Multimodal Technologies and Interaction

Review

Sleeping Soundlessly in the Intensive Care Unit

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Abstract: An estimated 70% of patients who have been in the Intensive Care Unit (ICU) experience some form of Post-Intensive Care Syndrome (PICS). As a stressful environment, the ICU can be traumatic for any patient; however, the disruption of sleep experienced by patients in ICU negatively impacts their mental status and recovery. One of the most significant contributors to sleep disruption is the constant blare of monitor alarms, many of which are false or redundant. Through multisensory approaches and procedural redesign, the hostile acoustic environment of the ICU that causes so many to suffer from PICS may be alleviated. In this paper, we present suggestions for improving the ICU acoustic environment to possibly reduce the incidence of post-ICU complications such as PICS.

Keywords: post-intensive care syndrome; post-traumatic stress disorder; multisensory alarm; multimodal design; proactive care; intensive care unit

1. Introduction

Patients in the Intensive Care Unit (ICU) require a high level of attention and treatment in order to help get them back to baseline. For many, they leave the ICU cured of the ailment that brought them in, yet may also leave with a new health complication. Post-intensive care syndrome (PICS) is estimated to occur in as many as 70% of patients who have been in the ICU [1]. The ICU ensures life-saving measures, but may also complicate a patient's full recovery. Sleep deprivation, pain, anxiety, and isolation are the inevitable result of the monitoring of patients in critical conditions. When these stressors continue for long periods, patients and their families are at risk of developing physical, cognitive, and psychiatric effects that endure beyond the ICU experience. In family members, the syndrome is referred to as PICS-family (PICS-F) and manifests similarly.

For the review presented in this article, we performed a two-part systematic review of the literature, published between January 1999 and November 2019, using references in English from PubMed and Google Scholar. In the first phase, we focused on PICS and used two broad search categories: post-intensive care syndrome (PICS) and sleep deprivation. In the second phase, we focused on alarm fatigue and redesign and used two broad search categories: alarm fatigue and multimodal design. Keyword search, used singly and in combination, was used. We then assessed all identified abstracts and retrieved the full paper for those that met the inclusion criteria. Furthermore, the references of all retrieved papers were checked for additional studies and citations. By combining these two research fields in the paper presented here, we suggest a change in the medical alarm paradigm to foster a more therapeutic ICU.

2. Post-Intensive Care Syndrome and the Intensive Care Unit

2.1. What is Post Intensive Care Syndrome?

The cognitive effects of a traumatic ICU stay are very similar to post-traumatic stress disorder (PTSD) and include anxiety, depression, decline in executive function, decreased attention, and decreased memory recall [2]. Those who go into a state of delirium while in the ICU are particularly vulnerable to developing cognitive symptoms. The main difference between PTSD and PICS is the presence of symptoms after a stay in the ICU [2]. While there is a significant overlap between the two conditions, the physical disability (neuromuscular weakness) seen in PICS is unique to that condition [3]. One year after their stay in the ICU, people experienced impairments in all three domains of the World Health Organization's International Classification of Functioning, Disability, and Health framework. These impairments included decreased pulmonary function, reduced strength of respiratory and limb muscles, reduced 6-minute walk test distance, reduced ability to perform activities of daily living and instrumental activities of daily living, and reduced ability to return to driving and paid employment [4].

One of the most common causes of PICS is the constant interruption of sleep that occurs in an ICU setting. Sleep quality is a strong indicator of overall well-being, which has led to many claiming it is "the new vital sign [5,6]". Monitors are constantly beeping, people are talking, pain is not perfectly controlled, and tests need to be run at all hours of the day and night [7,8]. Specifically, vital signs must be taken frequently, and vital sign alarms are triggered often and without actionable effect [9,10]. Without sleep, patients lose the cognition and emotional regulation needed to properly process their experience. Lack of sleep also prevents physical recovery and prolongs ICU stay. Furthermore, frequent sleep disturbances are associated with abnormal melatonin secretion, which can trigger delirium, specifically in the elderly population [11–13]. With its psychological and physical effects, sleep disturbance can simultaneously cause and increase the risk of developing PICS.

