SENSORISCH

Modulating music volume in the operating room

Several auditory factors can affect healthcare provider performance, well-being, and patient outcomes. Music volume in the OR is a key factor that can be controlled during time-sensitive situations. Therefore, the research questions for this paper are: does the CanaryBox increase the proportion of alarms that clinicians respond to during surgery, and does it reduce the time clinicians take to respond to alarms? Furthermore, how can we convert data from patient monitoring into usable formats to study how the surgical environment changes affect patient physiology and clinician behavior?

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Total noise volume in the operating room (OR) frequently exceeds 100 decibels (dB), significantly surpassing the recommended threshold of 45 A-weighted decibels (dBA) set by the World Health Organization (World Health Organization, 1999; Kracht et al., 2007). Noise in the OR can distract healthcare providers, impair communication between staff, and increase the possibility of errors in patient-related communication (Enser et al., 2017; Keller et al., 2016). Music is frequently played during surgical cases and contributes significantly to the overall noise level in the OR. Music may reduce the stress of the surgical team, but it is also distracting, impairs clinician focus by introducing an exogenous attention draw, and can reduce clinician vigilance to alarms (Narayanan et al., 2022).

The purpose of audible medical alarms is to draw attention to abnormalities in a patient's condition. When responding to an alarm, the clinician must determine the alarm's meaning and intervene appropriately. However, substantial auditory background noise affects their ability to do this, impacting the clinician's response time, accuracy, and ability to understand speech (Bruder et al., 2021; Han et al., 2022). In emergencies, delays in minimizing noise can be critical, so a device that modulates music volume based on alarm status could be advantageous.

In this study, we incorporate the CanaryBox (Canary Sound Design, LLC), an 'intelligent' audio device, into several Vanderbilt University Medical Center (VUMC) operating rooms. This device is 'intelligent' because it receives data from the patient monitor in the operating room and automatically modulates music volume according to the severity of patient vital sign deviations, without clinician input. The CanaryBox (CB) is programmed to lower the music volume by 50% for yellow 'warning' alarms and to shut off the music for red 'crisis' alarms (International Electronical Commission, 2006). Previous studies with the CanaryBox have shown that it is user-friendly, intuitive, and effective in modulating music volume (MacDonald and Schlesinger, 2018; Gururaja et al., 2022). Similar to the Smart and Silent ICU project, which is focused on using smart technologies and algorithms to reduce the frequency of alarms in the ICU, we use the smart technology of the CanaryBox to examine how clinicians' responses to alarms are affected by the noise environment of the OR ('Shhh! SASICU strives for,' 2024).

Methods

To answer the research question, data was collected in 100 total cases in the pediatric orthopedic OR at the Monroe Carell Jr. Children's Hospital at Vanderbilt (Children's Hospital). The CanaryBox device was used in 50 cases, and there were also 50 control cases where the CB was present but not activated. These rooms were chosen based on previous successful implementations of the CanaryBox music modulation protocol (Gururaja et al., 2022). Researchers were scheduled throughout the academic year and summer to attend orthopedic surgical cases at the Children's Hospital and randomly collect intervention or control cases. Any researcher's presence in the OR was approved by the circulating nurse, surgeon, and anesthesia team.

In each case, the CanaryBox was placed on an equipment rack containing the OR speakers next to the nurse's computer station. In both intervention and control cases, the CanaryBox receives audio from the computer and transmits it to the speakers. In intervention cases, the CanaryBox also receives patient vital data of heart rate (HR), blood pressure (BP), and oxygen saturation (SpO_2) from the PIIC iX monitors (Philips) and modulates music volume if vitals fall below certain thresholds. The upper and lower bounds for these thresholds were determined by the anesthesia monitor depending on whether the patient is classified as a pediatric or adult patient and also considers their baseline vitals. Researchers were present throughout each case and monitored the CanaryBox for any malfunctions. After each case, the PIIC iX alarm data containing anesthesia providers' response times to alarms was downloaded.

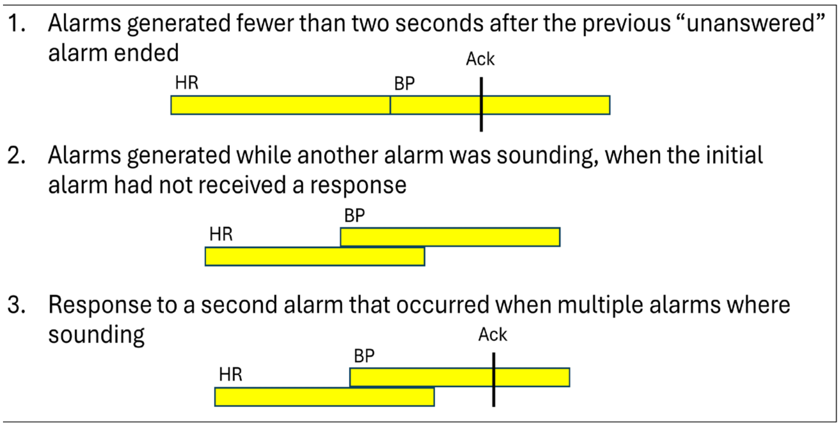

Figure 1. Alarms and responses excluded from further analysis.

