Cogn Tech Work (2004) 6: 239–246
DOI 10.1007/s10111-004-0162-2

ORIGINAL ARTICLE

Yuval Bitan · Joachim Meyer · David Shinar
Ehud Zmora

Nurses' reactions to alarms in a neonatal intensive care unit

Received: 19 July 2002 / Accepted: 13 April 2004 / Published online: 18 May 2004

Abstract Neonatal intensive care units (NICUs), like other intensive care units, are intended to provide immediate responses to any change in the patient's condition. Patient-monitoring alarms and alarms from other medical equipment are very common in these units, and most alarms have no clinical significance. This study addresses the question of how alarms affect nurses' actions by measuring the occurrence of alarms from different causes in a NICU, recording the nurses' reactions, and analyzing the relationship between the alarms and the actions. The results show that nurses often do not respond directly to alarms, but, rather, use them as additional sources of information in their ongoing flow of actions. The probabilities for their responding to an alarm depend on the causes of the alarm, its duration, and the characteristics of the patient. These findings support the view that experienced nurses dynamically adjust their activities according to the information they receive from alarm systems and other sources, and that they combine their reactive actions with the periodic performance of routine tasks.

Keywords Intensive care · Alarms · Scheduling strategic behavior

1 Introduction

The essence of an intensive care unit (ICU) is the continuous flow of information in real time about the status of the patient. This allows caregivers to react immediately to any change in the patient's condition. Information is provided through the monitoring of various biophysical variables. The monitors obtain information from sensors that measure biophysical signals and evaluate them. When a variable exceeds the range of predetermined normal values, auditory alarms go off, and visual indicators appear on the display monitor. Staff members are usually responsible for a small number of patients, between two and six at one time. They observe the patients' conditions and engage in a variety of tasks that are necessary to support the patient's recovery. Some of these actions must be performed periodically, while the need for others arises out of (often unpredictable) changes in the patient's condition. Alarm systems are intended to alert the nurses about such changes in the patients' conditions, allowing them to take immediate action when necessary.

Nurses in the ICU (like operators in control rooms) are commonly viewed as being engaged in a supervision task in which they should respond immediately to alarms that are generated from different systems. However, this view may be somewhat simplistic, and alarms may not simply be stimuli to which one necessarily responds. To gain a better understanding of the functions of alarms in a complex work environment, the current study evaluates the alarms in a neonatal intensive care unit (NICU) and their relation to the reactions of the nurses in the unit.

The critical character of the ICUs, where missed emergencies can easily cause severe harm to the patient, has lead to the adoption of lenient criteria for alarms. The manufacturers of electronic monitoring equipment tend to design their devices so that an alarm will be activated even when there is only a small probability of an emergency (Meredith and Edworthy 1995). Consequently, many studies observed high proportions of alarms that were unrelated to emergencies. O'Carroll (1986) found that only eight out of 1,455 alarms in an ICU indicated a real danger to the patient. Lawless (1994) observed in a pediatric ICU that 68% of all alarms were false alarms, and more than 94% of the alarms had no clinical significance. In another study in a

Y. Bitan · J. Meyer · D. Shinar · E. Zmora
Ben Gurion University of the Negev, Beer Sheva, Israel

J. Meyer (✉)
Department of Industrial Engineering and Management,
Ben Gurion University of the Negev, P.O. Box 653,
Beer Sheva, 84105, Israel
E-mail: joachim@bgumail.bgu.ac.il

pediatric ICU, 86% of the alarms were false alarms, and only 8% were genuine clinical alarms (Tsien and Fackler 1997). These studies support the conclusion that a large proportion of the alarms in the ICU are false alarms (i.e., alarms that were evoked even though the system is actually not malfunctioning). The differences between the studies are mainly due to the difficulties in determining whether an alarm indicates a situation of possible clinical significance, or whether it is a true "nuisance alarm". Nevertheless, all studies agree that only a small proportion of alarms indicate a situation that requires the staff members' immediate attention. Lawless (1994) used the term "crying wolf" for this phenomenon (see also Breznitz 1983) and noted that the frequent unwarranted alarms are likely to lead to a lower response rate by the medical staff.

