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NATURE SOUNDS FOR THE WIN: INFLUENCING THE PLEASANTNESS PERCEPTION OF PICU SOUNDSCAPES

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ABSTRACT

The intensive care environment can be acoustically hostile. This study explored to what extent eventful and uneventful soundscapes in a paediatric intensive care unit (PICU) can be influenced to become more pleasant. We collected two raw recordings of the PICU soundscapes to represent an eventful and uneventful soundscape. Separately, we defined two sound samples (musical and natural) to be pleasant: Mozart - Piano Concerto No. 27 in B-Flat Major, K. 595 and a nature sound sample with birdsong. Pleasant sound samples were used as design interventions to be overlayed to raw PICU recordings. Participants rated the pleasantness of raw PICU soundscapes on a scale of 1 – 10 with or without the intervention (music and nature sounds). The results showed an overall increased pleasantness with the addition of the nature sounds to both the eventful and uneventful PICU soundscapes. Yet, the improved soundscapes were rated relatively pleasant. We also ran a qualitative study to further understand what makes PICU soundscapes pleasant. The pleasant sound intervention with nature sounds is recommended only for uneventful PICU moments. We also offer strategies to introduce human-centered and contextual sound-driven solutions.

Keywords: *acoustic environment, pleasantness ratings, eventful soundscapes, nature and music sounds, sound-driven design.*

1. INTRODUCTION

Paediatric Intensive Care Units (PICU) are known to be a chaotic environment with overwhelming noise and many overlapping sound events. PICU sounds, in fact, have been found to exceed a level of 55dB for 70-90% of the time during a 24-hour period [1]. Staying in the ICU for more than 48 hours is considered a risk factor for hearing loss and excessive auditory stimulation has been suggested to influence the cortisol levels and lower immunity [1]; effectively hindering the ability for the patients to recover. The chaotic environment within the PICU can cause extra stressors for the children as they are often unable to get the sleep necessary to recover [2]. Perhaps, if the perception of the soundscape is more positively valenced, the overall experience of the PICU could be less stressful.

However, the experience of a patient in relation to the soundscape is quite a subjective one as corroborated by the International Standard, ISO 12913-3:2019 [3], which defines the term soundscape as "[the] acoustic environment as perceived or experienced and/or understood by a person or people, in context" [4]. It is important to note that there is a difference in acoustic comfort and the subjective evaluations of a soundscape. The way in which a soundscape is described may not describe the dimensions of it, but rather the experience associated with it; this relates to concepts such as expectation [5]. This was shown in the study of Johnsson et al. [1] by which some sounds caused patients to experience fear, such as those coming from treatments and inquiries of the patient beside them, while other sounds were experienced as pleasant and caused a sense of security and familiarity, such as those from a quiet working staff.

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Nevertheless, removing negatively valenced sounds does not necessarily make the overall soundscape more pleasant. Due to the absence of events, the removal of unwanted sounds can even create anxiety [6]. According to Cain and colleagues [5], soundscapes can be perceived as more pleasant if negatively valenced sounds are removed and replaced with more positively valenced sounds. As a way of identifying the underlying dimensions of a soundscape perception, Axelsson and colleagues conducted a listening experiment and offered three components that explain the experience of soundscapes: eventfulness, pleasantness and familiarity [7]. These components are widely used today and have been implemented in a two-dimensional model of 'eventfulness and pleasantness' to describe how humans interpret the affective quality of soundscapes in a given context [4][8]. According to ISO (12913-3:2019) [3], the affective qualities of soundscapes are measured through eight attributes Calm, Pleasant, Exciting, Eventful, Chaotic, Annoying, Monotonous and Uneventful. Eventfulness refers to the amount and diversity of sound events that occur within a certain period of time and context, and can influence our emotional and cognitive responses to a particular soundscape.

There is an open call to intervene in critical care acoustic environments beyond the ability to measure sounds with sound-driven design approach [9][10][11]. It is important to understand to what extent PICU soundscapes can be altered and what design strategies are available for sound-driven designers for healthcare. Thus, our study aims to contribute to design better hospital soundscapes based on evidence.

