Auditory design for the Intensive Care Unit (ICU): Guidelines and considerations

Author 125

Track10: The machine that goes "Ping"

ABSTRACT

This paper discusses the current state of auditory elements in the ICU and their effect in patients and medical staff. It presents a set of guidelines and observations that aim for a better alarm implementation and outcome based on user research with generic alarm sounds. Through metaphors, codification and categorization alarms can indicate urgency level and action required from the staff. The redesign of those auditory icons can also help the wellbeing of patients during their stay in the ICU.

Keywords

Alarm fatigue, auditory display, patient safety.

INTRODUCTION

The growing amount of medical devices in the ICU results in a stressful environment where alarm systems fill the auditory environment, making it difficult for clinical staff to react accordingly and endangering the patient's well-being. This effect is called alarm fatigue (Sendelbach, S, Marjorie, 2013).

Current solutions include front end actions like staff training and sound management (NACNS AFTF, 2014). A shift is needed where alarm environment is designed by filtering and categorizing auditory elements, remarking the ones that need immediate attention and provide information about how to respond properly. A set of guidelines are needed to include patient's perception, staff capability and device parameters.

The Intensive Care Unit Context

Intensive care units require a constant tracking on the patient development. Visual and auditory displays are used to notify about health-related irregularities as well as device malfunction or even normal state of the same device. This translates in alarms going off constantly even when they're not needed, creating a stressful environment for both patients and staff (Sendelbach, S, Marjorie, 2013).

According to the Joint Commission's Sentinel Database, between 85% and 99% percent of alarms in the medical environment do not need clinical intervention; they are a result of wrong sensor placement, tight measure parameters and other human errors. In long exposure, all of these outgoing signals desensitize the staff becoming a threat to patients.

In addition, patients and their families might suffer detrimental effects during and after their time in the ICU including sensory overload, sleep disorder and general delirium. Although medication and lightning are factors to consider (Goodman, 2015), sound affects both staff and patients equally and should be redesigned accordingly.

Auditory signals are the best method to attract attention in case of emergency (Borowski, M, 2011) since they give spatial references and are a natural call for action. A set of parameters should be implemented in early design stages to maintain the effectiveness of the alarm system when several devices act in a same space. If every event is tagged as an emergency then none of them will be perceived as one.

Considerations

The guidelines presented in this paper are proposed according to the following observations, scenarios and hypothesis:

A silent ICU – Future Devices

Eliminating auditory feedback from the medical devices as a way to reduce alarm fatigue is not the best solution to mitigate alarm fatigue since an active sound environment gives the patient the comfort of knowing that devices are working properly, even if there is a lack of meaning of that auditory display.

General sound discomfort and sleep deprivation is not always related to medical devices. Some of the sound disruptions, above 40 dB (A), are related to human actions like items falling on the floor, people talking, doors opening or equipment movement. The World Health Organization recommends a background sound level below 30 dB (A) and nocturnal peaks below 40 dB (A).

Devices also have an intrinsic auditory outcome result from their function, like ventilators, pumps, pneumatic drills and many others (Pugh, 2007). The sounds emitted from these devices are between 25 dB (A) to 80 dB (A). As technology evolves, like in any other device, sonorous outcomes might decrease as a direct effect of operational efficiency. Sound decrease should be an objective of device development as a way to improve the ICU.

Excessive monitoring

The need of patient development tracking in the ICU might become a major issue when no limits are established regarding what should be tracked or considered as an emergency. Since it is perceived as a non-invasive procedure, auditory feedback is used for many activities and several devices include this feature, even if there is no need for it (de Gruyter, 2011). Therefore a sound emission protocol based on clinical evidence is pertinent.

ICU as an environment

The present approach does not focus on a specific device, alarm or event. It aims for a holistic system where the ICU is perceived more pleasant in general to promote the patients and staff wellbeing (Andringa, 2013). The room would then represent the patient's state: the healthier the patient, the more comfortable the environment would be, adding an emotional level to the interaction.

Alarm management and control devices

Currently there are medical devices that gather information from different medical tracking machines to show a filtered analysis of patient development where medical staff can take better decisions. (Howe, 2013). These devices use visual interfaces to track progress over time and can be useful to anticipate incoming emergencies, but sound emission is based on those visuals and there is no differentiation between alarms.

AUDITORY DIFFERENTATION

To distinguish auditory emissions there are different elements that must be considered. This section explains the main factors that were examined for controlled experiment:

Pitch, Volume & speed

Urgency perception in alarms is related to factors such as intensity, volume and pitch (Haas, 1996). Higher levels on these parameters equal higher urgency perceived. Based on this fundamental observation, many devices emit auditory feedback with similar characteristics that translate in unpleasant environments and alarm fatigue in the long run.

Abstraction levels

Level of urgency should not be based only on volume and pitch since the message could be misunderstood without having a reference. Speech warnings are not useful either since they exclude population segments and needs more semantic understanding. Metaphors might be a good way to carry complex messages when limits are considered since they can convey different messages depending on the culture.