Data cleaning

Data was compiled to ensure that only clean cases (cases without interruptions, sufficient music volume, cases containing alarms) were used as part of the 50 intervention and 50 control cases generated at the end of data collection. The obtained PIIC iX dataset contained 5,700 rows of data. Using R (Open Source) and MATLAB (The MathWorks Inc.) scripts, we restructured this dataset into a file containing one line per alarm. We removed 25 alarm notifications from the PIIC iX dataset that met one of two criteria. First, some alarm notifications were doubled. For example, there might be two 'start' notifications for the same alarm that occurred within one second of each other. Second, some alarm notifications were 'orphaned' (for example, there might be a 'start' notification at the end of a case without a corresponding 'end' notification, or vice versa). This resulted in a data file containing data about 1035 alarms. The mean case duration was 63.66 minutes (*SD* = 47.30 minutes). On average, 8.66 alarms occurred per case (*SD* = 7.01 alarms). Next, we classified the recorded alarms by type and severity. We classified clinically relevant alarms into three categories: heart rate (HR) alarms, blood pressure (BP) alarms, and blood oxygen saturation alarms (SpO_2). Likewise, we identified the severity of each alarm.

Then, we determined whether each alarm received a response from a clinician. This required several steps. First, we determined whether an alarm occurred alone or along with other alarms. If an alarm occurred alone (i.e., not overlapping with other alarms) and a clinician response (silencing the alarm or pausing all alarms) occurred between the time of the alarm's onset and its ending, the alarm was coded as having received a response, and the response time was recorded as the time between the alarm's onset and the time of the response. For this analysis, we only included responses that occurred when only one alarm sounded. Thus, if an alarm was sounding (for example, a yellow heart rate alarm) and a second alarm started (for example, a yellow blood pressure alarm) before the first alarm received a response, we did not include either alarm in further analyses, since it was impossible to tell which alarm the clinician was responding to. This is the situation illustrated at the bottom of Figure 1. Fifteen percent of alarms fell into this category. On the other hand, if the first alarm received a 'silence' response and then a second alarm began more than two seconds later, we included both alarms in further analyses.

It is tempting to treat a response to a second alarm that sounds while a previous alarm is still sounding as a response to one event. While it is true that two alarms of the same severity that overlap in time will produce one auditory event, there is a corresponding visual change on the monitor corresponding to the new alarm. This makes it difficult to know whether a clinician response that occurs during the second alarm is a response to the auditory event or to the visual event. For this reason, we chose the conservative approach to dealing with multiple alarms detailed in the previous paragraph. As Figure 1 shows, similar situations occur when two alarms are fewer than two seconds apart, or when two alarms overlap and neither receives a response.

Table 1 shows the counts of clinically relevant alarms. The table shows that blood pressure (BP) alarms were most common at yellow severities. Heart rate (HR) alarms were most common at red severities.

Table 1. Results of clinically relevant alarms.

Severity	**Alarm**	**Condition**		**Total**
		Control	Intervention	
Yellow	BP	206	254	460
	HR	128	168	296
	SpO_2	24	19	43
Red	BP	0	1	1
	HR	22	24	46
	SpO_2	6	3	9
Total		386	469	855

Table 2 shows the proportion of alarms that were acknowledged, grouped by severity. On average, clinicians responded to 70% of alarms that occurred during cases (combining across severities). A chi-square test of these proportions showed that the proportion of alarms receiving clinician responses was higher in the control case than in the intervention case.

