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THE SOUNDSCAPE OF AN ICU

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ABSTRACT

The ICU can be a stressful place, where occupants are exposed to a multitude of stimuli, and can result in trauma-related conditions due to the intense sensory environment. A multi-disciplinary team performed a multi-sensory study in a hospital to better understand the perception of the sensory environment. Questionnaires were given to the acoustical communities pertaining to multisensory stimuli, including acoustic stimuli. The existing ICU was analyzed using a soundscape framework, including documenting the acoustic taxonomy, the acoustic itinerary of the communities, and understanding the rhythm and tempi of the sounds as they change from day to night. Sound levels were measured in the existing ICU, with long term sound levels as well as short term levels of specific acoustic events and sound walks. An expansion of the hospital was completed using the feedback and data and integrative acoustic design principles. With new planning principles that allowed for channeling of the staff itinerary through a main artery, leaving a patient and visitor artery along the perimeter of the rooms, as well as strategic changes in acoustic finishes and enclosing of nurses' stations, clinically relevant increases in patient, visitor and staff satisfaction levels and decreases in sound level were attained.

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1. INTRODUCTION AND BACKGROUND

Tallahassee Memorial Hospital, a 772 bed acute-care hospital, is the centerpiece of Tallahassee Memorial Healthcare, a private not-for-profit community healthcare system serving 17 counties in north Florida and South Georgia. The M.T. Mustian Center, Tallahassee Memorial HealthCare's (TMH) new surgery and critical care tower, provides state-of-the-art critical care services with cutting-edge adult intensive care units to meet the growing demand in the region. A master plan was developed to anticipate the region's needs for the next 50 years with a building that can adapt to emerging technologies. The ICU/Surgery tower consisted of 346,270sf, six stories, a new hospital entrance for surgery and intensive care services including cardiovascular, cardiopulmonary and neurology. The building included 28 operating rooms, four interventional radiology rooms with support services, 24 ICU's with a total of 72 rooms, and future floor expansion possibilities.

Using an Evidence-based design (EBD) approach, the design team reviewed relevant literature on the project topic, and the medical team was enthusiastically engaged on environment-behavior focused findings from nursing journals, as well as Hamilton and Shepley's (2010) _Design for Critical Care: An Evidence-based Approach_.[1] An integral design concept developed for this project the "on stage-off stage approach." This design configuration seeks to separate patient-facing areas (considered on-stage) from staff only areas (considered off-stage) in an effort to optimize patient care and experience. This design concept, which originated from Walt Disney World Resorts, intentionally curates the sensory experience of users within the space by purposefully designating separate pathways and spaces for those intended to use the on-stage or off-stage areas. The on-stage, off-stage concept was created by Disney to optimize the consumer experience by minimizing guests' exposure to the noisy, messy, sometimes chaotic activity required in the production of entertainment services (McGough, Jaffy, Norris, Sheffield and Shumway, 2013).[2] The purpose of this design concept is to maximize a positive experience and minimize any possibility for anxiety for theme park guests. This concept is a powerful tool when used analogously within healthcare spaces, where creating spaces to minimize anxiety are also paramount, and layouts can shield patients from stress-inducing behind-the-scenes clinical work. This is especially relevant within intensive care units (ICU) which utilize specialized equipment and monitoring systems to care for high-acuity patients with complex medical conditions (McCullough, 2010)[3]. The resulting sensory assault common within ICUs from the discordant mixture of sounds, sights and smells often lead to levels of stress for patients, their families and medical staff much higher than experienced in inpatient wards (Hweidi &Nizami 2015; Pisani et al, 2015).[4; 5]