Operators indeed tend to ignore alarms with high false alarm rates (e.g., Sorkin 1988). In laboratory tasks, people lower the probability of responding to alarms if the false alarm rates are high (Bliss et al. 1995), and if they do respond, they may respond more slowly (Getty et al. 1995). In a survey of Canadian anesthesiologists, 57% reported that they had deliberately deactivated auditory alarms as a reaction to too many false alarms (Kestin et al. 1988). Similarly, Seagull and Sanderson (1998) found that anesthesiologists responded to $<50\%$ of the alarms during most of the phases of surgery. This phenomenon is not limited to medical settings. For instance, Kragt and Bonten (1983) reported that operators in a chemical plant responded only to a small percentage of alarms.

The excess of signals from electronic equipment in ICUs may have additional negative effects. Morris and Montano (1996) found that auditory alarms have an advantage over visual alarms for quickly alerting about the patient's medical condition. However, ICUs are plagued by excessive noise that is generated by medical instruments, and especially by electronic monitors (Gerald and Grumet 1993; Meredith and Edworthy 1994). Sabar and Zmora (1997) concluded from observations in an NICU that auditory alarms were likely to be a burden on both nurses and babies. Alarms in ICUs can be unnecessarily loud and cause distress for the patient, who may have a lowered tolerance for noise (Momtahan et al. 1993). The problem of excessive alarms is further complicated by the fact that there are no accepted standards among manufacturers concerning the auditory alarms used in medical equipment (Meredith and Edworthy 1995). It is often difficult to determine which monitor generated the alarm sound, especially when there is more than one patient in the room, and this can cause the staff considerable anxiety (Kerr and Hayes 1983). Cropp et al. (1994) found that the medical staff recognized the source of an auditory alarm in $<50\%$ of the cases when using only auditory signals. This situation is more acute with less experienced nurses (Kerr and Hayes 1983). The large number of alarms in the ICU, in addition to the patients' complicated medical situations (Gaba and Lee 1990) and to the psychological pressure under which the medical staff work (Hay and Oken 1972), can lead to very high levels of workload in the ICU (Wiklund and Hoffman 1988).

The role of a nurse in an ICU is very similar to the role of operators in other complex systems. They must all observe the information that is provided by the system, and must decide whether the situation exceeds certain limits so that it becomes necessary to intervene. They also have to perform numerous routine tasks that they themselves initiate. For example, the nurses in the ICU have to measure different biophysical parameters of the patient every few hours. Thus, the nurses combine two forms of action: they respond to events, such as alarms, and they initiate actions, often according to some more or less pre-determined schedule. Each nurse can be considered as being, at any moment in time, at a specific point on a continuum, which has purely respondent behavior at its one end and purely self-initiated, scheduled behavior at its other end (Y. Bitan and J. Meyer, *Self-initiated and respondent actions in a simulated control task*, submitted, provides an in-depth discussion of this issue and some laboratory experiments; see also Meyer et al. 1999 for preliminary results). The nurses' position on this continuum depends to a large extent on the system's characteristics and, in particular, on the value of the information that the system provides. Nurses may come to rely entirely on highly dependable indicators and may cease to collect additional information or initiate actions. In contrast, nurses may ignore cues from less reliable indicators and initiate all actions themselves. In this respect, responses to alarms are essentially responses to a simple type of automation, and, as with other forms of automation, the user can use it too little, appropriately, or too much (Parasuraman and Riley 1997).

Respondent and pre-scheduled actions are not independent. For instance, when a nurse fails to perform a routine task, failures in the medical equipment or a deterioration of the patient's state may become more likely and they may cause events that require the nurses' intervention. Hence, the scheduled actions help to minimize the necessity of unscheduled actions (e.g., preventive maintenance lowers the chances of a breakdown). An excessive amount of information from alarms can possibly interfere with nurses' ability to schedule their tasks efficiently. If a nurse responds to each of the very frequent alarms she or he will not be able to perform the pre-scheduled actions. The fact that the medical staff in ICUs are able to provide patients with adequate treatment, despite the high frequency of alarms, raises the question of how the staff actually use the information from alarms in their work. The main goal of our study was to observe nurses in the NICU and to see to what extent their interventions are responses to the alarms or pre-scheduled actions. We recorded all alarms that occurred on an observed monitor, and registered the nurses' actions that concerned the monitored patient. The data should allow us to gain some insights into the nurses' responses to alarms within their general patterns of actions and to identify the strategy, or strategies, they employ when attending differentially to some alarms and ignoring others.

