was used to analyze the relationships among nurses' clinical alarm knowledge, attitudes, and behavior. We also performed a multivariate analysis of the factors that influence nurses' clinical alarm behavior. The results for which $a = 0.05$ and $P < 0.05$ were considered significant.

3. Results

3.1. Descriptive data

A total of 2368 completed responses (98.66% response rate) were obtained from 2400 participants. Most participants (97.4%, $n = 2306$) were female, and the mean age of nurses was 29.4 years ± 6.0 (mean ± SD; range: 22–55 years of age). The average nursing stint among participants was 8.1 years ± 6.8. The department with the highest number of respondents was surgery (35.3%, $n = 835$), followed by intensive care unit (ICU) wards (12.4%, $n = 294$), and 50.1% ($n = 1186$) were nurse practitioners. Nurses reported using the multi-parameter monitor (95.7%, $n = 2267$), infusion pump (85.1%, $n = 2014$), and injection pump (61.2%, $n = 1450$) the most.

The highest scores for alarm behavior came from nurses in ICU, followed by anesthesia, surgery, internal medicine, emergency, and pediatrics ($F = 9.166$, $P = 0.000$).

Nurses in the group aged 46 or above had the highest alarm behavior scores, while those in the 26–30-year-old group scored the lowest. The longer the nursing stint (working years of nurses), the higher the alarm behavior scores ($F = 9.564$, $P = 0.000$). Nurses-in-charge scored the highest on alarm behavior, while nurses in senior positions (professional titles of associate director nurse and above) scored the lowest.

The alarm behavior scores of nurses in the third-level hospitals were higher than that of nurses in the second-level hospitals ($t = 2.705$, $P = 0.007$). The behavior scores of nurses in hospitals affiliated with colleges or universities were higher than those in non-affiliated hospitals ($t = 2.278$, $P = 0.023$).

There were no statistical differences in the scores for alarm behavior of nurses based on gender, educational background, marital status, whether or not they have children, administrative position, organizational attributes, or whether they have experienced adverse events related to clinical alarm in the past 2 years, as shown in Table 1.

The majority of nurses (73.9%, $n = 1751$) responded that their departments had implemented alarm management protocols over the last 3 years. Some respondents (7.0%, $n = 165$) experienced alarm-related adverse events over the last 2 years. More than half of the nurses (53.8%, $n = 1273$) indicated that his or her department did not have assistive technology to improve alarm management. Most of the nurses in the study (94.0%, $n = 2226$) were willing to participate in alarm-related training, as shown in Tables 1 and 2.

The average score for the NCAKAB was 121.82 ± 5.24 (full score = 155), and the major influencing factors included age, title, educational background, department, whether nurses have received alarm-related training, willingness to participate in alarm-related training, whether or not departments have improved alarm management over the last three years, and whether or not departments have formulated norms for alarm managements.

The average score for clinical alarm knowledge (NCAK) was 7.43 ± 2.56 (full score = 12), and on average