In intensive care units (ICUs), the leading environmental stressors typically involve excessive noise, inadequate lighting, and congestion due to spatial constraints in the facility's design (Hweidi & Nizamli, 2015; Pulak & Jensen, 2016)[4; 6] Elevated noise levels and inappropriate lighting conditions significantly disrupt the sleep patterns of critically ill patients, often resulting in sleep deprivation, which can severely impair the body's natural healing process (Pulak & Jensen, 2016).[6] The United States Environmental Protection Agency (EPA) advises maintaining sound levels at 45 decibels during daytime and 35 decibels at night. Nonetheless, research suggests that average ICU noise levels frequently range between 55–80 decibels, far surpassing these guidelines, primarily due to alarms and conversations among staff (Pisani et al., 2015; Xie et al., 2009).[5; 7]

The overwhelming sensory conditions within ICUs not only affect patients but also have a profound impact on their family members. Historically, ICU design has overlooked the needs of both patients and their loved ones (Beesley et al., 2016)[8]. As a result, nearly half of the families of ICU patients report psychological distress, including acute stress reactions, symptoms of post-traumatic stress disorder, anxiety, and depression during and after the ICU experience (Adelman et al., 2014; Davidson, Aslakson, Long, et al., 2017; Davidson, Jones, Bienvenu, 2012; Lautrette et al., 2007)[9; 10; 11; 12]. Healthcare personnel, particularly nurses and clinical staff, are also vulnerable to the demanding atmosphere of the ICU, which often leads to burnout and compassion fatigue (van Mol et al., 2015)[13]. These conditions are psychological and emotional responses to persistent stress exposure—sometimes labeled as secondary traumatic stress disorder—and are influenced by both emotional strain and environmental stress factors (van Mol et al., 2015; Figley, 1995; Nimmo & Huggard, 2013)[13; 14; 15].

At Tallahassee Memorial Healthcare, the three existing ICUs were designed in a traditional radial configuration with the nurse station in the center and the patient rooms around the perimeter. While this was great for visibility from the nurse station into the patient rooms, it afforded very little privacy for staff and patients and an environment overloaded with sensory stimuli. Radial ICU designs lead to sensorily overwhelming environments and have been likened to a war zone, leading to poor sleep for patients, burnout and compassion fatigue for medical staff and a phenomenon known as ICU psychosis and PTSD for patients and staff (Adelman et al., 2014; Davidson, Aslakson, Long, et al., 2017; Davidson, Jones, Bienvenu, 2012; Lautrette et al., 2007).[9; 10; 11; 12]

A soundscape study of the ICU was performed in conjunction with the design team to help document and understand the acoustic conditions in the current facility, provide ideas for soundscape design strategies to improve the acoustic environment and document conditions in the new facility.

1.1 Acoustic Communities in the ICU

The **acoustic communities** that make up the inhabitants of an ICU include patients, visitors and staff. Staff can be further divided into many sub categories including: doctors, nurses, Certified Nurses Assistants (CNA's), Support Staff, Janitorial, Biomed, Environmental Services (EVS), Food & Nutrition, Pharmacy, Surgery, Imaging, Security, etc. These communities use the ICUs in different ways, inhabit different areas and are exposed to different sounds as they make their way on their acoustic itineraries. Figure 1 shows a conceptual diagram of the various user groups that make up the acoustic communities of the ICU.

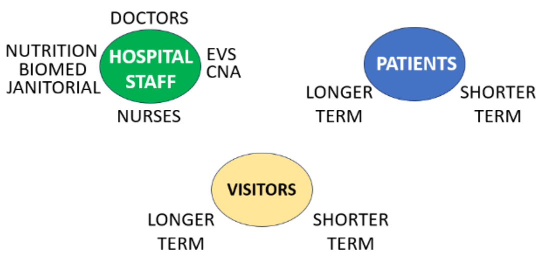

Figure 1. Summary of typical acoustic communities found in the ICU.

1.2 Acoustic taxonomy of the ICU

An **acoustic taxonomy** of sounds was documented in the existing building on several floors. The Acoustic taxonomy was broken into categories of human induced sounds, building systems, and operational sounds. An image map of the acoustic taxonomy is shown in Figure 2.