2 Method

The study was conducted in the NICU at the Soroka Medical Center in Beer Sheva, Israel. This medical center serves the population of the Negev, an arid area in the south of Israel. Due to the demographic characteristics of the region, the number of births in the hospital is high (about 12,000 annually for a population of 300,000).

The NICU is an ICU for pre-mature neonates or neonates with particular problems, which require intensive care treatment. There are approximately 350 admissions per year to the NICU, about half of which are very-low-birth-weight infants with birth weights of < 1,500 g (3.3 pounds). The survival rate of these infants is about 83%. The NICU can treat 22 patients at a time, and up to six patients are in the maximal intensive care area at the center of the unit, in which the most acute cases are treated. We focused our study mainly on this area. Two nurses work here, and each is independently responsible for no more than three patients.

Thirty-five registered nurses, most with paramedical academic degrees, work in the NICU. All nurses were trained for neonatal intensive care in special courses and orientation programs. The nurses varied in their experience in the NICU, ranging between 9 months for the least experienced nurse and 15 years for the most experienced nurse. More than half of the nurses in the unit are qualified to work in the maximal intensive care area. The nurses change their working positions in the NICU every shift and change their working shifts during the week, so most of the qualified nurses were on duty at least once during our observations.

We had 47 valid observation periods during the NICU working shifts—19 for the morning shift (7 a.m.–3 p.m.), 16 for the afternoon shift (3–11 p.m.), and 12 for the night shift (11 p.m.–7 a.m.). The total observation time was 30 h and 42 min and the average duration of each observation was 39 min and 11 s.

During an observation, we recorded all outputs from the neonate's monitor (Mennen Medical—Horizon 1000) on a research computer. The monitor receives data from a number of sensors that are attached to the neonate, which usually monitor the heart rate, the respiration rate, and the oxygen saturation. We did not collect data on infants for which more than the usual sensors were used (e.g., infants who also had blood pressure or temperature sensors attached).

The monitor shows the values of all parameters on a 15″ color screen, and it alerts to deviations from predefined limits with an alarm sound and a red visual indication on the screen. The three alarms that we recorded differ in the alarm tone frequency and the temporal pattern, and experienced nurses can distinguish between the different alarm sources. The recorded information consisted of the values of the three monitored parameters (heart rate, respiration rate, and oxygen saturation), at a resolution of half a second, as well as the time and duration of every alarm and the parameter that triggered it. When counting the number of alarms in an observation, we excluded instances in which the alarm went off while the nurse was treating the infant to which the alarm was attached. These alarms were generally generated when the nurse temporarily removed a sensor or otherwise changed the state of the infant, without the alarm having any clinical significance.

In addition, an observer stood in a corner of the room in a position that enabled her or him to see the nurses and the monitored neonate. A treatment was defined as the nurse approaching the patient and performing an action on the patient or the medical equipment attached to the patient. The observer pressed a button whenever the nurse treated the monitored neonate, causing the action to be recorded and combined with the data from the monitor. Although the observed treatments could not be directly related to alarms, marking the time stamp of the treatments on the same time line with the alarms provides us with the possibility to see the relations between the events. We could use this information to calculate the response time for the alarm, based on the assumption that the nurse heard the alarm and used this information to decide when to treat this patient next. We did not distinguish between actions that were part of the daily scheduled treatments and actions that were initiated in response to the alarms.

Even though each observation focused on a single station, all three stations in the particular area of the NICU were connected to the computer, and the monitored station was selected through a distribution box (after being randomly chosen at the beginning of the observation). Therefore, the nurses could not know for sure which station was recorded in a particular observation. Still, we cannot rule out the possibility that, in some observations, the nurse may have guessed which monitor was observed.

3 Results and discussion

The analysis of results consists of two main parts. First, we analyzed the frequency and duration of alarms and the causes for alarms. Then, we analyzed the nurses' reactions, compared these actions to the alarms, and estimated to what extent and in what way nurses respond to alarms.