2. BACKGROUND

Considering the ISO (12913-3:2019) [3], our study focuses only on the components of soundscape eventfulness and its perceived pleasantness. We explored to what extent eventful and uneventful PICU soundscapes can be influenced to become pleasant. For that, we looked into design interventions such as overlaying commonly accepted pleasant sounds (e.g., music or nature) onto the existing PICU soundscapes. Generally, PICU soundscapes change over the course of the day, with mornings always being more hectic due to the caregiving and treatment activities, while after dinner it is often quieter with only family visits. Thus, we also wanted to better understand the relationship between pleasantness and eventfulness and whether un/eventfulness of the soundscapes would play a role in the pleasantness perception of the PICU soundscape. We expect that adding sounds generally perceived as pleasant to the soundscape of the PICU will result in an overall improved pleasantness in the perception of the PICU soundscape, but the degree of pleasantness perception may be altered by the eventfulness of this soundscape.

There are a few studies that elaborate on a certain "Mozart Effect", by which exposure to Mozart's music showed higher abilities for spatial-temporal reasoning [12]. A study conducted on adult students revealed that listening to classical music for a 60-day period (listening to classical music every day according to a music listening schedule) led to a statistically significant effect on their Trait Anxiety and Psychological Well-being scores [13]. In an experiment, Jo (2019) found that exposure to forest sounds resulted in the following significant differences in comparison to exposure to city sounds: "*decreased oxy-Hb concentrations in the right prefrontal cortex; decreased ln(LF/HF); decreased heart rate; improved feelings described as "comfortable," "relaxed," and "natural"; and improved mood states.*" [14]. Theses findings demonstrated that forest-like auditory stimulation induced physiological and psychological relaxation. Goel and Etwaroo (2006) observed that exposure to a recording of birdsong combined with classical music significantly reduced self-reported depression and anger in a sample of university students, both depressed and non-depressed [15]. In the ICUs, burn-injured patients felt less anxious when exposed to natural sounds [16].

Accordingly, there is sufficient evidence to use music and nature sounds as design interventions to be overlayed on PICU soundscapes so that these soundscapes are perceived to be more pleasant. The design space with music and natural sounds is vast [17]; yet, we are interested in preliminary findings on the efficacy of our design concept. Thus, we chose the following sounds which were used in earlier studies and shown to have positive effects on listeners: one sample from Mozart's Piano Concerto No. 27 in B flat major- K.595 [18] and one recording of birds and other nature sounds from the rainforest [19].

Overall, the eventfulness of the PICU soundscape depends on the time of day, number of patients and their criticality. Thus, we visited the PICU of Sophia Children's Hospital, in Rotterdam (NL). Although there were a wide range of sounds related to the machinery in the ICU (breathing monitors, alarms, etc.), predominantly the loudest continuous sounds were that of talking, from both medical staff and parents. Although the time in which our observation took place was the "quiet hour" in which the sounds were minimised and the lights were turned off, the median dB reading was 55 dB indicating a rather loud acoustic environment for an environment intended to be

restorative. Overall, the eventfulness of the PICU soundscape may be relatively high or low compared to traffic noise or classrooms, and thus, should be considered within its own boundaries.

3. METHOD

Our study was a 3 x 2 within-subjects factorial design with ICU Soundscape Type (Eventful and Uneventful) and Design Intervention (Music, Nature, Raw) with our independent variable being the pleasantness ratings of the PICU soundscapes. We also ran a qualitative study to further understand what makes PICU soundscapes pleasant. The comments of the listeners were analysed qualitatively through inductive coding, meaning the data was first reviewed and then the codes were created.

3.1 Participants

For privacy reasons and taking into consideration the health of the patients, it was not possible to conduct this study with patients, families, or nurses within the PICU. As perceived pleasantness is already a subjective topic, it was decided to conduct this study with participants that did not necessarily have ICU experience. Twenty-eight healthy adults (18F and 10M) with normal or corrected to normal hearing participated with a mean age of 39,75 years (SD=18.31).