2.2. Long-Term Consequences of PICS

Many long-term consequences result after an ICU stay. Sleep abnormalities such as sleep disruption or lack of sleep, are common during and after ICU stays [14]. Many also suffer from higher mortality rates and delusional memories [15]. Hatch et al. (2018) found that those with depression were almost 50% more likely to die within the first year after their ICU stay [16]. This is after adjusting for illness severity, age, sex, and the presence of other mental health diagnoses. There is little research on the long-term consequences of PICS beyond mortality, so PTSD, with its similar manifestations, can be used as a proxy measure for the other long-term consequences of developing a stress disorder. Gradus, J. (2017) reviewed studies looking at patient outcomes in PTSD, and found that substance misuse and dependence were nearly two times more likely in patients with PTSD than those without a stress disorder [17].

It is also important to note that treatment for PICS is limited and under-researched. Currently, treatment consists of ICU Diaries [18], the ICU Recovery Manual [19], and clinical counseling [20]. Despite these showing some benefit, they are reactive, instead of proactive care. If the design of the ICU environment can be more thoughtful and comforting to patients, then these debilitating symptoms may be prevented.

2.3. Risk Factors for Developing PICS

There are several risk factors for developing PICS. Patients with a pre-existing psychopathological condition are at high risk [16,21], but there are many more factors that can contribute. For instance, psychological distress in the ICU (anger, nervousness, acute stress, or depression) has been continuously associated with the development of PICS. Delusional memories and delirium, in particular, have been linked to PICS symptoms one year after an ICU stay [21]. Delirium is an acute distortion of reality where patients are unable to tell the difference between what is real and the terrifying hallucinations and beliefs about what is happening to them [22]. The most common cause of delirium is the use of benzodiazepine and/or opioid medications [23], both commonly used in the ICU setting. In addition to pharmaceuticals, sleep deprivation is a likely contributor to delirium [24].

Sleep deprivation precipitates anxiety [25], thereby causing the psychological distress that is a known risk factor for the development of PICS [26]. There is a myriad of ways that both sleep and circadian rhythm are disrupted during an ICU stay [27]. Examples include noise, lighting, patient care, diagnostic procedures, sedatives, the stress of being near death, organ dysfunction, pain, inflammatory response causing brain inflammation, and delirium. The noise from monitors is particularly concerning because it not only disrupts sleep but also causes the patient to fear their condition is declining [28,29]. This fear can then be amplified if no one responds or if healthcare providers are slow to respond. This slow response on the part of the healthcare provider is dubbed 'alarm fatigue', and it is a well-documented issue in intensive care settings that negatively impacts provider response to alarms [30,31].

3. Patient Perspective of the ICU Environment

"Unnecessary noise is the most cruel absence of care that can be inflicted on the sick or the well."—Florence Nightingale, Notes on Nursing: What It Is, and What It Is Not [32].

There are several stressors in the ICU environment that we cannot change. Lifesaving treatments and tests are what has improved the survival of patients in the ICU over the last 30 years [33]. Two things we can change, however, are sound levels and the fear induced by poor healthcare provider response to alarms. Sound levels in the ICU are consistently higher than the World Health Organization (WHO) recommended 30 dB, instead hovering between 50 and 65 dB [34]. In fact, sound coming from monitors and alarms was perceived by patients as one of the most stressful sounds in the ICU [35]. Monitor alarms go off an average of six times per hour, and one patient reported the following experience:

"I feel trapped, surrounded by uncomfortable noise. Just behind my head I hear the continuous sound from my ventilator. Sometimes the alarm starts ringing and then I wake up rapidly, scared to death that the machine is about to stop. I know that I can't breathe on my own so if the ventilator stops, I will die. There are also other alarms that come and go and since I am not sure what they mean, it is disturbing, not knowing where they come from. Maybe, the signal is an indication of danger [36]."

Similar sentiments are echoed in ICU diaries and patient reflections. While monitoring and testing are crucial tasks in the ICU, changes to the acoustic environment can be made to alleviate unnecessary disruptions. Below we discuss these suggested changes.

4. Alarming Solutions

Based on risk factors for PICS, and given that sound from alarms is a key contributor, we suggest that a reduction of sound exposure would help improve the ICU environment. It would not only benefit the patient, but also the healthcare provider. Some novel alarm devices have been developed and tested to show a benefit for user performance, yet no change has been made to clinical practice to reflect this updated technology. In addition to novel alarm systems, simple measures can be taken to reduce patient exposure to bothersome alarms. For reasons listed below, we urge further development and implementation of a change in the acoustic environment of the ICU to create a more comforting and informative experience for both patient and provider.