Items	*n*	Constituent ratio (%)	Alarm settings	Alarm notifications	Alarm recognitions	Alarm responses	Alarm learning	Total behavior score	
								Score	Comparison
Gender									$t = 0.112$ $P = 0.911$
Male	62	2.6	20.06 ± 4.26	5.94 ± 2.25	7.98 ± 1.80	27.05 ± 4.09*	4.00 ± 0.83	65.03 ± 8.40	
Female	2306	97.4	19.22 ± 3.87	6.26 ± 1.83	7.62 ± 1.67	28.02 ± 3.62	4.02 ± 0.85	65.15 ± 7.94	
Age (years)									$F = 4.619$ $P = 0.000$
20–25	623	26.3	19.29 ± 4.08	6.10 ± 1.90*	7.50 ± 1.75	27.83 ± 3.76*	3.99 ± 0.89*	64.70 ± 8.35	
26–30	1043	44.1	19.01 ± 3.94	6.26 ± 1.84	7.66 ± 1.66	27.76 ± 3.62	3.97 ± 0.87	64.66 ± 8.05	
31–35	360	15.2	19.41 ± 3.58	6.47 ± 1.76	7.70 ± 1.63	28.11 ± 3.57	4.06 ± 0.81	65.75 ± 7.32	
36–40	188	7.9	19.53 ± 3.64	6.36 ± 1.89	7.73 ± 1.61	28.97 ± 3.41	4.20 ± 0.75	66.79 ± 7.59	
41–45	112	4.7	19.68 ± 3.52	6.10 ± 1.70	7.65 ± 1.79	29.00 ± 3.38	4.21 ± 0.71	66.63 ± 7.17	
46–55	42	1.8	20.38 ± 3.46	6.45 ± 1.69	7.88 ± 1.44	28.26 ± 3.60	4.26 ± 0.83	67.24 ± 5.99	
Nursing stint (years)									$F = 9.564$ $P = 0.000$
≤5	1044	44.1	19.23 ± 4.05*	6.09 ± 1.84*	7.57 ± 1.67	27.80 ± 3.63*	4.01 ± 0.87*	64.70 ± 8.05	
6–10	755	31.9	19.00 ± 3.83	6.37 ± 1.86	7.65 ± 1.71	27.83 ± 3.72	3.95 ± 0.89	64.81 ± 8.23	
≥11	569	24.0	19.59 ± 3.60	6.40 ± 1.79	7.71 ± 1.66	28.57 ± 3.49	4.14 ± 0.77	66.41 ± 7.22	
Hospital class									$t = 2.705$ $P = 0.007$
Class III	1582	66.8	19.52 ± 3.78*	6.25 ± 1.88	7.70 ± 1.66*	27.95 ± 3.63	4.03 ± 0.85	65.45 ± 7.93	
Class II	786	33.2	18.69 ± 4.02	6.26 ± 1.77	7.49 ± 1.70	28.08 ± 3.66	4.01 ± 0.87	64.52 ± 7.96	
Hospital Affiliated to College or not									$t = 2.278$ $P = 0.023$
Yes	1777	75.0	19.39 ± 3.88*	6.26 ± 1.87	7.71 ± 1.66*	27.97 ± 3.69	4.03 ± 0.85	65.36 ± 8.06	
No	591	25.0	18.80 ± 3.84	6.23 ± 1.76	7.40 ± 1.71	28.07 ± 3.48	3.99 ± 0.86	64.50 ± 7.57	
Title									$F = 4.425$ $P = 0.004$
Nurse	595	25.1	19.23 ± 4.13	6.16 ± 1.91	7.46 ± 1.79*	27.99 ± 3.77*	4.00 ± 0.89*	64.85 ± 8.40	
Nurse practitioner	1186	50.1	19.12 ± 3.90	6.31 ± 1.84	7.66 ± 1.65	27.75 ± 3.64	3.98 ± 0.87	64.82 ± 8.06	
Nurse-in-charge	507	21.4	19.55 ± 3.58	6.26 ± 1.79	7.77 ± 1.62	28.57 ± 3.49	4.13 ± 0.78	66.28 ± 7.17	
Associate director nurse and above	80	3.4	19.15 ± 3.50	6.09 ± 1.59	7.56 ± 1.57	27.96 ± 3.20	4.19 ± 0.71	64.95 ± 6.80	

Table 1. Continued

Items	*n*	Constituent ratio (%)	Alarm settings	Alarm notifications	Alarm recognitions	Alarm responses	Alarm learning	Total behavior score	
								Score	Comparison
Education									$F = 0.129$ $P = 0.879$
Secondary/tertiary schools	615	26.0	19.18 ± 3.99	6.30 ± 1.85	7.53 ± 1.69	27.98 ± 3.61	4.03 ± 0.87	65.01 ± 8.05	
Undergraduate	1678	70.9	19.26 ± 3.85	6.25 ± 1.85	7.67 ± 1.67	28.00 ± 3.65	4.01 ± 0.85	65.20 ± 7.92	
Master's and above	75	3.2	19.29 ± 3.70	5.99 ± 1.59	7.60 ± 1.68	28.00 ± 3.60	4.17 ± 0.80	65.05 ± 7.89	
Marital status									
Married	1456	61.5	19.26 ± 3.79	6.28 ± 1.83	7.66 ± 1.68	28.05 ± 3.63	4.04 ± 0.84	65.29 ± 7.84	$F = 0.750$
Unmarried	889	37.5	19.23 ± 4.04	6.19 ± 1.88	7.60 ± 1.67	27.90 ± 3.65	3.99 ± 0.88	64.92 ± 8.15	$P = 0.473$
Divorced	23	1.0	18.43 ± 3.54	6.74 ± 1.48	7.09 ± 1.54	28.00 ± 3.78	4.04 ± 0.83	64.30 ± 7.22	
Have child	1253	52.9	19.29 ± 3.75	6.30 ± 1.83	7.67 ± 1.68	28.09 ± 3.60	4.06 ± 0.82*	65.42 ± 7.74	$t = 1.773$
Not have child	1115	47.1	19.19 ± 4.02	6.20 ± 1.85	7.59 ± 1.68	27.88 ± 3.68	3.98 ± 0.88	64.84 ± 8.16	$P = 0.076$
Administrative duties									$t = 0.336$ $P = 0.737$
Nurse	2165	91.4	19.23 ± 3.92	6.27 ± 1.86	7.65 ± 1.68	27.96 ± 3.66	4.01 ± 0.86*	65.13 ± 8.02	
Head nurse and above	203	8.6	19.26 ± 3.43	6.10 ± 1.63	7.49 ± 1.71	28.32 ± 3.37	4.14 ± 0.75	65.31 ± 7.10	
Ranking attribute									$F = 1.907$ $P = 0.149$
Formal	1241	52.4	19.38 ± 3.77	6.26 ± 1.82	7.70 ± 1.64	28.03 ± 3.64	4.04 ± 0.83	65.41 ± 7.65	
Contracting system	1049	44.3	19.07 ± 4.02	6.25 ± 1.87	7.55 ± 1.73	27.93 ± 3.66	4.00 ± 0.88	64.79 ± 8.33	
Temporary employment	78	3.3	19.46 ± 3.58	6.12 ± 1.89	7.68 ± 1.57	28.31 ± 3.34	4.09 ± 0.72	65.65 ± 7.20	
Department									$F = 9.166$ $P = 0.000$
ICU	294	12.4	20.41 ± 3.47**	6.62 ± 2.11**	8.34 ± 1.33**	28.43 ± 3.35**	4.11 ± 0.78**	67.90 ± 7.40	
Surgery	835	35.3	19.08 ± 3.97	6.17 ± 1.82	7.44 ± 1.80	27.70 ± 3.91	3.99 ± 0.90	64.38 ± 8.43	
Internal medicine	700	29.5	19.10 ± 3.87	6.08 ± 1.74	7.55 ± 1.67	27.94 ± 3.49	4.04 ± 0.83	64.72 ± 7.72	
Pediatrics	196	8.3	18.69 ± 3.92	6.35 ± 1.87	7.49 ± 1.56	28.08 ± 3.83	3.91 ± 0.82	64.52 ± 7.85	
Emergency medicine	132	5.6	19.28 ± 3.71	6.13 ± 1.63	7.57 ± 1.47	27.67 ± 3.12	4.11 ± 0.77	64.76 ± 6.77	
Anesthesia	104	4.4	19.28 ± 4.20	7.02 ± 1.81	7.81 ± 1.46	28.84 ± 3.27	3.98 ± 0.89	66.92 ± 7.41	
Others	107	4.5	19.13 ± 3.68	6.33 ± 1.83	7.81 ± 1.74	28.87 ± 3.48	4.07 ± 0.86	66.21 ± 7.11	