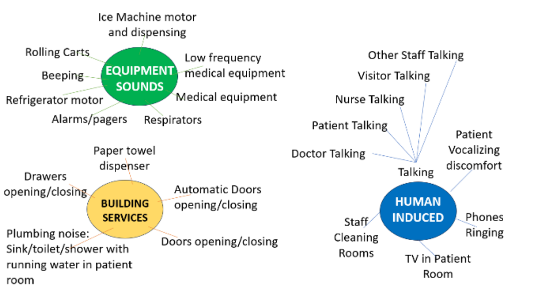

Figure 2. Acoustic taxonomy in ICU broken into categories for Equipment Sounds, Building Services and Human Induced sounds.

1.3 Acoustic Itineraries of the Acoustic Communities in the ICU

Acoustic itineraries are understood as the sonic environment a member of the acoustic community experiences as they move in space and time.

Existing Floorplan. Sample acoustic itineraries for the 3 typical acoustic communities are shown overlaid on the existing floor plan. There is significant overlap between the itineraries of these acoustic communities. Visitors must pass in the same corridors as the staff. The nurses at the radial nurses' stations were fixed in configurations that faced a number of patient's rooms That allowed for visual access and easy walkability, but disturbing sound levels to the patient rooms. Even though the acoustic communities had different reasons for being there, their itineraries often overlapped. Figure 3 shows itineraries for Staff, Visitors and Patients.

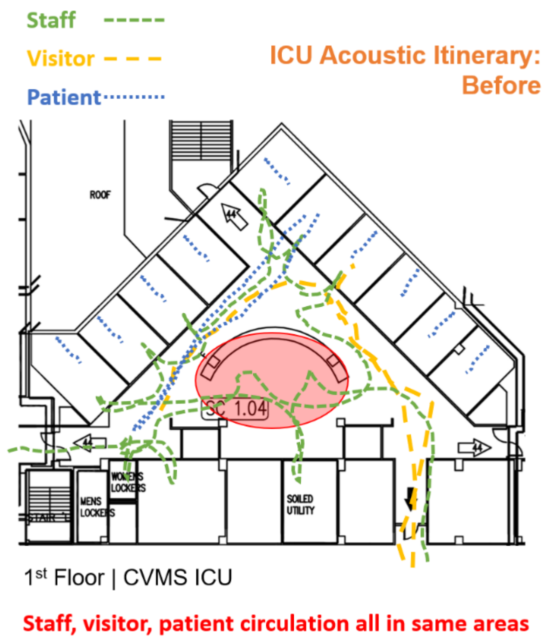

Figure 3. Acoustic itinerary showing overlapping itineraries between various acoustic communities.

In recognizing that the acoustic itineraries overlapped, resulting in multiple acoustic communities inhabiting the same areas at the same time, it was recommended that the acoustic communities be separated architecturally to the extent possible. Using distance to allow sound to dissipate, as well as enclosing the Nurses' Station was recommended as strategies for the new facility to test.

Schematic design of the new MT Mustian tower began with a series of studies on the blocking and stacking of the new addition. Several floor sizes and arrangements were drawn, measured, and evaluated for their advantages and disadvantages. While the design team considered both 24-bed and 36-bed ICU floor plates, ultimately the 24-bed layout with the internal "off-stage" corridor was selected. The staff believed the internal staff/service corridor had great benefits—most notably keeping noise and disruptions out of the perimeter patient corridors and patient rooms which aimed to optimize patient sleep and healing. The eight-bed pods provide good visibility to each ICU room from the core while reducing travel distances to support spaces. Decentralized nurse computer stations were also incorporated directly adjacent to patient rooms with windows into the patient rooms to reduce travel distances for nursing staff and reduce patient disruption during continual observation. The main nurse stations located along the central staff corridor were enclosed in glass for sound attenuation from staff conversations and activity to the patient rooms. Quality and efficiency were addressed through standardized surgery and ICU floors to reduce medical errors, dedicated patient and staff pathways and elevators to make patient rooms quieter and increase efficient staff flow, reducing travel times from operating rooms, the emergency department and the ICU to the imaging department, satellite pharmacy and labs.