Auditory icons and metaphors (representations of sound in the nature or similar) should be relatable to a majority of people and the message should be clearly understood. The sound of roosters or crickets could mean something in the occidental culture but might be different for oriental ones. Although there is a learning curve to understand the relation between sound and meaning, device development should aim for an intuitive reaction from the users.

The use of harmonics, delayed tunes and amplitude waves can also have a relation with urgency (Edworthy, 1991) but having different harmonic configurations (different devices) might be perceived as unpleasant.

SOUND CATEGORIZATION

As a first level of filtering, auditory elements must be mapped accordingly to their urgency level. The proposed division is shown below:

Recurring message – Below 20 dB (A)

Auditory indicator of device status. Constant feedback of a specific activity. (Eg. Heart monitors, intravenous fluid, nebulizer).

This type of auditory feedback is expected to be constant in the ICU, therefore should be perceived as pleasant. It gives an immediate message to the patient that a device is working.

Announcement – Below 50 dB (A)

Non-threatening event or irregular development. Action might be required in a non urgent way. (Eg. Intravenous liquid running out, treatment cycle ending).

Although an action might be needed from the staff, the appearance rates of these events imply that the sound should be more pleasant than the ones listed below (Low and High Urgency levels).

Low level Urgency – Below 80 dB (A)

Request for action. Potential threatening event if an action (from staff) is not executed. (Eg. Device battery running out, sensor misplacement, human-error events).

The important thing to remind in this level is that not every event should be considered as an immediate emergency, and that most of the urgency events can be avoided if the correct follow track is applied. Many of the alarms related to human errors might adjust in this category, (eg. Misplacement of a pulse sensor). Medical device design should consider a feature that gives the product the possibility to distinguish when a sensor is misplaced and when the patient is in danger.

Emergency – Above 80 dB (A)

Life threatening event.

An immediate action is needed from the staff. Alarms should be an indication of immediate action, therefore an uncomfortable sound might be a good approach since it is an uncommon event. (Eg. Cardiac arrest, pulmonary malfunction).

PRACTICAL EXPLORATION

To better understand the perception of different sound waves and their effectiveness as an alarm in different scenarios a small intervention was designed where users could map different alarms and sounds depending on their qualities. The objective of this experiment was to define the criteria needed for further categorization.

Experimentation

Five different sounds were selected based on four factors: Pitch, volume, source and complexity (intensity, speed, harmony, etc). Five persons were asked to categorize each sound depending on their discomfort level, urgency perceived and source. People were asked on how easy it is to identify from other alarms and then tested. An open section was provided for the users to explain personal opinions.

A common digital (clock) alarm was used as a control measure for discomfort, urgency perceived and message understanding. This sound was selected because of the common understanding between users about its meaning and urgency level.

In the first part of the experiment people were exposed to each individual alarm separately. People described their impression on each of them and rate their qualities (urgency, discomfort) in a scale of one to five.

For the second part of the experiment the ten alarms were active at the same time and users were asked to choose the most recognizable ones. Results differ for people that heard a gradual addition of alarms than the ones that heard all the alarms going off at the same time.

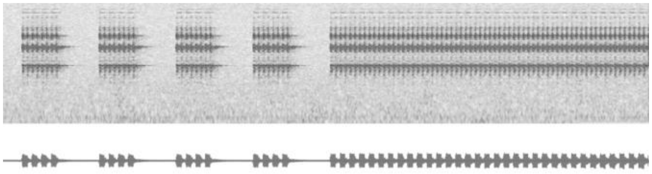

Figure 1. Common high-pitched digital alarm graph. (Control experiment).

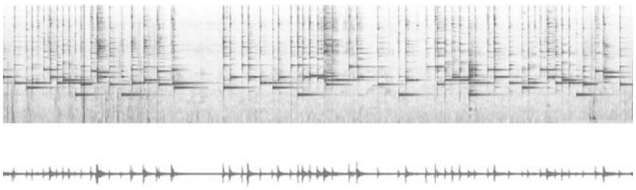

Figure 2. Complex (Low and high pitch) tune graph.

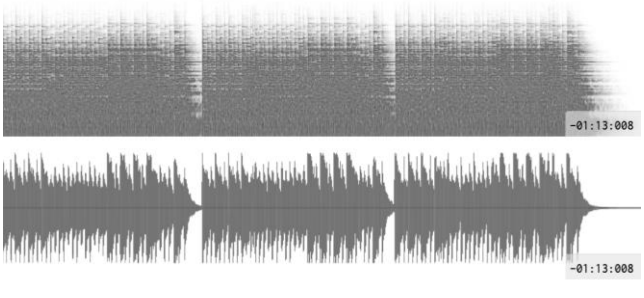

Figure 3. High volume, low key tune.