3.1 Alarm occurrence

Table 1 presents the frequency and the duration of the observed alarms in the NICU. A monitor alerted, on average, 16.74 times per hour, and the average alarm

Table 1 Duration and frequency of the alarms in the NICU. The average duration and the percentage of alarm time per hour refer to the total number of alarms per hour. Longer alarms were alarms that lasted for more than 5 s

Shift	Average duration (s)	Total number of alarms per hour	Number of longer alarms per hour	Percentage of alarm time per hour	Number of valid observations
Morning	12	21.5	9.90	7.09	19
Afternoon	12	15.4	7.79	5	16
Night	31	10.9	5.30	9.33	12
Daily average	15	16.7	8.01	6.94	47

duration was 15 s. By combining the frequency and duration of the alarms, we computed the percentage of time during which a monitor gave off an alarm sound. A monitor in the NICU alerted on average 6.94% of the time. The percentage of time with alarms differed between shifts. During the morning shift, the monitor alerted, on average, 21.5 times per hour, and the average alarm duration was 12 s. During the afternoon shift, the monitor alerted, on average, 15.4 times per hour, and the average alarm duration was 12 s. During the night shift, the monitor alerted only 10.9 times per hour but the average alarm duration was 31 s.

The proportion of time, p_t, with at least one active alarm out of n alarms, each with a probability p of being active, is $p_t = 1-(1-p)^n$. Given that a nurse was responsible for three patients with monitors that are each activated 6.94% of the time, the nurse hears an alarm approximately 19% of the time from at least one station for which she was responsible, and 35% of the time from at least one of the six stations in the maximal intensive care part of the unit if all six stations are occupied. Clearly, alarms occur very frequently in the NICU, and if a nurse was to respond to each alarm, it would be almost impossible to perform any activity that requires more than a few seconds.

The main cause for the alarms was the oxygen saturation measure (similar results were found, for example, by Kestin et al. 1988; Lawless 1994; Sabar and Zmora 1997). The saturation sensor generated, on average, 13.25 alarms per hour, with an average duration of 17 s. The second cause for the alarms was the heart rate. It caused 3.18 alarms per hour with an average duration of 7 s. The respiration rate caused only 0.75 alarms per hour, and the average duration of the respiration alarms was 11 s (the total number of alarms was smaller than the sum of the number of individual alarms because two or more alarms could be activated at the same time). Many of the alarms were short. Specifically, 6.32 alarms per hour of the saturation alarms, 2.05 alarms per hour of the heart rate alarms, and 0.49 alarms per hour of the respiration alarms lasted <5 s.

3.2 Nurses' actions

The nurses treated the neonates, on average, 6.38 times per hour for 32 s each time. Treatments were more frequent during the morning shift—7.69 per hour, each with an average duration of 29 s. In the afternoon shift, there were 6.62 treatments, lasting, on average, 23 s each. During the night shift, only four treatments were performed per hour, each for an average duration of 61 s.

To determine the relation between the nurses' actions and the alarms, we computed the probabilities for a nurse treating a patient within a certain time period following an alarm. We consider a treatment within this time period as a possible indication for a response to an alarm (although the treatment, of course, could also be unrelated to the alarm). The results show that the probability that the nurses will respond to alarm is 0.053 within 15 s, 0.067 within 30 s, and 0.098 within 60 s from the alarm onset (these probabilities are cumulative over time).

However, nurses clearly do not simply ignore the alarms. To determine the potential effect of the alarms on the nurses' actions, we computed the overall probabilities for an action in a 15, 30, and 60-s time period and the probabilities that, within a 15, 30, or 60-s time period following an alarm, the nurse will take some action. If the two probabilities are equal, nurses ignore alarms. A higher probability for a treatment following an alarm is likely to indicate that nurses respond to the alarms. Table 2 shows the relevant probabilities.

In order to compute the significance of the differences in the nurses' responses to the alarms, we computed the risk ratios (RR) of the probabilities of a treatment following an alarm and the overall probability of a treatment in a time period (see Daniel 1999 for a description of RR and its uses). RR is 1 when the probability of treating a patient following an alarm is the same as the overall probability of treatment in a time period. Values of RR that are larger than 1 indicate an increased tendency to treat a patient following an alarm. The significance of the difference between RR values can be assessed through the confidence interval (CI) around RR. If the CI does not include 1, the RR is significantly >1, and one can reasonably assume that the two probabilities differ from each other. Figure 1 shows the log RR for the different types of warnings for all alarms and alarms that lasted more than 5 seconds (which were referred to here as longer alarms). The log RR was used in order to achieve symmetric values around the neutral value of $RR = 1$, which is $\log RR = 0$. The inspection of the upper panel of Fig. 1shows that almost all values of log RR are close to 0 and the CI for all except one alarm