3.2 PICU Soundscapes & Design Interventions

Since the experiment was to be carried out outside of the PICU setting, we recorded 30 seconds of two PICU soundscapes depending on daily activity: Eventful and Uneventful. A simple recording device was used to collect audio footage of a PICU environment during the visits. Both raw environmental soundscapes reflect the real situations in a PICU, with elements such as alarms from the equipment that indicate the health of the patient, conversations between doctors and nurses, transportation of equipment, patient sounds such as babies crying, etc. The raw uneventful soundscape consisted of only one alarm that plays in the background, a baby making soft noises and a constant low static sound created by the medical equipment. The raw eventful soundscape had several alarms overlapping with each other, people's chatting in the background (content indistinguishable), infants crying, and people and instruments moving around. Permission to record the soundscapes was asked of the PICU inhabitants present at the time. The spectrogram of the Uneventful and Eventful PICU soundscapes can be found in Figure 1. Sound events are recorded as they happened without adjusting their perceived loudness from the same position and no post-processing (e.g., normalisation) on loudness took place on the digitised soundscapes.

The design intervention for these two scenarios was in the form of adding a sound sample to each of the raw PICU soundscapes, creating compound soundscapes. These were the classical music sound sample by Mozart, and the nature sound sample of a recording of a forest. The soundscapes consist of eight tracks as seen in Table 1: Eventful and Uneventful ICU Soundscapes (2x), the Music and Nature sound samples (2x), and the compound PICU soundscapes consisting of Eventful and Uneventful ICUs each overlayed with one of sound samples (4x).

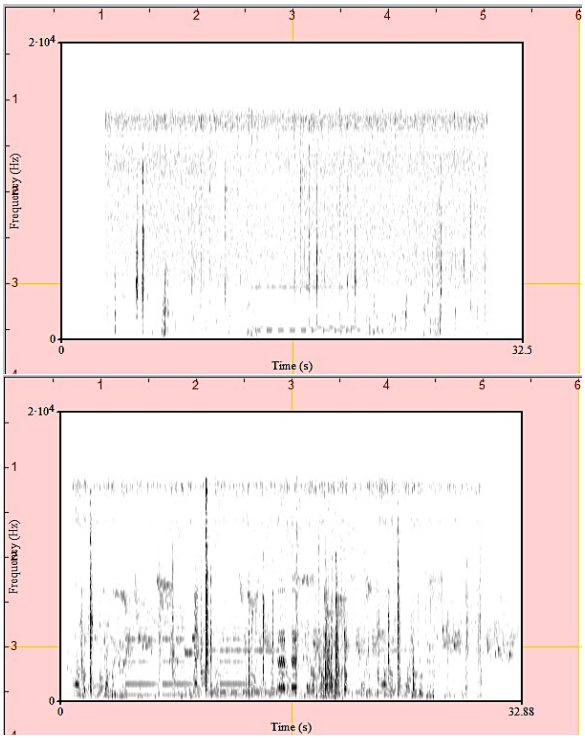

Figure 1. Spectrograms of Uneventful (top) and Eventful PICU Soundscapes (bottom).

3.3 Procedure

At the start of the study each participant was asked for consent to voluntarily participate in the study without monetary compensation. Participants were asked to rate each soundscape on a scale of 1 – 10 (1-Unpleasant and 10-Pleasant). Music sounds and Nature sounds were also rated on the same scale to determine their baseline pleasantness. To avoid scaling order effects [20], the order in which the soundscapes were played were split into four possibilities of randomisation. The study ran on an online platform, Qualtrics, approved by the university for research.

Table 1. Descriptions of design interventions depicting Music and Natures sounds, Raw Eventful and Uneventful Soundscapes and the compound soundscapes.

Design intervention	Description
Music	A sample taken from Mozart's Piano Concerto No. 27 in B flat major-K.595
Nature	A sample of a recording taken in the forest with bird noises and other nature sounds.
Raw Eventful soundscape	Raw recording made in the PICU in a situation where it was chaotic and loud.
Raw Uneventful soundscape	Raw recording made in the PICU in a situation where it was calm and rather quiet.
Eventful + Music	The music sound sample layered over the raw eventful soundscape
Eventful + Nature	The nature sound sample layered over the raw eventful soundscape
Uneventful + Music	The music sound sample layered over the raw uneventful soundscape
Uneventful + Nature	The nature sound sample layered over the raw uneventful soundscape