Note: $^{**}P < 0.01$; $^{*}P < 0.05$.
ICU, intensive care unit.

Table 1. Clinical alarm behavior scores and demographic data of surveyed nurses ($n = 2368$).

Items	Frequency (*n*)	Constituent ratio (%)
Department has implemented the alarm management improvement project in the past 3 years		
Yes	1751	73.9
No	617	26.1
Department has used assistive technology to improve alarm management		
Yes	1095	46.2
No	1273	53.8
Have received education and training related to clinical alarm		
Yes	1877	79.3
No	491	20.7
Willingness to participate in alarm related training		
Willing	2226	94.0
Not sure	24	1.0
Not willing	118	5.0
Have experienced alarm-related adverse events during the last 2 years		
Yes	165	7.0
No	2203	93.0

Table 2. General demographic data of surveyed nurses (n = 2368).

61.9% of questions were answered correctly Nurses scored highest on questions related to knowledge of alarm signal (average score of 0.83 (full score = 1)1 and scoring rate of 83%) and lowest for questions related to knowledge of alarm classification (average score of 0.63 (full score = 2) and scoring rate of 31.5%).

The average score for alarm attitudes (NCAA) was 49.25 ± 5.21 (out of 55). ICU nurses scored higher than nurses from other departments; 41 to 45-year-old nurses scored the highest on alarm attitude, and 20 to 25-year-old nurses scored the lowest. The statement that received the highest score was "Minimizing false alarms lowers alarm load of nurses and improves alarm response rate" (average score of 4.62 out of 5). The statement that received the lowest score was "Proper handling of alarms affects the inpatient satisfaction of medical services" (average score of 4.20 out of 5).

The average score for NCAB was 65.14 ± 7.95 (out of 85). The dimensions for alarm-related behavior, from high to low scores, were alarm learning (4.02 ± 0.85, out of 5), alarm response (27.99 ± 3.64, out of 35), alarm setting (19.24 ± 3.88, out of 25), alarm recognition (7.63 ± 1.68, out of 10) and alarm notification (6.25 ± 1.84, out of 10), as shown in Table 1.

Upon receiving an alarm signal, 49.2% (n = 1165) of nurses reported that they always respond immediately. Nearly half (47.5%; n = 1124) of nurses responded that "When multiple alarms occur simultaneously, I can always arrange the order of response according to the priority level of alarm". Only 41.4% (n = 981) of nurses responded that "if I can't handle the alarm, I will always actively seek the assistance of other colleagues". The aforementioned items scored in the top three for current alarm behavior, with average scores of 4.39 ± 0.70, 4.30 ± 0.81, and 4.23 ± 0.78 (all out of 5), respectively.