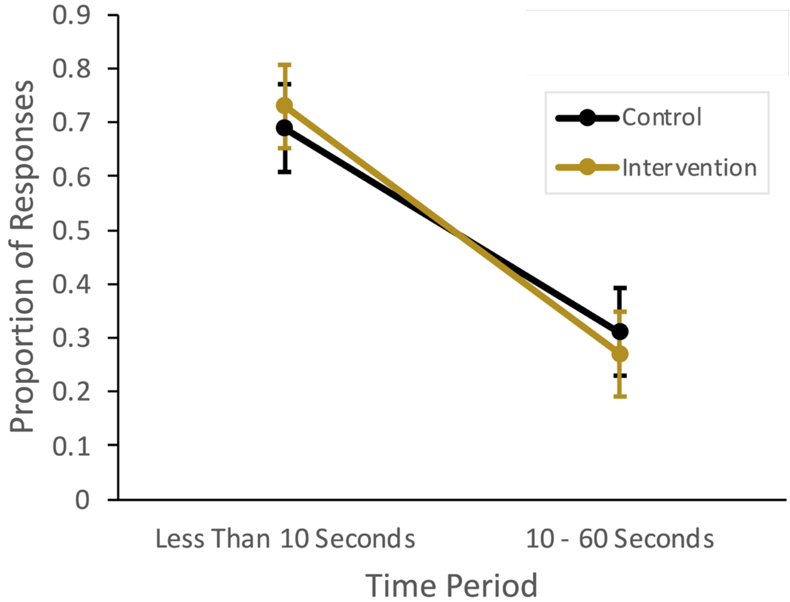

Figure 2. The mean proportion of responses to emergent and urgent alarms in the control and intervention conditions.

Results

Responses to urgent and emergent alarms

We examined whether using the CanaryBox improved clinician responses to emergent and urgent alarms. Emergent alarms are alarms in their first ten seconds of occurrence, and the emergent period was defined as less than or equal to ten seconds after alarm onset. Urgent alarms are alarms that have persisted for more than ten seconds, and the urgent period was defined as from ten seconds to sixty seconds after alarm onset. For each case, we identified responses to emergent and urgent alarms. Then, we calculated the proportion of alarms that occurred during the emergent period and the urgent period. Figure 2 shows the mean proportion of responses to emergent and urgent alarms in the control and intervention conditions. We found a potential 4% increase in responses to emergent alarms when the CanaryBox was used to modulate music volume compared to cases when the CanaryBox was not activated.
Then, we compared these proportions across the control and intervention cases, controlling for case durations and number of alarms. We performed a two-way repeated measures Analysis of Variance using alarm type (emergent vs. urgent) and condition (intervention vs. control) as factors, proportion of responses as the dependent variable, and number of alarms and case duration as covariates. We did not find main effects of alarm type or condition, nor any interaction of these two variables. However, we note that the observed power of the statistical analysis to detect a true effect is only 0.11.

Table 2. Proportion of alarms that were acknowledged, grouped by severity.

Severity	Acknowledged	Condition		Total
		Control	Intervention	
Yellow	No	95	121	216
	Yes	222	264	486
	Proportion Acknowledged	0.70	0.68	0.69
Red	No	0	1	1
	Yes	14	13	27
	Proportion Acknowledged	1.00	0.93	0.96

Discussion

This study examined clinician responses to alarms that occur during surgical cases when an intervention (the CanaryBox) is used to modulate the music volume when alarms occur. We used data collected from a patient monitor about the alarms that occur during a case and the clinicians' interactions with the monitor to evaluate hypotheses about CanaryBox's effectiveness in promoting clinician responses to alarms. We were not able to conclude that the CanaryBox increased clinician responses to emergent alarms. However, the major advance of this project is the development of data analysis algorithms and methods for converting raw patient monitor output files into a format that summarizes the number, type, and severity of alarms generated during a case, as well as clinician responses to those alarms. These tools make it possible to take information that is collected as a normal part of a surgical case and use it to answer questions about whether changes to the surgical environment impact patient physiology and clinician behavior. These data analysis methods could contribute to future studies focused on improving the sound environment in the OR, like the work currently being done by the Smart and Silent ICU project. That project uses 'smart' technology to both reduce the frequency of alarms in