New Floorplan

To separate the staff from the visitors both acoustically and operationally was the goal and therefore create acoustic itineraries that overlapped less. In working with the design team, inspiration from Disney in that there is a separation of "on stage" vs "off stage" areas of a theme park, with curated environments for the visitors.

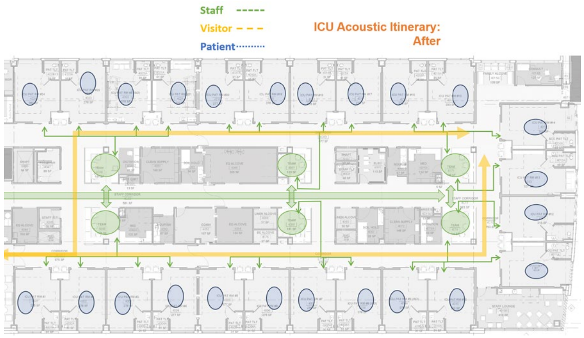

Figure 4. Acoustic itinerary after new construction. The green areas indicate a Staff corridor for staff-use only. The yellow area indicate a Visitor corridor. The overlap of the acoustic communities is more minimal than the previous design.

1.4 Acoustic Zones in the ICU and Patient Rooms

Acoustic zones of an ICU can include elements such as the main Nurse's Station, patient rooms, corridors, Visitor's waiting area, Staff lounge, staff offices, Elevators, restrooms and others. Each zone or acoustic room has its typical acoustic community users, it's typical function and typical acoustic itineraries associated with it. In looking at a patient room from the existing facility, it was found that there was not space and accommodations for patient's visitors. If they wanted to stay with the patient, they would have to sleep in the lounge area. In bringing evidence-based design practices into the new facility, the new patient rooms included a visitor respite area within the same room as the patient. This allowed a space for caregivers to access the patient continuously and not have to be separated. It has been found that this allows for better care of the patient and better advocacy. Mapping of the acoustic itinerary inside the new patient rooms shows the creating of a new mini acoustic zone or room inside each patient room. The visitors now have a designated area in the room where they can make themselves comfortable, sleep, and interact with the patient and staff.

The use of a larger space and adding in furniture to welcome the visitors changed the way the visitors could be present during the stay of their loved one, allowed them to better advocate for the treatment of their loved one and changed the dynamic of the localized soundscape inside their room. Figure 5 shows a patient room in the new facility.

Figure 5. Acoustic zones in the room correlate with the design of the patient room. The new patient rooms were larger, with comfortable seating. Image: courtesy of Gresham Smith

Survey and Focus Groups

To assess perceptions of sensory stress, surveys were distributed to both patients and staff. In addition, staff focus groups were organized to collect insights about both the existing and renovated ICU environments. These discussions aimed to identify the root causes and impacts of sensory stressors, highlight areas for potential improvement, and evaluate how the physical environment either alleviates or contributes to sensory stress. Data collection occurred during both the pre- and post-renovation phases. The pre-renovation phase, which included space syntax analysis, acoustic measurements, staff focus groups, and sensory stress surveys for patients, families, and staff, was conducted from March to October 2019. Post-renovation data collection took place from November to December 2019. This study received approval from a local Institutional Review Board (IRB) to collect data on perceptions of sensory stress. Survey participants included ICU patients, their family members, and ICU staff. Eligible patients were those who had been admitted to either the original or renovated ICU during the pre- or post-renovation phases. Family member participants were those who had been present with a patient during an ICU stay in the same periods. Staff eligible for participation in both the surveys and focus groups were individuals who had worked in the ICU—either in the original or updated facility—during the pre-renovation or post-renovation timeframe.