For frequent false or interfering alarms, 33.1% (n = 784) of nurses responded that they often turn off/mute the alarm and 18.5% (n = 437) always turn off/mute the alarm. When asked how frequently they were alerted to the alarm by the patient or escort, 22.7% (n = 537) and 8.5% (n = 202) of nurses responded "often" and "always", respectively. When asked how frequently they sought ways of acquiring alarm-related knowledge, 41.0% (n = 971) and 32.7% (n = 775) of nurses responded "often" and "always," respectively (See Tables 1 and 3).

3.2. Influencing factors of NCAB

The nurses' total alarm behavior score was positively correlated with the total alarm knowledge score (r = 0.267; P < 0.001). The total alarm attitude score was positively correlated with the total alarm behavior score (r = 438; P < 0.001). Surgery (control = ICU) (P < 0.001), internal medicine (control = ICU) (P < 0.001), pediatrics (control = ICU) (P < 0.001), emergency department (control = ICU) (P = 0.001), anesthesia department (control = ICU) (P < 0.05), professional title (from low to high) (P < 0.05), the department has not implemented the alarm management improvement project (control = yes) (P < 0.001), the department or hospital has not formulated

Behavior items	Never do like this (*n*, %)	Not normally do like this (*n*, %)	Occasionally do like this (*n*, %)	Often do like this (*n*, %)	Always do like this (*n*, %)	Number	Minimum	Maximum	Mean ± SD
Dimension 1: alarm settings						5	5	25	19.24 ± 3.88
1. When using alarming devices, adjusting alarm-related settings.	18 (0.8)	87 (3.7)	490 (20.7)	952 (40.2)	821 (34.7)	1	1	5	4.04 ± 0.88
2. Setting personalized alarm thresholds according to patient condition.	40 (1.7)	198 (8.4)	583 (24.6)	887 (37.5)	660 (27.9)	1	1	5	3.81 ± 0.99
3. With the changes of patient conditions, adjusting alarm settings.	78 (3.3)	288 (12.2)	444 (18.8)	826 (34.9)	732 (30.9)	1	1	5	3.78 ± 1.11
4. While rotating shifts, checking alarm settings.	39 (1.6)	204 (8.6)	490 (20.7)	793 (32.5)	842 (35.6)	1	1	5	3.93 ± 1.03
5. Adjusting alarm volume according to the environment and time of ward.	73 (3.1)	291 (12.3)	587 (24.8)	792 (33.4)	625 (26.4)	1	1	5	3.68 ± 1.09
Dimension 2: alarm notifications						2	2	10	6.25 ± 1.84
1. You will be alerted to alarm by patient or escort.	361 (15.2)	545 (23.0)	723 (30.5)	537 (22.7)	202 (8.5)	1	1	5	2.86 ± 1.18
2. Missing alarm because you can't hear it.	133 (5.6)	195 (8.2)	962 (40.6)	769 (32.5)	309 (13.0)	1	1	5	3.39 ± 1.00
Dimension 3: alarm recognitions						2	2	10	7.63 ± 1.68
1. You can accurately identify the alarm-triggering device according to alarm signal.	35 (1.5)	121 (5.1)	460 (19.4)	1148 (48.5)	604 (25.5)	1	1	5	3.91 ± 0.88
2. According to different alarm signals, identifying different levels of alarm	68 (2.9)	218 (9.2)	555 (23.4)	1001 (42.3)	526 (22.2)	1	1	5	3.72 ± 1.00
Dimension 4: alarm responses						7	15	35	27.99 ± 3.64
1. Responding to all alarms generated in the responsible area.	21 (0.9)	91 (3.8)	307 (13.0)	1024 (43.2)	925 (39.1)	1	1	5	4.16 ± 0.85
2. Upon receiving an alarm signal, responding immediately.	9 (0.4)	30 (1.3)	153 (6.5)	1011 (42.7)	1165 (49.2)	1	1	5	4.39 ± 0.70
3. When multiple alarms occur simultaneously, you order the responses according to the priority level of alarms.	15 (0.6)	69 (2.9)	226 (9.5)	934 (39.4)	1124 (47.5)	1	1	5	4.30 ± 0.81
4. Correctly handling various events leading to alarms.	15 (0.6)	37 (1.6)	286 (12.1)	1264 (47.5)	766 (32.3)	1	1	5	4.15 ± 0.74
5. You will not respond to alarms that you believe are false or interfere with.	186 (7.9)	355 (15.0)	640 (27.0)	867 (36.6)	320 (13.5)	1	1	5	3.33 ± 1.12
6. For frequent false or interfering alarms, turning off/muting alarm.	166 (7.0)	308 (13.0)	673 (28.4)	784 (33.1)	437 (18.5)	1	1	5	3.43 ± 1.14
7. For alarms that you cannot handle, actively seeking the assistance of other colleagues.	11 (0.5)	41 (1.7)	317 (13.4)	1018 (43.0)	981 (41.4)	1	1	5	4.23 ± 0.78
Dimension 5: alarm learning						1	1	5	4.02 ± 0.85
Actively seeking ways of acquiring alarm-related knowledge.	11 (0.5)	78 (3.3)	533 (22.5)	971 (41.0)	775 (32.7)	1	1	5	4.02 ± 0.85
Total behavior score						17	33	85	65.14 ± 7.95

Note: SD, standard deviation.