4.1. Improve Alarm Accuracy

Bonafide et al. found 87% of pediatric ICU and 99% of ward clinical alarms were nonactionable or false, meaning that they incorrectly identified physiologic status or did not warrant clinical intervention. Furthermore, the response time of nurses increased as nonactionable alarm exposure increased [37]. These false alarms may be due to inaccurate presets for certain patients or motion artifacts, but undoubtedly contribute to distraction and miscommunication in the clinical environment—both interfering with patient care [38]. One of the most deleterious effects of these false alarms is the development of alarm fatigue in healthcare providers. Alarm fatigue, mentioned earlier, is the desensitization to alarms based on high quantity, low information, and commonly erroneous alarms. Since false alarms contribute so highly to alarm fatigue, there have been many attempts through multimodal design to decrease the incidence of its development.

For example, several groups have used multimodal rhythmicity estimation to decrease the number of false alarms for arrhythmia [39,40]. One group used machine learning and resulted in a true positive rate of 95% and a true negative rate of 78% [41]. Since cardiac health is a critical issue in ICU patient care, the accuracy of these arrhythmia alarms must be high enough to limit alarm mistrust and fatigue as much as possible. Similar attempts to increase the accuracy of alarms should be taken by both clinical teams and manufacturers of monitors. For example, monitor thresholds could be more accurately calibrated to a patient's baseline levels by the clinical team. Furthermore, future monitor developers could integrate an adaptive technology and machine learning method directly into their monitors that adjust the thresholds for each patient based on their day to day data. In order to improve the accuracy of monitoring, individualized data should be integrated into alarm thresholds and detection.

4.2. Reduce Patient Exposure to Alarms

In addition to the high percentage of false alarms, there is still a high number of total alarms saturating the clinical environment. Many of these alarms may be accurate, but redundant, meaning that alarms communicate the same alert in multiple forms. In theory, this prevents a missed alarm, but in practice, this results in alarm fatigue and patient interruption. Therefore, redundant alarms have contributed to alarm fatigue without improving patient safety. Seeing the need to eliminate this interference, a team working in the pediatric ICU specifically decreased redundant alarms from a baseline of 6.4% of all alarms to 1.8% using the Model for Improvement, with no adverse patient effects. Additionally, the overall alarm rate decreased from 137 alarms/patient day to 118 alarms/patient day during the intervention period [42]. By minimizing the redundant alarms, each alert to the healthcare worker has a greater salience. As an additional result, patients have fewer interruptions in their sleep and may feel their caretakers are more in tune with the monitoring systems. Both effects may relieve some anxiety and decrease the risk of PICS.

Since the interruptive sound environment persists throughout the day—a combination of monitors, staff conversations, and other ICU tasks—the most efficient intervention would be one that prevents noise from reaching the patient. The simplest solution is to set aside a time strictly for rest without tests or alarms audible to the patient. Protocols such as "Naptime," have attempted to achieve this rest period, but were not able to completely minimize interruptions for the desired time period [7]. Without substantially altering the clinical staff's responsibilities, non-pharmaceutical sleep-promoting interventions such as earplugs and eye masks were found to have some benefit on sleep and prevention of delirium [43]. Another study by Gallacher et al. found that noise-canceling headphones reduced sound exposure by a mean 6.8 dB for a patient [44]. This reduction does not necessarily decrease the sound environment down to the WHO accepted 30 dB, but it is nonetheless an improvement.

Taking the concept of earplugs a step forward, a group at Vanderbilt University created the novel device, SLAAP: Silencing Loud Alarms to Attenuate PTSD. SLAAP is a frequency-selective silencing device that filters out alarm sounds from the patient's perception while allowing all other sounds to the patient. Since alarms are only necessary for the healthcare providers, the patient's sleep is left undisturbed and their anxiety caused by constant alarms decreased [45]. By decreasing sleep disruptions and the overall anxiety of patients, the incidence of PICS can also be decreased.