Paper and online surveys were given to patients and family members. Both versions of the survey utilized an adapted form of the Perceptions of Sensory Stress Survey (Hweidi & Nizamli, 2015)[4]. The instrument was divided into three sections, with a total of 40 items. In the first section, participants were asked to evaluate their experiences of sensory stress for 21 specific factors using a five-point scale ranging from 0 ("did not experience") to 4 ("very stressful"). These factors covered various categories, including lack of control (e.g., "not being able to sleep" or "not being in control of yourself") and auditory disturbances (e.g., "nurses and doctors talking too loudly" or "unfamiliar and unusual noises"), among others. The second section invited respondents to rate the significance of 16 environmental aspects regarding their overall ICU experience. Using the same 0–4 scale, where 0 meant "not important at all" and 4 meant "important," this section included items that closely mirrored those found in the first section.

The final part of the survey consisted of three open-ended questions, allowing participants to describe environmental elements that had a positive or negative effect, along with space for any additional comments. A mixed-effects multiple regression analysis was conducted to examine the impact of ICU renovation phase (pre- vs. post-renovation) on perceived sensory stress. The model also assessed differences in responses between patient and family participants versus ICU staff. Specifically, the regression tested for main effects of renovation phase, respondent type (patients and family members vs. staff), and the interaction between phase and respondent type. This interaction term was used to determine whether changes in sensory stress perceptions from pre- to post-renovation varied depending on whether the response came from a patient/family member or a staff member responding on behalf of the perceived patient/family experience. The model also included both ICU floor-level and individual-level covariates. At the individual (person) level, covariates were drawn from the sensory stress survey's Importance Rating items, focusing on aspects such as lighting control, sound (including conversations among medical staff, medical equipment noise, noise from other patients, and ability to control sound), and environmental factors related to sleep quality.

Individual Sensory Stress Items Related to Sound
Among the 21 survey items addressing environmental stressors, six focused specifically on auditory sources. These items measured participants' perceptions of stress linked to:

- nurses and doctors speaking too loudly,
- hearing other patients cry out,
- unfamiliar and unusual sounds,
- the sound of heart monitor alarms,
- mechanical buzzers and alarms, and
- ringing telephones.

These sound-related items were also analyzed as individual outcomes in a regression using the same model structure as the *Total Sensory Stress* analysis. The findings revealed a significant reduction in perceived sensory stress for five out of the six noise-related items following the ICU renovation. The exception was "hearing the heart monitor's alarm go off," which did not show a statistically significant drop in stress perception from pre- to post-renovation. This is logical, as the acoustic interventions cannot reduce the sound level of the direct sound of the heart monitors.

2. DATA

Acoustic measurements of sound walks and long term sound level measurements were made for 6 days in the existing ICU on 3 floors, as 2 locations per floor. Similar measurements at similar locations were taken in the new ICU to compare sound levels.

Obviously, the sound level of the sources of talking and equipment sounds will not vary, as the architectural environment cannot directly affect the direct sound levels. However, analyzing the number of occurrences and sound levels averaged over a longer period of time to account for the sources taking place less often helped to be able to visualize the change in sound level.

Sounds are no quieter in one Nurse's station versus the other (Figure 6), but patient rooms were much quieter due to the distance and architectural separation. Figure 7 shows the 10-15 dB difference in sound levels in the "Quiet" patient rooms. This is attributed to a number of factors: The location of these rooms was not directly on the main circulation path, therefore reducing the amount of human traffic by these locations. The separate paths of circulation for the Staff and Visitors allowed for a concentration of the acoustic itinerary in a central corridor and away from the patient rooms. The Nurses' Station was redesigned to be located farther away from the quiet rooms and had a glass wall that acoustically separated it from the patient rooms. The new design also included decentralized computer stations for just 1 nurse, as opposed to having the computer stations inside the patient room. The small decentralized nurse stations provided a recessed alcove with a viewing window that allowed the nurses to enter data without disturbing the patient. Medicine rooms were separated from patient rooms. Sound absorbing finishes were used in corridors and patient rooms. These design strategies combined helped result in lower sound levels throughout the ICU patient rooms.