Table 3. Clinical alarm-related behavior scores of nurses ($n = 2368$).

the alarm management-related system or specification (control = yes) ($P < 0.001$), has not received the clinical alarm related education and training (control = yes) ($P < 0.001$) had a negative correlation with the clinical alarm behavior score, and the regression equation was statistically significant ($F = 67.123$; $P < 0.001$, $R^2 = 35.8\%$, shown in Tables 4 and 5).

4. Discussion

4.1. The scores for NCAB items from high to low were alarm learning, alarm response, alarm setting, alarm recognition, and alarm notification behavior

4.1.1. Alarm learning

Alarm learning behaviors in the study mean seeking ways of acquiring alarm-related knowledge. Alarm learning scored highest for all NCAB items; 41.0% ($n = 971$) of nurses responded that they often actively seek ways of acquiring alarm-related knowledge, and 32.7% ($n = 775$) responded that they always do. These data reflect a lack of clinical alarm knowledge in nurses. In this study, 49.1% of surveyed nurses indicated that they had not received alarm-related training during the last year. Other studies report that more than 60% of nurses indicated that they needed more training on the use of bedside and central monitors,[5] and it reported that nurses lacked knowledge of equipment alarms and equipment with alarm functions.[7] More than 90% of nurses reported that they have learned how to operate the equipment, the purpose of using equipment, and the function of equipment.[13] Our results, taken together with those from other studies, suggest there is an urgent need to enhance clinical alarm-related training and education for nurses and other hospital personnel.

4.1.2. Alarm response

Alarm response behaviors refer to how to handle an alarm once the nurse is informed of it, in the study. As for frequent false or interfering alarms, 33.1% ($n = 784$) and 18.5% ($n = 437$) of nurses responded that they often or always, respectively, turn off/mute alarm. Nearly half (49.2%; $n = 1165$) of the nurses reported that they always respond immediately upon receiving an alarm signal, which was in agreement with previous studies. Voepel-Lewis et al. reported that 26% of oxygen saturation alarms in general surgery wards were not responded to by nurses,[14] and another study reported that the response rate to ECG alarms was only 46.8% in non-critical care settings.[15] Another study found that 14/34 (41%) red alarms never responded immediately and 70% of patient monitor alarms never responded promptly.[16] Funk et al. [7] reported that nurses sometimes do not respond to alarms or lower sound volume, heighten alarm thresholds, inappropriately silence alarms, or even disconnect them.

In this study, 41.4% ($n = 981$) nurses responded that "if they can't handle the alarm, they will always actively seek the assistance of other colleagues." Similarly, another related study found that ICU nurses relied on the collective efforts of the team to be aware of the alarms.[17] In response to "You will not respond to alarms that you believe are false or interfere with." A total of 36.6% ($n = 867$) of nurses responded "often" and 13.5% ($n = 320$) responded "always". Insufficient staffing, high severity of illness on the unit, and unbalanced nursing skills are likely to contribute to inadequate alarm response as described above. These findings are in agreement with others who reported that nurses' responses to ECG monitors were affected by limited reflection on changes of illness, an inability to distinguish different emergency levels, insufficient recognition of the risk from the alarms, and lack of energy to respond.[18]

4.1.3. Alarm setting

Alarm setting refers to adjusting the alarm thresholds, the priority of the alarm according to the patient's situation when using the alarm device, and adjusting the alarm volume according to the ward environment and time. In this study, when using alarming devices, 34.7% ($n = 821$) of nurses always adjusted alarm-related settings, and 40.2% ($n = 952$) often adjusted them. Only 15.4% ($n = 364$) of nurses responded that they generally did not adjust alarm volume according to the environment and time on the ward, and 30.9% ($n = 732$) of nurses always stated that personalized alarm thresholds were followed according to the patient condition. In a recent study, only 35% of nurses agreed with a requirement for the documentation of alarm settings at their institution.[19] This may be due to the disproportionate increase in alarm devices, or nurses may be too busy or not pay attention to alarm settings. As a diagnostic test, monitoring was set up to be highly sensitive, but poor with specificity. Predictably, the resulting high false-positive rate led to the emergence of alarm fatigue, which ultimately reduced the sensitivity of monitoring.[20] The challenge, therefore, is to reduce the frequency of false-positive, clinically meaningless alarms with appropriate, personalized alarm settings.