A possible prophylactic addition may be the use of positive sounds such as soothing music or familial conversation to improve the comfort and ease in the ICU environment. ICU Diaries [18] and collaborative songwriting [2] have both been shown to be beneficial for reducing post-traumatic symptoms in the ICU and with other vulnerable populations such as veterans and prisoners. Similarly, the use of patient-controlled music reduced the anxiety felt by patients who received acute ventilatory support [46]. Additionally, since PICS-F is commonly developed in conjunction with patient PICS, family support and conversation may aid in bringing a positive ambiance into the environment and help both patients and family members [47–49]. Any addition of outside influence and normality may help the patient in their recovery and decrease the risk of developing PICS. It is important to decrease the negative stimuli present in the ICU; however, simple additions such as music are easy ways to uplift the ambiance of the patient's stay and minimize trauma.

4.3. Increase Information Communicated by Alarms

The reduction of false alarms and negative patient exposure is one step to reducing PICS, but alarms that communicate more to the healthcare provider may improve the sound environment of the ICU. By communicating more through each alarm, there is a reduction in the needed alarms, and possibly a decline in the development in alarm fatigue. The increase in alarm information can be achieved by restructuring the alarm sound and stimulus modality.

Currently, most alarms use a flat amplitude envelope, with a rapid onset and rapid offset. In contrast, most natural sounds have percussive amplitude envelopes, which have a rapid onset and then a gradual decay. By using a more natural sound for alarms, Sreetharan et al. found percussive amplitude envelopes to have decreased perceived annoyance and increased accuracy in a memory recall task [50,51]. Furthermore, using the standard auditory alarm, Schlesinger et al. found that sub-threshold alarms, alarm intensities (volume) lower than currently used, had similar accuracy to alarms at thresholds intensities [52]. By using a natural sound and lower alarm intensity in alarms, the acoustic burden experienced by healthcare providers may be relieved.

Multisensory alarms may be an additional way to increase the information available for users that is given without overpowering the sensory stream. Additionally, multisensory alarms communicate important information without decreasing demanding task performance [53] as well as increase cognitive processing speed and attentional capacity [54].

Specific to the challenge of proper sleep, a team has developed the Haptic Audio Visual Sleep Alarm System (HAVAS) to determine the most appropriate time to wake someone based on sleep cycles [55]. As previously discussed, sleep quality is an important factor in patient recovery, so an alarm system such as HAVAS, in sync with the body's rhythm, could help improve sleep–wake cycles and therefore improve patient outcomes.

The integration of multisensory alarms in the ICU may also benefit the healthcare provider by communicating more information per alarm. Auditory icons, sounds that mimic the indication they assess such as a "lub-dub" sound for heart rate monitoring, show improved performance compared to conventional auditory alarms [56]. Furthermore, auditory icons combined with a tactile stimulus to create a multisensory alarm resulted in higher accuracy of alarm change identification [57]. Furthermore, the addition of a secondary sensory stream may decrease the informational burden on a single sensory stream by allowing a salient alarm to be delivered at a lower intensity. A second group found a personal and wearable visual–tactile alarm to lower response time, improve ratings on suitability and feasibility, and lower annoyance level when compared to acoustic alarms [58]. Tactile stimuli have an advantage over visual stimuli, specifically in healthcare environments where visual attention may be necessary such as the operating room or other procedures.

5. Conclusions

The effects of PICS interfere with recovery and quality of life, even after the initial ailment has been resolved. PICS and PICS-F affect a large proportion of patients and families who require medical attention in the ICU, with sleep disruption being one of the strongest contributors to its development. While there are some treatments available for treating PICS, there is more that can be done prophylactically within the acoustic environment of the ICU to minimize the deleterious effects on patient sleep and overall anxiety. The first step is to improve the accuracy of alarms to reflect legitimate health declines and actionable changes. Second, patient exposure to upsetting alarms may be limited through headphones that block all sound while sleeping, or only filter out alarm frequencies. Finally, steps can be taken to re-engineer the conventional auditory alarm into one that can effectively communicate more accurate information to healthcare providers in the event of an emergency. While the integration of novel devices into the ICU requires substantial research, financial and administrative support, simple tasks such as minimizing testing for certain durations and supplying earplugs for nighttime can be implemented in the ICU in the meantime. By addressing the saturated and disruptive acoustic environment of the ICU, patient comfort can be placed as a priority and post-ICU complications can be minimized.

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