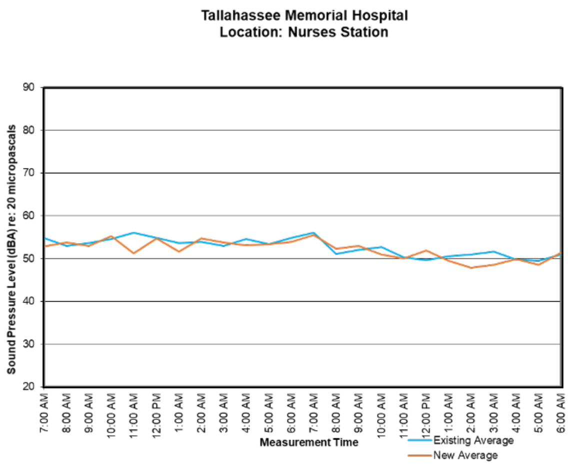

Figure 6. Graph showing similar sound levels at the Nurses' Station. Sound levels from the direct sound of people speaking are not greatly affected by architectural features.

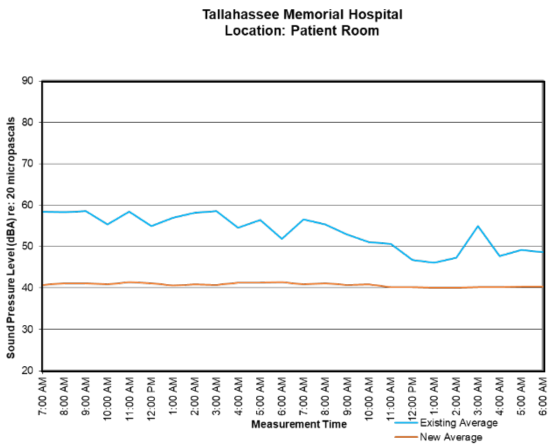

Figure 7. Sound level measurements in the "Quiet" patient rooms had 10-15 dBA reductions for 1 hour LAeq measurements.

3. CONCLUSIONS

Staff behavior regarding noise levels remained consistent between the old and new ICU environments—indicating no significant change in how quietly staff operated. This suggests that any observed differences in sound levels are more likely attributable to the influence of the ICU's architectural layout, particularly the shift to an on-stage/off-stage design configuration.

Acoustic measurements confirmed that specific architectural design elements can significantly affect sound levels within ICU units. The original ICUs, designed with a centralized nurses' station surrounded by patient rooms, recorded ambient sound levels that were 5 to 15 decibels higher than those found in the newly designed ICUs. In the newer layout, nurses' stations were fully enclosed and physically separated from patient care areas. Patient rooms situated closer to nurses' stations and unit entrances registered higher noise levels compared to those located farther away—further supporting the role of physical layout in controlling acoustic exposure.

Interestingly, noise levels within the nurses' stations themselves remained similar across both the old and new units. This is likely due to the consistency in staff activities—including phone conversations, staff collaboration, and routine clinical duties—that are essential to ICU operations. While these behaviors did not change, the design in the new ICU protected patient areas from these routine sounds.

In the older units, nurses' station noise easily traveled into patient rooms, especially when doors were open. The centralized design placed significant foot traffic—including that of physicians, nurses, ancillary staff, and visitors—directly adjacent to the patient rooms, increasing overall noise exposure. In contrast, the redesigned ICU utilized two parallel corridors with enclosed service zones at the center, effectively buffering patient rooms from unit traffic. This design minimized activity near patient rooms, reducing noise from conversations, rolling medical carts, and general movement.

Sound levels within patient rooms located at the quiet ends of these new corridors were measured at one-half to one-third the intensity of sound near comparable rooms in the original ICUs. This reduction is attributed to the increased physical distance from the nurses' stations as well as decreased circulation of staff and visitors near these quieter areas.

Overall, these findings highlight the strong potential of thoughtful architectural design to improve the acoustic environment of ICUs, benefiting patients, staff and caregivers.

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