Table 2 Probabilities of treatments in 15, 30, and 60-s time periods following alarms for the three possible causes of alarms and the general probabilities for treatments (i.e., the probabilities for treatments, irrespective if an alarm occurred) in these time periods. Presented below are probabilities of treatment following all alarms, and probabilities of treatment following longer alarms, defined as alarms lasting more than 5 s. Also presented are the overall probabilities for treatment in the different time periods

Type	Treatment within 15 s	Treatment within 30 s	Treatment within 60 s	Number of instances
All alarms				
Heart	0.033	0.076	0.078	102
Respiration	0.033	0.033	0.133	23
Saturation	0.055	0.063	0.104	398
Longer alarms (lasting more than 5 s)				
Heart	0.075	0.182	0.189	36
Respiration	0.2	0.2	0.4	8
Saturation	0.087	0.106	0.201	208
General				
	0.027	0.054	0.108	1,841

includes 0. Thus, there was no overall increase in the probability of treating a patient after an alarm when all alarms were considered. The lower panel of Fig. 1 shows log RR and the CI for alarms that lasted longer than 5 s. Here, the values of log RR were clearly larger than 0, and all except one CI did not include 0. Hence, the tendency to treat a patient was significantly increased if a 5-s or longer alarm had been given.

Overall, a treatment became about twice as likely after an alarm from oxygen saturation and heart rate than without an alarm. The probability for a treatment was even higher when the alarm was generated from respiration. Thus, it seems that nurses do not respond immediately when they hear an alarm, but they register the occurrence, evaluate the urgency of the problem that is indicated through the alarm, and eventually act on it within their ongoing flow of activity.

To analyze nurses' responses to alarms, we need to rule out the possibility that the relationship between alarms and actions is due to differences in the patients' clinical status. Clearly, some patients have more severe problems than others. These patients are likely to require more frequent treatments, and they are also likely to have more alarms that indicate more severe problems. Thus, a relationship between treatments and alarms could arise, even if nurses do not respond at all to the alarms. To assess the degree to which the relationship between alarms and treatments is due to the confounding variable of the patient's status, we computed, for each observed infant, the probability of a treatment in a minute, the probability of a treatment in a minute following any alarm, and the probability of a treatment following an alarm that lasted more than 5 s. The general probability for a treatment and the probability for a treatment following an alarm should be identical if nurses ignore the alarms. If they rely partly on alarms, the probability for a treatment following an alarm should be greater than the overall probability. Figure 2 presents these probabilities for all alarms and for alarms that lasted more than 5 s. The results show that, for infants that received infrequent treatments (i.e., had a low overall probability of treatments), the probability for a treatment following an alarm was close to the

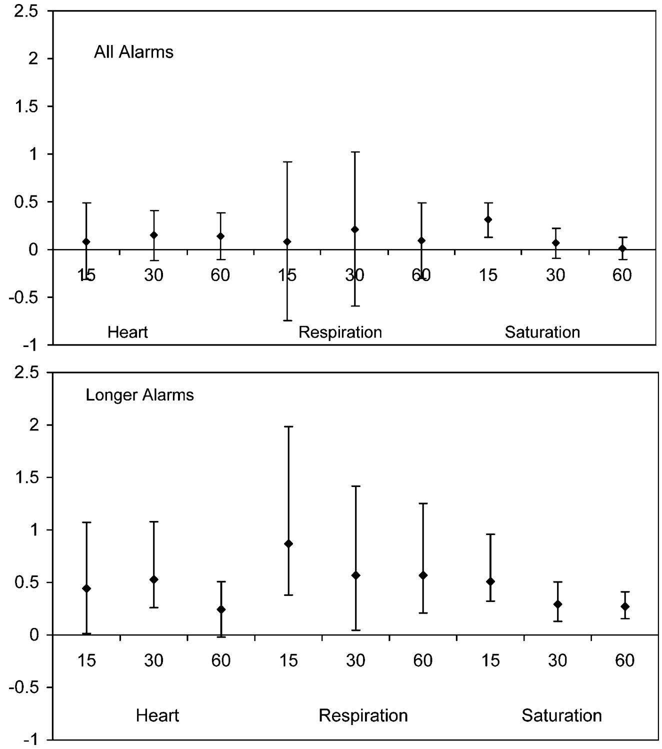

Fig. 1 Log RR between the probabilities for treating an infant following an alarm and the overall probability of treating an infant in a 15, 30, and 60-s time interval. The upper panel presents the RR for all alarms and the lower panel presents the RR for longer alarms, lasting more than 5 s. Also presented are 90% CI around the RR