4.1.4. Alarm recognition

Alarm recognition behaviors refer to identifying accurately the alarm trigger device and alarm priority

Factors	Variable name	Assignment statement
Age (age)	X1	
	X1.1	20–25: Yes = 1, no = 0 (reference)
	X1.2	26–30: Yes = 1, no = 0
	X1.3	31–35: Yes = 1, no = 0
	X1.4	36–40: Yes = 1, no = 0
	X1.5	36–40: Yes = 1, no = 0
	X1.6	41–45: Yes = 1, no = 0
	X1.7	Over 46: Yes = 1, no = 0
Hospital level	X2	Level 3 hospitals = 1
Department	X3	Level 2 hospitals = 2
	X3.1	ICU: Yes = 1, no = 0 (control)
	X3.2	Surgery: Yes = 1, no = 0
	X3.3	Internal medicine: yes = 1, no = 0
	X3.4	Pediatrics: yes = 1, no = 0
	X3.5	Emergency anesthesia surgery department: yes = 1, no = 0
	X3.6	Others: is = 1, no = 0
Title	X4	
	X4.1	Nurse: Yes = 1, no = 0 (control)
	X4.2	Nurse: Yes = 1, no = 0
	X4.3	Nurse in charge: yes = 1, no = 0
	X4.4	Deputy director nurse and above: yes = 1, no = 0
Education	X5	
	X5.1	Secondary or tertiary school: yes = 1, no = 0 (control)
	X5.2	Undergraduate=: yes = 1, no = 0
	X5.3	Master's degree or above: yes = 1, no = 0
Have you received alarm-related education and training?	X6	Yes = 1, no = 0 (control)
Are you willing to take part in alarm-related training?	X7	Willingness = 1, unwillingness = 0 (control)
Has the department implemented the alarm management improvement project in the past 3 years?	X8	Yes = 1, No = 0 (control)
Does the department or hospital in which it is located formulate relevant systems or norms for alarm management?	X9	
Have received alarm-related training or not.	X10	
Willing to attend alarm-related training or not (from willing to unwilling)	X11	Yes = 1, no = 0 (control)
Have experienced alarm-related adverse events over the last 2 years or not	X12	
Have used auxiliary technology to improve alarm management?	X13	
Department or hospital have an alarm management system or not.	X14	
Alarm knowledge score	X15	
Alarm attitude score	X16	
Alarm behavior score	Y	

Note: ICU, intensive care unit.

Table 4. Factors that influence nurses' clinical alarm behavior.

Items	Non-standardization coefficient			95%confidence interval of B			
	B	*SE*	*B'*	*t*	*P*-value	Lower bound	Upper bound
1. Age	0.000	0.083	0.000	0.003	0.997	–0.163	0.164
2. Hospital level (control = tertiary hospital)	–0.165	0.320	–0.010	–0.517	0.605	–0.793	0.462
2.1 Affiliated Hospital of University (control = yes)	0.005	0.350	0.000	0.016	0.988	–0.681	0.692
3. Surgery Department (control = ICU)	–2.960	0.457	–0.178	–6.477	0.000	–3.856	–2.064
4. Internal Medicine Department (control = ICU)	–2.637	0.455	–0.151	–5.794	0.000	–3.529	–1.744
5. Pediatrics Department (control = ICU)	–2.298	0.615	–0.080	–3.739	0.000	–3.504	–1.093
6. Emergency Department (control = ICU)	–2.237	0.678	–0.065	–3.299	0.001	–3.567	–0.908
7. Anesthesia operating Department (control = ICU)	–1.667	0.746	–0.043	–2.235	0.026	–3.130	–0.204
8. Other department (control = ICU)	–1.047	0.749	–0.027	–1.398	0.162	–2.515	0.421
9. Professional title (from low to high)	–0.627	0.296	–0.061	–2.120	0.034	–1.208	–0.047
10. Education level (from low to high)	0.005	0.350	0.000	0.016	0.988	–0.681	0.692
11. Working seniority	0.130	0.072	0.111	1.812	0.070	–0.011	0.271
12. Have received alarm-related training or not (control = have)	–1.546	0.353	–0.079	–4.384	0.000	–2.238	–0.855
13. Willing to attend alarm-related training or not (from willing to unwilling)	0.292	0.309	0.016	0.944	0.345	–0.314	0.897
14. In 3 years, have the alarm management improvement project or not (control = yes)	–1.503	0.351	–0.083	–4.280	0.000	–2.192	–0.815
15. Have used auxiliary technology to improve alarm management? (control = yes)	0.417	0.291	0.026	1.431	0.152	–0.154	0.989
16. Department or hospital have alarm management system or not.(control = have)	–1.617	0.372	–0.087	–4.352	0.000	–2.346	–0.889
17. Total alarm knowledge Score	0.282	0.055	0.091	5.128	0.000	0.174	0.390
18. Total Alarm attitude Score	0.478	0.027	0.313	17.551	0.000	0.425	0.532

Note: $P < 0.05$.
ICU, intensive care unit.