4. RESULTS

4.1 Analysis of Pleasantness Ratings

We conducted a two-way ANOVA in order to test the main effects of ICU Soundscape Type (two levels) and Design Intervention (three levels) on Pleasantness ratings. We also checked for the interaction effect between these dependent variables. individual differences between design intervention types were compared via Student's t-Tests. Moreover, a simple descriptive analysis was conducted and mean ratings are presented in a bar chart in Figure 2. The results are separated into Design Intervention (Raw sounds of Music and Nature) and Eventful and Uneventful PICU soundscapes as a function of Design Intervention Type (with Music, with Nature, and Raw PICU sounds). All effects were measured at the alpha level of .05. We also drew a line on the midpoint at 5.5 on a scale of 1 – 10 indicting a more neutral point between Pleasant and Unpleasant ratings. Thus, below this line would be considered Unpleasant and above Pleasant.

First, our assumption that Music and Nature are pleasant sound samples was demonstrated with high and similar pleasantness ratings with mean ratings being 8,46 and 8,21 respectively with no significant difference ($F(1,27)=0.467$, $p=.500$). This result assured that our interventions were likely to have positive effects.

Secondly, Eventful and Uneventful PICU Soundscapes were found to be rather unpleasant with mean pleasantness ratings being 2,86 and 4,36. Raw Uneventful PICU soundscapes are perceived relatively more pleasant than the Raw Eventful soundscapes ($F(1,27)=16.200$, $p=.0004$), yet they are still under the midpoint of the rating scale (5.5). This finding also confirmed that PICU soundscapes in general need improving and our study goal is valid.

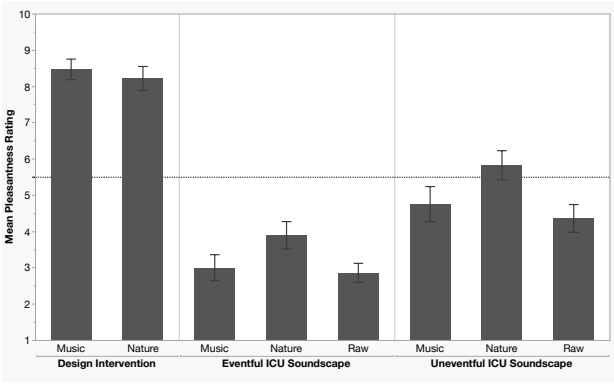

Figure 2. Pleasantness ratings as a function of Design Interventions, Eventful and Uneventful ICU Soundscapes.

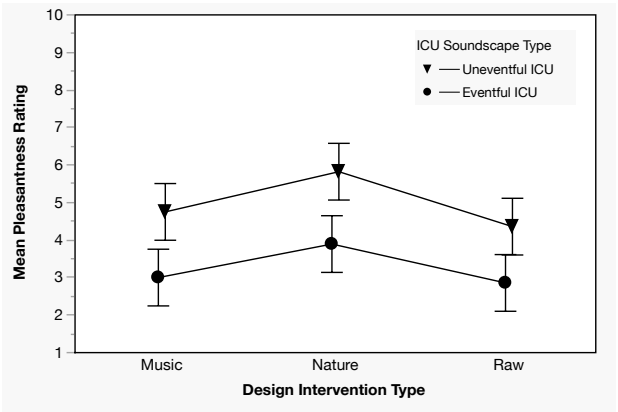

Figure 3. Comparison of Eventful and Uneventful ICU soundscape as a function of Design Intervention Type.

Figure 3 depicts the overall differences between Eventful and Uneventful ICU soundscapes. Uneventful ICU soundscapes seem to have consistently more pleasant ratings than Eventful ICU soundscapes. There seems to be the same effect of Design intervention overall: Nature design intervention has the highest ratings for Eventful (M=3.892) and Uneventful soundscapes (M=5,821). Music design intervention and Raw ICU soundscapes seem to have similar ratings overall in both Eventful (M_{Music}=*3.000* and M_{Raw}=*2.857*) and Uneventful soundscapes (M_{Music}=*4.750* and M_{Raw}=*4.357*).

We also found main effects for ICU Soundscape Type (F(1,27)=26.258, p<.0001) and for Design Intervention Type (F(2,54)=9.597, p=.0003). No interaction effect was found between the two factors (F(2,54)=0.250, p=.780). We also found out that only Nature design intervention is significantly more pleasant than Music design intervention (t(55)=2.729, p=.009) and Raw ICU soundscapes (t(55)=-4.098, p=.0001). There was no significant difference in pleasantness ratings between Music design intervention and Raw ICU soundscapes (t(55)=-1.218, p=.229).