overall probability of a treatment. One can, therefore, conclude that, for these patients, there is no relation between the alarms and the treatments. For patients who received more frequent treatments (i.e., had a higher overall probability of treatments), the probability for a treatment following an alarm lasting more than 5 s was clearly greater than the overall probability for a treatment. This finding seems to indicate that nurses rely to a greater degree on longer alarms when dealing with patients who require frequent treatments. For patients who require less frequent treatments, interventions are

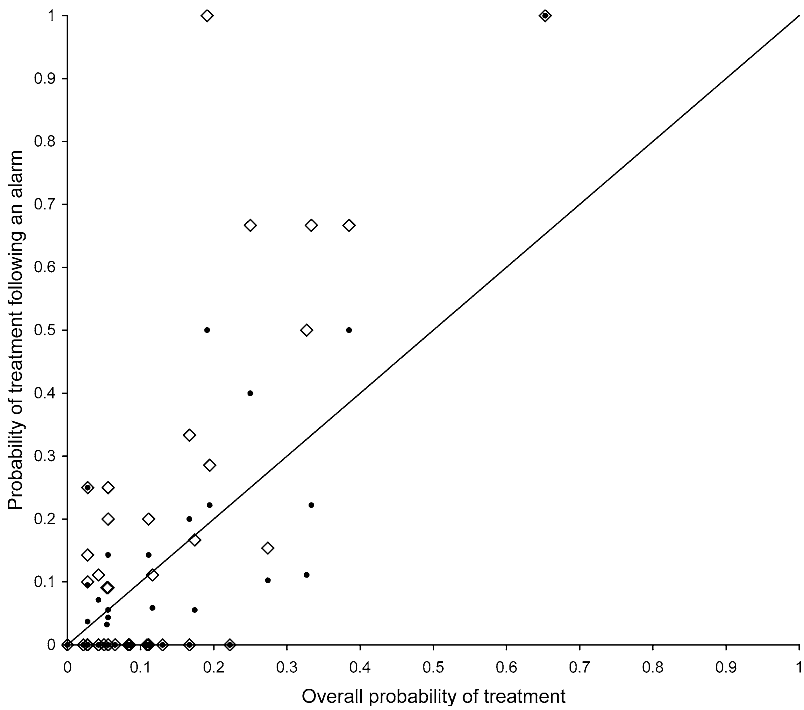

Fig. 2 Probability of a treatment during the minute following an alarm for all alarms (*dots*) and alarms that lasted more than 5 s (*diamonds*) as a function of the general probability of a treatment per minute for the different observations. The *diagonal line*indicates the case where the probability of treatment following an alarm is identical to the overall probability, i.e., nurses essentially ignore the alarms

generally unrelated to alarms. This pattern of results can be interpreted as evidence that, for patients whose conditions are more critical, the staff attends closer to the information about the patient and responds to it. Other patients, who require less frequent interventions, are monitored with lower intensity, and actions are unrelated to information from alarms.

4 Conclusions

The view that alarms are stimuli to which an operator should always, and immediately, respond is appropriate under three conditions: (1) the alarm is the only available source of credible information that is relevant for the operators' actions, (2) the operators' responses to the alarm have priority over any other activities in which she or he may be engaged at the moment, and (3) the operator has no other pre-scheduled task to perform with the system. These assumptions do not hold for operators of many complex systems. The nurses in NICU are one example. They have a wealth of information about patients and are engaged in a number of tasks that are critical for the patients and are not necessarily cued by alarms. The nurses' work is further complicated by the high frequency and low validity of the alarms. Our work cannot determine what percentage, if any, of the observed alarms were, indeed, due to changes in the patient's condition that required intervention. Judging from previous research, it is very likely that the vast majority of the alarms had no clinical significance.

In spite of the high frequency of alarms, nurses seem to attend to them to some extent. Overall, they consistently intervened more frequently when an alarm sounded than without one. Hence, alarms seem to provide valuable information for nurses, even though they are clearly not simply triggers that elicit actions. Alarms, apparently, serve as indicators for a patient's status, and are integrated with other available information. These findings support our suggestion that nurses do not react to alarms by performing a specific immediate action, but, rather, by adjusting the sequencing of activities.