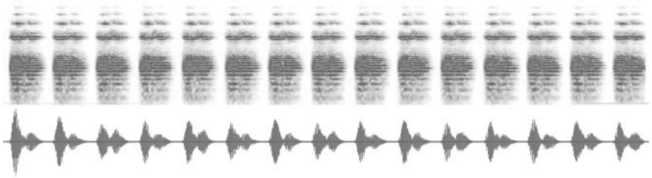

Figure 4. Detrimental digital sound wave.

Results

The perception of high pitch tunes, even in low volume, is perceived as irritating (Figure 1). This was the same outcome for digital or mechanical sounds compared to natural sounds (water, musical instruments or voice). On the other hand, the more unpleasant the sound, the more urgency perceived.

Complex tunes (Figure 2) are more identifiable than simple key tunes. The test also showed that participants could keep track of that complex tune when listening to it individually and then gradually adding background noise.

The speed of the auditory feedback is intrinsically related to urgency with either low or high pitch sounds. Low key tunes (Figure 3) were described as more pleasant than high pitched ones while still being perceived as urgent, but other adjectives were expressed by users and should be taken into consideration (eg. Fear emotions).

When exposed to different auditory sources most of the people would identify simple sounds faster than complex or detrimental ones (Figure 4). High pitch was also a factor that helped users identify each alarm.

GUIDELINE MODEL

Based on the results obtained a visualization was generated as a tool to aid the development phases of medical devices, specifically the ones related to alarm management (Figure 4).

Urgency levels are inversely proportional to the general pleasant environment. Therefore auditory surroundings should remain in a calm state for the majority of time.

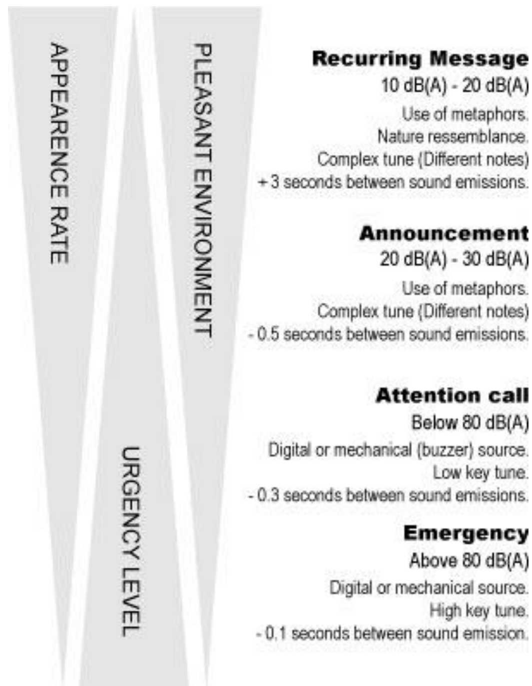

Figure 4. The guidelines produce a comfortable environment when the patient's health is improving and would call to immediate action when needed.

CONCLUSIONS

Volume of the auditory environment in the ICU often exceeds the recommended levels for wellbeing and might have severe effects in patients and medical staff. Medical devices are part of a bigger system as they are placed in the ICU, therefore they must be designed as a component and not as a stand-alone device.

Auditory parameters must be established for all manufacturers to develop products that can work as an individual device as well as a part of a bigger environment.

Unpleasant sounds should still be part of the ICU as long as they are established in moderation based on the appearance rate of each event.

DISCUSSION

The visualization shows the gradual difference between resting state and emergencies. Considering the ICU as a closed environment and that every auditory makes a difference in it, the presented model aims for a better coexistence in that precise context. Different medical surroundings would require different considerations since urgency levels change depending on the patient state and in the action needed.

These guidelines are the outcome of human-centered design approach where the experiences of the users are the main source of information and both patients and doctors are taken into consideration. The main purpose of these guidelines is to establish certain parameters in the medical equipment design phase.

Further improvement

Elements in the top and bottom categories of the spectrum might be the easier ones to place, but for the one in-between further categorization is needed. Based on clinical evidence, gradual steps should be designed. This first approach defines the general qualities of the auditory outcome. To know the category of specific events a special commission is needed. Professionals with different backgrounds should participate in an alarm regulation to take into account the type of event (medical), psychological impact in both staff and patients.

Notes

Certain parameters should be taken into consideration since auditory capability is not the same depending on the age. Hearing impediments might be better handled with visual indicators and should not be removed.

Participants on this study represent a population segment that might be only part of the medical staff in the ICU (people between 25 and 30 years old). Semantics might differ between younger and older people, and should be taken into consideration for further analysis.

The results are an average of the answers given by the participants. The next step would be to establish different sound icons in the same category and observe the reaction on each of them to determine the specific characteristics that an alarm should have (eg. the low key note of the alarm).

Volume is an important factor when tracking a sound in a noisy environment. The aim of the study was not to determine which melodic sound was more recognizable than other but to establish parameters for the sound usage (eg. It is better to use low key alarms at high volume than high pitch tunes at the same volume).

Although auditory feedback gives a spatial reference (location of the source), alarm management should be part of the environmental design. Hearing a high pitch from a distance might reduce the urgency perceived. It would be better to have a monitoring station where all of the alarms are generated.

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