4.2 Commentary on ICU Soundscape Pleasantness

We asked 12 industrial design students (age range of 20-30) for their 'professional' opinion of what makes PICU soundscapes pleasant after listening to the raw PICU soundscapes and the design interventions.

4.2.1 Raw PICU Soundscapes

When asked to reflect on pleasantness, a participant said "It's not unpleasant because things are happening, kids are being attended to, it's kind of weird to say this sounds unpleasant". This shows a conflict between the perception of the sound and its meaning. Also a pattern was noticed in participants' responses while rating pleasantness, about whether they would mind staying for a long time in this physical environment or not. For example, in an uneventful PICU a participant said "I can hear people and alarms but can't feel the commotion, I wouldn't mind staying for a while if I'm visiting someone, I think it is a calm environment" vs in an Eventful PICU they said "Telephones are quite annoying and high pitched, sometimes kids sounds make me worried, I don't want to stay here for a long time".

4.2.2 Uneventful PICU Soundscapes + Design Intervention

Although there was a minimal change in the perception of the uneventful soundscape with the addition of both the music and the nature sounds, the participants indicated that the overall perception increased to be slightly pleasant. Both added samples, Music and Nature, did not create a perceived conflict with the raw PICU soundscapes, since there was not that much environmental noise compared to the eventful soundscape. Yet, nature sounds were found to be more fitting. This is evidenced by comments from the participants such as "I quite liked it, the alarm fits in the randomness of the birds, it blended into the background".

4.2.3 Eventful PICU Soundscapes + Design Intervention

The eventful PICU soundscape had a lot of different stimuli with high-pitched sounds, such as alarms from the medical equipment and a telephone ringing, amongst others. This represented a direct conflict with the added soundscapes of nature sounds and classical music. This was evidenced by participants with comments such as "It's loud, so many sounds are overlapping" and "There was even more beeping, not totally unbearable but not nice" which is why the overall rating of the eventful environment is deemed unpleasant. The biggest conflict for the music sound sample was that both the individual tones and the melody from the piano are too similar to those of the alarms from the medical equipment, so the participants didn't know what they needed to focus on, as "it was distracting from all the other important noises that I needed to hear". Nonetheless, even though the participants say they disliked the compound eventful soundscapes, the pleasantness did increase with the intervention especially with nature sounds.

4.2.4 Qualitative analysis through thematic coding

In the qualitative analyses, we first coded the comments from the participants by differentiating if they refer to the corresponding soundscape as pleasant, neutral or unpleasant (see Figure 4). These codes were subsequently classified into themes, from which more general themes were abstracted. Almost every category had a positive and negative version of the code. We found two general themes: Participants either referred to the quality about a specific soundscape or to the relation between soundscapes and the actual PICU context. Soundscape qualities can be further divided based on whether they refer to the raw PICU soundscapes or the design interventions with nature and music. As seen in Figure 4, more codes refer to unpleasant (red coloured codes) rather than pleasant experiences (green coloured codes). This is consistent with the overall pleasantness ratings found in the earlier analysis.

The content of the neutral experiences varied. Some codes represented a conflict of interpretation since they depend greatly on the specific soundscape the participant was

listening to when the comment was made. For example, the code "the design intervention (music/nature) provides something else to focus on" varied depending on if the participant got distracted from the PICU sounds while listening because they liked the design intervention or they disliked it. Nonetheless there were other comments that explicitly depicted neutrality, such as mentioning that "the uneventful soundscape was dull and neutral".

Regarding the qualities of the PICU soundscapes with design interventions, they mainly reflected the personal preferences of the participants. For example, some people mentioned that they find "classical music boring and depressing" while others found it "soothing and nice to listen to". Overall it is important to point out that very high pitched sounds were unpleasant to listen to, especially when they competed with other sounds in the PICU environment. Some participants mentioned disliking the Mozart music because it was "too sad", whereas other participants thought it was beautiful and ergo felt happier.