Even though nurses consider the information from alarms, the alarms do not usually cause them to take immediate actions. The overall likelihood of a nurse responding to an alarm was very small, and, for more than 90% of alarms, the nurse did not attend to the infant during the minute following the alarm. When we analyzed only the longer alarms (that lasted for more than 5 s), we found a greater tendency of nurses to attend to the infant. This tendency differed for different types of alarms. Nurses were more likely to intervene after a relatively rare alarm (respiration) than after the frequent saturation alarm.

The finding that nurses responded mainly to longer alarms may indicate that nurses effectively ''filter out'' short alarms, while being aware of alarms and monitoring their duration. Otherwise, it would not have been possible for them to distinguish between short and long alarms. Alternatively, the nurse may set a threshold for responding to an alarm, based on information about the patient and the duration of the alarm.

Our findings point towards the need to reduce the total number of alarms that occur in working environments such as the NICU. A reduction could increase the value of each alarm sound, enabling nurses to rely more on the alarm system and lowering their workload.

Instructing the nurses to use the "suspend" function whenever they treat a patient will also reduce unnecessary alarm sounds in the NICU. The monitors' "suspend" function silences the monitors' alarm sound for 2 min, while the nurses performed the treatment. Nurses tended not to use this function very often.

A major target for improvements seems to be the oxygen saturation measurement that caused a large percentage of the alarms. The very short alarms also often do not provide valid information. It may be necessary to design more complex alerting algorithms that will not simply sound an alarm when a physiological value deviates from some preset limits, but, rather, will filter out short deviations and provide more valid alarms.

The results and some thoughts about the situation lead one to a few conclusions. It is important to realize that nurses process and respond to information from many sources, including information from the monitor displays, the monitor's alarm system, the medical records, or from other members of the medical staff. Ideally, an alarm system for such an environment should not only inform the nurse about the different threats, but it should also assist in determining the adequate sequence of activities for optimal task performance. This sequencing must be adjusted continuously, in light of changes in the monitored system. To achieve this goal, the number of alarms must be reduced so that nurses can actually respond to them. Information to which the nurses do not have to respond immediately should probably be provided through other methods and not as alarms.

The reduction of alarms should, however, be done with caution. Stanton et al. (2000) point out that the mere reduction of the frequency of alarms will not necessarily reduce workload and improve performance. If alarms serve as meaningful information sources, they may have value for operators, even if they do not directly elicit responses.

In summary, the large number of alarms in an ICU makes it impossible for nurses to simply respond to the alarms. Instead, the nurse uses the alarms as an additional source of information about the patient's condition. The understanding of nurse's reactions to alarms and the design of alarm systems for different types of actions must take the complex role of alarms as information sources into account. This understanding may help us develop systems that provide the nurses with the necessary information, while not creating an excessive burden of alarms that are unrelated to direct actions.

The current study combined quantitative measures from automated logging of monitor data and observational data on nurses' actions. This combination provides a different picture on the nurses' actions than a pure observational approach or the mere logging of data. However, there are also some possible shortcomings to this method. Since we relied only on very limited interactions with the nurses (so as not to interfere with their work), we cannot say what caused a nurse's reaction. We assumed a simple relation between alarms and actions—namely that the alarm indicated that the nurse should take some action with respect to some patient, and the nurse responds to the alarm by taking this action. In fact, alarms may have much more complex functions. It is quite possible that nurses learn to respond to alarm patterns that may actually differ between patients. Some patients may have unjustified alarms at a certain frequency and a decrease in the frequency of alarms could perhaps indicate a problem. For instance, infants who are attached to pulse oximetry alarms may trigger an alarm by moving the arm to which the sensor is attached. In this case, alarms can indicate healthy and desirable activity and a drop in the frequency of alarms may actually indicate a problem.

Our method provides a glimpse at the complex ways in which nurses use alarms and information from other sources. Nurses adjust their response strategies to the properties of the alarm and are, apparently, able to function efficiently even when the alarm system is rather problematic. Further research should aim to provide a better understanding of nurses' use of alarms in their work. Such an understanding may allow us, eventually, to predict the effects of changes in properties of the alarm system on nurses' reactions and to provide guidance for the design of better systems.