Table 5. Multivariate linear regression analysis of alarm behaviors and related.

according to the alarm signal once the nurse is informed of it, and the recipient of the alarm understands the meaning of the alarm and can predict what changes in the patient's condition may occur.in the study. When asked if they could accurately identify the alarm-triggering device according to the alarm signal, 48.5% (n = 1148) of nurses responded "often," and only 25.5% (n = 604)responded "always." Only 22.2% (n = 526) of nurses responded that they can always identify different levels of alarm according to different alarm signals, and 42.3% (n = 1001) responded with "often." One study reported that 99% (n = 164) of nurses stated that alarms should indicate alarm priority, and only 36% (n = 59) of nurses agreed that alarms frequently could not be heard or were missed and 62% (n = 102) of nurses felt that environmental background noise had interfered with alarm recognition.[21] With currently used clinical alarms, it is not easy to distinguish the alarm parameters and priority, which may make the nurses handle one alarm and miss other, more important alarms[22]; therefore, better training on alarm recognition is required.

4.1.5. Alarm notification

Alarm notification means that once an alarm is generated, the nurse can be notified in time, as mentioned in the study. Only 13.0% (n = 309) of nurses responded that they "always" missed an alarm because they could not hear it, and 32.5% (n = 769)responded "often". When asked if they were alerted to an alarm by the patient or escort, 22.7% (n = 537) and 8.5% (n = 202) responded "often" and "always," respectively. This agrees with a study that reported that family presence at the bedside helps nurses prioritize alarm responses in hectic work environments.[23] A descriptive qualitative study conducted using focus groups has shown that nurses mentioned patient education and explanations about alarms as a way to minimize patient concerns and reduce

anxiety.[17] Ruppell et al. [24] reported that although initial alarm notifications declined by 68% after their intervention, these notifications accounted for only about half of all alarm notifications. At present, there are two ways to be alerted of the ECG monitor: sound alarm and visual alarm. If the noisy environment of the hospital affects the audibility of the alarm, when nurses are busy with other work and far away from the monitor, the alarm will not be received. To overcome this, some institutions have made massive investments in personnel, such as monitor "watchers" to help nurses identify actionable alarms. As alarm notification behaviors were the lowest scores of all NCAB items, it is important to take measures to improve timely alarm notifications in the alarm management process.

4.2. Factors related to NCAB

In this study, we showed that significant differences in alarm behavior scores of nurses are due to factors such as age, nursing stint, professional title, department, hospital level, alarm knowledge level, and alarm attitude level.

4.2.1. Age

Nurses 46 years of age and older scored highest for alarm behavior, which may be explained by the eagerness for professional knowledge learning and rich experience with proper handling of alarm-related events. The low scores for alarm-related behavior in the 20–30 years age group were probably due to insufficient professional knowledge, inadequate equipment-related know-how, shorter working experiences, and less safety awareness of patients.

4.2.2. Nursing stint

The longer the working years of nurses, the higher the alarm behavior scores. Nurses-in-charge scored the highest for alarm behavior, likely related to their long working life, rich working experiences, and higher levels of self-confidence. Senior nurses scored high for alarm-related knowledge and attitude yet low for behavior. Senior nurses generally have abundant clinical experiences, meticulous handling of safety issues, and comprehensive, specialized knowledge and skills. However, with little practical experience in alarm management, the low scores for behavior may be due to weaker risk awareness, and a reduced ability to predict risks.

4.2.3. Department

ICU nurses scored highest for behavior, followed by anesthesia and surgical nurses; these findings are in agreement with a previous study in which nurses who worked in ICUs performed better in relation to clinical alarms than those working in other wards. As physiologic monitoring is most common in ICUs, alarm fatigue in the ICU setting has been well studied.[25] We hypothesize that there are better clinical alarm management initiatives in the ICU than in other departments.

4.2.4. Hospital level

Compared to second-level hospitals, the alarm behavior scores of nurses in the third-level hospitals were higher. The behavior scores of nurses at hospitals affiliated with colleges or universities were higher than for nurses at non-affiliated hospitals. This may be explained in part by the fact that critical patients at third-level hospitals are relatively complex and more patients may require monitoring equipment, thus providing these nurses with richer clinical alarm experiences.

4.2.5. Alarm attitude and alarm knowledge of nurses

Higher scores for alarm attitude or alarm knowledge were positively correlated with higher scores for alarm-related behavior. The theoretical model of knowledge, belief, and action[26] divide change in human behavior into three interrelated processes: acquiring knowledge, generating beliefs, and forming behaviors. Knowledge is the basis of change; faith indicates behavioral tendency, and the premise of changing behavior is to change beliefs and attitudes. To change behaviors, we must have knowledge and information as the basis and correct beliefs and positive attitudes as the driving forces. In this study, nurses with high alarm knowledge scores had high attitude and behavior scores, which corroborates the view of Lorenz,[8] who suggests reducing alarm fatigue through training and using personalized patient-related alarm restrictions.