The other theme, the relation between the soundscapes and its context, is further divided into whether participants compared the sound sample to the other soundscapes or to the physical context of the PICU which both provided a positive and a negative version of the code. Quotes from participants that described the soundscapes with the design intervention such as "Quite pleasant, the music kind of soothed the ambiance, it made the situation calm" can be interpreted as that such sounds blended well with other environmental sounds. In comparison, an example of a comment made when the sound sample would be considered unsuitable for the PICU environment was "it is deceitful, I don't like when nature sounds are applied to non natural environments, seems fake because its very transparent that they are trying to calm people down, seems like a quick fix".

5. DISCUSSION

Our study aimed to demonstrate whether positively valenced sounds would also positively contribute to the pleasantness experience of PICU soundscapes. We added Music or Nature sounds as design interventions over the recordings of Eventful and Uneventful PICU soundscapes and asked the participants to rate design interventions, and the raw and compound soundscapes. The results showed that Music and Nature sounds are indeed commonly experienced as pleasant and would make suitable positive design interventions. We also demonstrated that existing PICU soundscapes are indeed experienced as rather unpleasant, especially Eventful soundscapes, and would benefit from a design intervention such as being overlayed by pleasant sounds in order to create a more pleasant acoustic environment, or at least acoustically a less unpleasant one.

Thus, by overlaying Music and Nature sounds on Eventful and Uneventful PICU soundscapes, we created hypothetic design interventions to be evaluated on their pleasantness quantitatively by collecting rating data and qualitatively by collecting 'professional' opinions on the design interventions. The analysis of the Pleasantness rating showed that both Music and Nature sounds have a positive

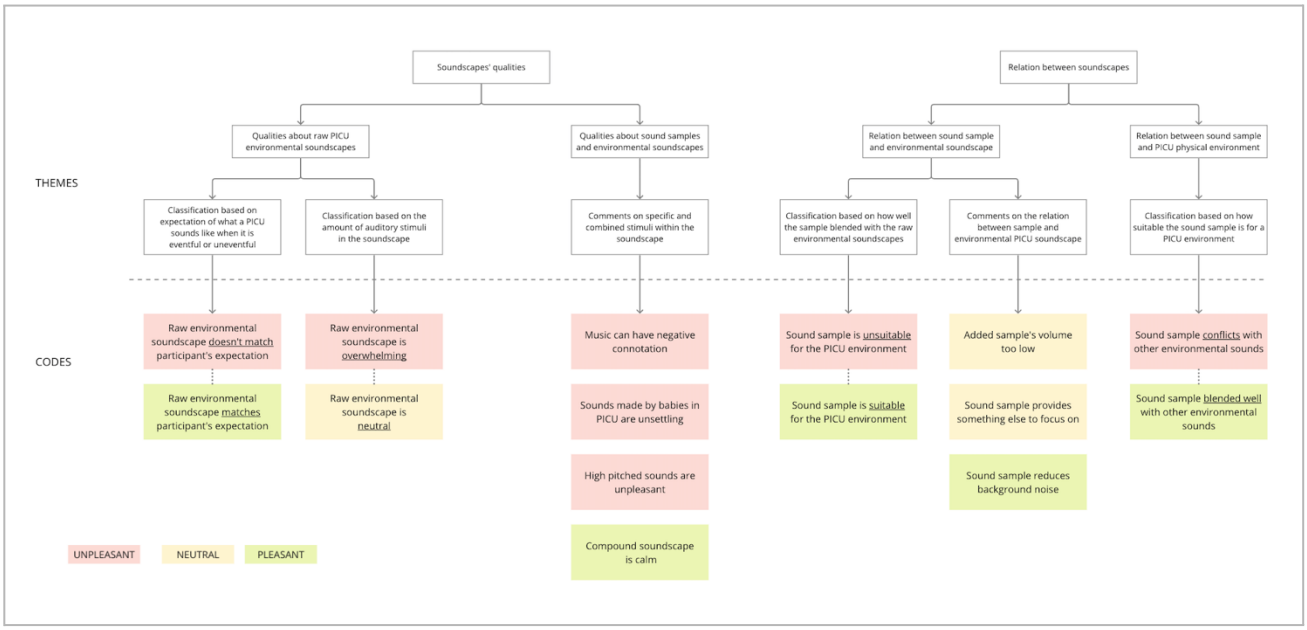

Figure 4. Thematic Analysis: Categorization of codes and themes based on the participant's comments

effect by increasing the ratings in comparison to raw PICU soundscapes but only Nature sounds were able to make a significant difference in the improved pleasantness experience. Nature sounds were most effective in the Uneventful PICU soundscapes since the mean Pleasantness ratings increased beyond the 5.5 mid-point of the scale. Thus, Nature sounds had the ability to decrease the unpleasantness of the raw soundscapes. This finding was similar to Cain et al. (2013) [5] that it is possible to change the perception of soundscapes by adding new sounds.