Acknowledgments This research was partly funded by a grant from the Israel Ministry of Health. We thank Mirit Shomer, Ayelet Yakubovish, Dror Ben-Yakar, and Idit Catz for their help in data collection in the NICU. Parts of this study were presented at the 44th Annual Meeting of Human Factors and Ergonomics Society, San Diego, CA, August 2000.

References

Bliss J, Gilson R, Deaton J (1995) Human probability matching behaviour in response to alarms of varying reliability. Ergonomics 38:2300–2312

Breznitz S (1983) Cry-wolf: the psychology of false alarms. Erlbaum, Hillsdale

Cropp AJ, Woods LA, Raney D, Bredle DL (1994) Name that tone—the proliferation of alarms in the intensive care unit. Chest 105:1217–1220

Daniel WW (1999) Biostatistics: a foundation for analysis in the health sciences. Wiley, New York

Gaba DM, Lee T (1990) Measuring the workload of the anesthesiologist. Anesth Analg 71:354–361

Gerald W, Grumet MD (1993) Sounding board. N Engl J Med 328:433–437

Getty DJ, Swets JA, Pickett RM, Gonthier D (1995) System operator response to warnings of danger: a laboratory investigation of the effects of the predictive value of a warning on human response time. J Exp Psychol Appl 1:19–33

Hay D, Oken D (1972) The psychological stresses of intensive care unit nursing. Psychosom Med 34:109–118

Kerr JH, Hayes B (1983) An "alarming" situation in the intensive therapy unit. Intensive Care Med 9:103–104

Kestin IG, Miller BR, Lockhart CH (1988) Auditory alarms during anesthesia monitoring. Anesthesiology 69(1):106–109

Kragt H, Bonten J (1983) Evaluation of a conventional process alarm system in a fertilizer plant. IEEE Trans Syst Man Cybern SMC-13:589–600

Lawless ST (1994) Crying wolf: false alarms in a pediatric intensive care unit. Crit Care Med 22:981–985

Meredith C, Edworthy J (1994) Sources of confusion in intensive therapy unit alarms. In: Stanton N (ed) Human factors in alarm design. Taylor and Francis, London, pp 207–219

Meredith C, Edworthy J (1995) Are there too many alarms in the intensive care unit? An overview of the problems. J Adv Nurs 21:15–20

Meyer J, Bitan Y, Shinar D, Zmora E (1999) Scheduling of actions and reliance on warnings in a simulated control task. In: Proceedings of the Human Factors and Ergonomics Society, 43rd annual meeting, Houston, Texas, September/October 1999. Human Factors and Ergonomics Society, Santa Monica, California, pp 251–255

Momtahan K, Hetu R, Tansley B (1993) Audibility and identification of auditory alarms in operating room and intensive care unit. Ergonomics 36:1159–1176

Morris RW, Montano SR (1996) Response times to visual and auditory alarms during anaesthesia. Anaesth Intensive Care 24:682–684

O'Carroll TM (1986) Survey of alarms in an intensive therapy unit. Anaesthesia 41:742–744

Parasuraman R, Riley V (1997) Humans and automation: use, misuse, disuse, abuse. Hum Factors 39:230–253

Sabar R, Zmora E (1997) Nurses' response to alarms from monitoring systems in NICU. Pediatr Res 41:1027

Seagull FJ, Sanderson PM (1998) Anesthesia alarms in surgical context. In: Proceedings of the Human Factors and Ergonomics Society, 42nd annual meeting, Chicago, Illinois, October 1998. Human Factors and Ergonomics Society, Santa Monica, pp 1048–1052

Sorkin RD (1988) Why are people turning off our alarms? J Acoust Soc Am 84:1107–1108

Stanton NA, Harrison DJ, Taylor- Burge KL, Porter LJ (2000) Sorting the wheat from the chaff: a study of the detection of alarms. Cogn Technol Work 2:134–141

Tsien CL, Fackler JC (1997) Poor prognosis for existing monitors in the intensive care unit. Crit Care Med 25:614–619

Wiklund ME, Hoffman LR (1988) When electronic devices outnumber flower bouquets in the hospital room. In: Proceedings of the Human Factors Society, 32nd annual meeting, Anaheim, California, October 1988. Human Factors and Ergonomics Society, Santa Monica, pp 430–434