the ICU and detect patients at risk of developing post-intensive care syndrome ('Shhh! SASICU strives for,' 2024). Similarly, the interoperability of the CanaryBox and patient monitoring equipment provides potential opportunities to reduce the cognitive load of clinicians in the operating room and improve patient outcomes.
The lack of evidence in favor of the CanaryBox in our study does not necessarily mean that the CanaryBox does not affect clinician responses during surgical cases. On the contrary, we think it likely that we did not find a positive effect because our study had low statistical power (barely greater than a 10% chance of detecting a true statistically significant effect, according to the results of the ANOVA we used to test for differences in means). Several factors contribute to low-powered studies. While it is possible that the CanaryBox has a real effect that was too small to be detected by our study, we think it is more likely that sources of variability in the naturalistic setting of the study reduced our study's power. Because the data were collected in the operating room (a naturalistic setting), we had no control over the duration of each case, the number, type, or severity of the alarms that occurred during the case, or the strategies that clinicians chose to use to respond to alarms. For example, clinicians could respond to an alarm either by silencing that alarm, which muted only that alarm but did not prevent other alarms from sounding, or by pausing all alarms, which both silenced any current alarms for five minutes, as well as prevented any information about alarm conditions from being written to the PIIC iX data file for the same amount of time.
Our goal is to collect more data with the CanaryBox to improve the power of the statistical analysis. We also plan to conduct lab studies of the CanaryBox to investigate the psychoacoustic features of sound and music in a controlled setting, because the anesthesia team does not wholly have control of the music in the operating room. A lab-based study would allow us to examine responses to music-modulated alarms when confounding factors such as the number of alarms that occur during a case and the duration of a case are controlled across cases. The results of such a study will give us a better sense of the true effect size of music-based interventions such as the CanaryBox, which will, in turn, allow us to plan future naturalistic studies investigating its effectiveness.

Conclusion

The total noise volume in the operating room is loud, and the physical conditions of the operating room contribute to increased physical and mental workload for the clinician. The benefits of music in the operating room are disputable, and its volume may hinder the clinician's response to auditory alarms about the patient. When developing auditory alarms and patient monitoring systems for operating rooms, considerations include reducing the overall noise levels and ensuring that alarms can be discriminated against the background noise. Additionally, because the surgical team typically controls the music being played, clinicians should consider shifting this responsibility to the anesthesia team, which actively monitors the patient's physiological status and can control the music volume and genre as appropriate.
Overall, this study assessed how reducing music volume during alarm events in surgery affects clinician responses to alarms. We implemented the CanaryBox in surgical cases in the OR and collected data about alarm types and clinician responses to the alarms. We developed data analysis algorithms to convert this data to a usable format for analysis of how changes in the surgical environment impact patient physiology and clinician behavior. These results can aid in future studies of alarm volume and in the creation of technologies to improve the performance of surgical staff and the ergonomics of the operating room.

Evaluation of this study on human factors criteria

This study uses a systems approach because it focuses on how the clinician's performance is influenced by the acoustic environment, a factor that significantly impacts the surgical staff's effectiveness yet lacks thorough research. This study is design-driven as it focuses on the elements of the CanaryBox and how to integrate the CanaryBox smoothly with the anesthesia equipment in the operating room. It also considers how sound systems in the operating room can be improved. System performance is also considered because this study considers the performance of clinicians using the CanaryBox device when responding to alarms. Weigl et al. (2016) showed that increased mental workload, process deviations, and disruptions in the operating room resulted in significantly worse technical performance by surgical staff, so all impacts of music must be considered. A future step in this design will be to integrate the CanaryBox, a peripheral device, into current technology like anesthesia machines to improve useability and ergonomics.

Institutional Review Board (Human Subjects)

This study was approved by the Vanderbilt University Institutional Review Board (IRB), IRB #190276.

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Samenvatting

Muziek wordt gebruikt om te ontspannen en efficiënter te werken tijdens operaties, maar de aanwezigheid ervan kan de effectieve controle en aanpak van veranderingen in de vitale functies van patiënten door zorgverleners belemmeren. In dit onderzoek werd nagegaan hoe het

verminderen van het muziekvolume tijdens alarmsituaties in de chirurgie de reacties van clinici op alarmsituaties beïnvloedt. We gebruikten het CanaryBox-apparaat in de operatiekamers van het Vanderbilt University Medical Center. Dit apparaat moduleert het volume van de achtergrondmuziek op basis van bepaalde waarden van de vitale functies. We implementeerden de CanaryBox in 50 chirurgische gevallen en 50 zonder volumemodulatie. We konden niet concluderen dat de CanaryBox de respons van artsen op noodalarmen verhoogde, maar schrijven dit toe aan de lage statistische power van het onderzoek (waargenomen power = 0,11) en niet aan het gebrek aan effectiviteit van de CanaryBox. Het belangrijkste resultaat van deze fase is de ontwikkeling van algoritmen voor gegevensanalyse die de ruwe output van patiëntmonitoren omzetten in bruikbare formaten om te bestuderen hoe veranderingen in de chirurgische omgeving de fysiologie van de patiënt en het gedrag van de arts beïnvloeden.

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Contribution to the human factors criteria

This study examines the volume modulation of music in the OR and its effect on clinicians responding to patient vital sign alarms. This can be used as a foundation for improving the acoustic conditions in the operating room for clinicians.

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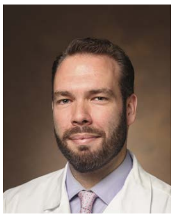

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