The experience of a soundscape is essentially an emotional one [21]. Past experiences of patients may influence the way in which they experience the soundscape and hence, rate their pleasantness. Our analysis of the listeners' commentary showed that pleasantness experience is innately personal and there are more nuances to the experience based on the listeners' commentary. Thus, our quantitative data only shows averaged results as listeners may have different opinions on what makes the design intervention pleasant or how they influence the perception of the raw soundscapes. Yet, there was consensus that PICU acoustic environments are generally perceived as unpleasant and therefore our design interventions at least create a comfortable distraction for listeners with birds chirping and participants feeling surrounded by nature.

It is interesting to see that while both Music and Nature sounds are found to be pleasant in isolation, they do not have the same effect on the acoustic environment. Our interpretation is that listening to music is a dedicated, and continuous activity that engages people in a purely aesthetic way [22]. Thus, it is possible that PICU sound events may have hindered the pleasure of listening, indicating that the effect was reversed here such as raw PICU sounds intervened the pleasure of listening to music.

Nature sounds, however, often can be heard over mundane activities and are part of our daily lives. We usually engage with nature sounds in a distant way. Thus, it may be more acceptable to have nature sounds overlayed in PICU rather than music. Yet, the comments also indicate that adding nature sounds that have a similar pitch and frequency as the alarms competed directly with other elements from the raw PICU soundscapes. Nonetheless, it is necessary to keep in consideration that sounds of nature, such as the chirping of birds, can vary in pitch and frequency, so a sample that contains less high pitched elements can be chosen. Adding sound samples mostly overwhelmed the participants and a more silent context could also be more pleasant at times and for certain people. If a soundscape is to be added, then it could be used in uneventful moments in the PICU.

6. CONCLUSIONS

Our study yielded the conclusion that the pleasantness of ICU soundscapes can be influenced and yet the experience of soundscape pleasantness is subjective and contextual. Prior experience and biases can affect the way in which acoustic environments are perceived. But a general understanding is that the PICU is an unpleasant sound environment with too many alarms and sound events that categorize as "noise". Thus, the success of sound-driven design interventions would then depend on how eventful or uneventful the acoustic environment is.

Our method, a quantitative study in addition to qualitative one, opens up the discussion to rely on listeners' opinions for a truly human-centered and contextually relevant decision and its application. Moreover, an added step would be to truly understand the context of such soundscapes and how people interact with it. In an observational study that took place in another critical care context (i.e., operating rooms), Özcan et al. [23] offered the notion of Acoustic Biotopes to highlight how different listeners interact with each other and with the occurring sound events and how their listening style and involvement in the task at hand changes their perception and assessment of soundscapes. Thus, in any intensive care unit, it would also be valuable to extend the sound design intervention to all the listeners of the soundscape, not only patients, to be able to consider the real value of design and its effectiveness.

Our Nature design intervention seems to be effective only in uneventful ICU moments. Yet, eventfulness of an ICU cannot be fully influenced by design as it is determined purely by context, i.e, tnumber of active patient beds and events, number of people, the alarms running, the reactions of infants, the sounds from operating equipment, especially including the respiratory tube. One design recommendation would be to employ machine listening techniques to determine real-time how the soundscape of the PICU changes. This type of monitoring is possible by identifying and classifying sounds in the PICU, and when the algorithm can match a set of sound parameters (as mentioned above) against a trained model, it will be able to successfully identify the situation as 'eventful' or 'uneventful'. This can then be used to determine the type of sound design sample and the loudness level at which it should be used (or not used at all), to ensure that it does not coincide with the frequency range of alarms, does not obstruct the focus and flow of nurses and doctors, and does not create additional dissonance in the environment. Thus, adaptive technologies would be required for the such a design intervention.

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