For nurses who have received alarm-related education and training, the alarm knowledge and behavior scores were positively correlated, (On the other side, those who have not received the clinical alarmrelated education and training (control = yes) ($P < 0.001$) have a negative correlation with the clinical alarm behavior score). Additionally, nurses that were more willing to participate in alarm-related training had higher scores for alarm-related attitude and behavior. Education and training have been considered effective measures for improving nurses' alarm behavior: these factors may be mutually beneficial.[27]

4.2.6. Improvements of alarm management

There were statistical differences in alarm-related behavior scores depending upon the use of auxiliary technology such as central monitoring stations for

improving alarm management or formulation of alarm management-related systems or norms. Nurses who had used auxiliary technology to improve the management of alarms scored higher for alarm-related behaviors than those who had not used the technology. Similarly, nurses who worked at departments or hospitals with alarm management-related systems or norms scored higher than those who did not have such systems in place. Although critically ill patients are concentrated in ICUs at hospitals, there are still no authoritative medical equipment alarm management processes or parameter setting guides for ICUs.[28] In our study, if no improvement project for alarm management had been implemented over the last 3 years (control = yes) ($P < 0.001$) and no relevant system or norm of alarm management had been formulated (control = yes) ($P < 0.001$), there was a negative correlation with scores for alarm behavior. Quality control circle activities or quality management project improvements have recently been implemented in some hospitals here for improving alarm proficiency.[29] Optimal alarm management systems should be created through multi-channel collaborations at the levels of clinical staff, hospital administrators, and equipment manufacturers.[28] However, now, there is lack of national clinical management norms and guidelines in China. Clinical norms are usually based on departmental operating rules, such as checking alarms and requiring timely responses to alarms during shifts. Few hospitals use such mobile devices as wristband watches, pagers, or mobile bracelets to improve alarm notification.

4.2.7. Adverse events related to clinical alarms

There were no statistically significant differences in the scores for alarm behavior of nurses whether or not they had experienced adverse events related to clinical alarms in the past 2 years. Although 7% ($n = 165$) of nurses in this study experienced alarm-related adverse events, which was less than those in foreign studies (18%),[7] did not improve their scores for alarm-related behavior. One possible explanation is that clinical nurses do not consistently report adverse events related to medical equipment. Also, administrative departments may not pay enough attention to or draw useful lessons from these adverse events. Interestingly, in China, unlike other countries, there is no systematic alarm management or alarm adverse event warning training and no protocols for analysis or improvement of clinical alarm adverse events. For example, six hospitals in Ireland reported adverse events related to clinical alarms in 2018, and more than half of nurses (54%, $n = 88$) knew about adverse patient events related to clinical alarms.[21]

In the present study, there were no statistically significant differences in the scores for alarm behavior among nurses regardless of gender, educational background, marital status, administrative position, organizational attribute, or whether they have children. In our study, highly educated nurses scored higher for alarm-related knowledge and attitude, but lower for alarm behavior. However, some researchers have shown no differences in alarm-related knowledge among nurses with different educational backgrounds.[30] The lack of statistically significant differences in scores for alarm-related behavior for nurses with varying educational backgrounds may indicate a dearth of teaching content about clinical alarm management in nursing schools in China and warrants further exploration.

5. Conclusions

This study regarding alarm-related clinical behavior of nurses demonstrates that the best alarm behavior of nurses was alarm learning, followed by alarm response, alarm setting, alarm recognition, and alarm notification behavior. The major factors that influenced alarm-related behavior included age, professional title, departments, nursing stint, hospital level, alarm-related training, willingness to participate in alarm-related training, whether or not departments have improved alarm management over the last 3 years, and whether or not departments have formulated norms for alarm management. Nurses with higher scores for clinical alarms knowledge and attitude had higher scores for alarm-related behavior. The results from this suggest clinical alarm management and education are urgently needed. Additionally, specialized clinical policies and procedures for alarm behavior management according to the level of nurses' clinical behaviors and influencing factors should also be considered. New directions and strategies for patient safety management at modern hospitals should include recognition of the importance of alarms formulation of alarm-related systems and norms, and strengthening drills for medical staff.

Limitations

Although the sample size of Hunan province is relatively large, the study provided a representative inspiration for the current situation and influencing factors of clinical alarm behavior of nurses. However, it is still necessary to investigate in other provinces to make a more in-depth study on the nurse's clinical alarm-related behavior and its influencing factors.

Ethical approval

The relevant ethical principles were approved by the institutional Ethical Review Committee of Xiangya

Hospital of Central South University. The survey was anonymous, with no personal or identifiable data collected. A participant information sheet was provided.

Conflicts of interest

All contributing authors declare no conflicts of interest.

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