DOI: 10.61782/fa.2025.0523

FORUM ACUSTICUM EURONOISE 2025

LISTENING TO HOSPITALS: TOWARDS AN ASSESSMENT TOOL OF AUDIO DATA ETHICS FOR ICUS

Andrea Giglio[1*] **Sara Lenzi**[2,3] **Simone Spagnol**[4] **Elif Özcan**[1]

[1] Critical Alarms Lab, Faculty of Industrial Design Engineering, TU Delft, The Netherlands
[2] Deusto Design Research Group, University of Deusto, Bilbao, Spain
[3] Ikerbasque Basque Foundation for Science, Bilbao, Spain
[4] Department of Architecture and Arts, Iuav University of Venice, Italy

ABSTRACT

In Intensive Care Units (ICUs), excessive non-human and human sounds cause behavioural and psychological problems in patients and reduce professionals' job satisfaction and performance. Rather than relying solely on quantitative (psycho/acoustic) metrics, their combination with qualitative data (soundscape descriptors) provides the most reliable method to assess this context, as it considers the perceived environment. Moreover, sound event detection (SED) and classification techniques enhance the reliability of the assessment model. However, they also raise ethical concerns regarding vulnerable patients' rights. Therefore, the development of audio data ethics is essential for designing research strategies that strike a balance between patients' rights and research effectiveness. This study aims to define audio data ethics based on expert interviews and outline the basics of a tool to identify and assess risks for mitigation strategies. Results indicate that quantitative and qualitative data present minimal ethical risks, but audio recording for event identification poses significant ones. Managing these risks helps prevent patient re-identification, discrimination, and mistrust in research. The results will be validated in an ICU.

Keywords: *Audio data ethics; Sound event detection; Soundscape measurement; ICU*

**Corresponding author*: *a.giglio@tudelft.nl.*

1. INTRODUCTION

Intensive care units (ICUs) are structured systems that offer specialised medical and nursing care for critically ill patients. Over the years, with the advancement of technology, the levels of sensory stimuli in these acoustic environments have increased significantly, leading to higher noise levels. Due to the significant consequences of acoustic noise, the WHO recommends that noise levels in ICUs should not exceed 35 dBA during the day and 30 dBA at night, with no peaks exceeding 45 dBA [1]. However, the available evidence indicates that the noise levels measured in ICUs are much higher than what is recommended [2]. Thus, there is a need for not only monitoring the acoustic environment of such healthcare spaces, but also identifying the harmful sound sources for implementing noise mitigation strategies [3].

Furthermore, advancements in computational models leveraging sound data offer possibilities for automatic sound event detection (SED) and recognition [4]. Current needs for acoustic comfort and advancements in computing technologies encourage us to develop a novel sound monitoring system to be used inside ICUs [5]. However, such a system would need to rely heavily on listening to the environment, posing ethical concerns regarding vulnerable patients' rights. Therefore, developing strategies to mitigate ethical risks is essential for designing research in ICUs, striking a balance between patients' rights and research aims.

1.1 Negative effects and acoustic assessment in ICUs

Patients, families, and healthcare professionals experience excessive sounds in all ICUs, including adult, paediatric,

and neonatal care [6, 7]. For professionals, alarms can induce stress and desensitisation [8, 9] and impact job satisfaction and performance [10]. Besides alarms, staff conversations and activities are significant disturbances in critical care [11] along with non-human sounds (such as ventilation systems, telephones, and delivery trolleys) [12] and human sounds (conversations, voices etc.).

Traditional assessments of sound quality in ICUs depend on sound pressure level (SPL) measurements, which do not adequately reflect how people perceive sound quality in context, nor do identify the sources of unwanted sounds. This identification is essential for enhancing the overall sound environment in ICUs, which should account for human perception. Accurate soundscape descriptions should be supported by identifying and classifying individual sounds, using methods like listening tests and categorisation based on perceived similarity [13]. Regularly occurring sounds in a specific environment have high contextual relevance [14], and listeners can judge their appropriateness [15]. Combining subjective and perceptual information with quantitative analysis enables the representation of sound quality as humans perceive it. Thus, studying the appropriateness of sound events in the ICU soundscape makes the representation of sound quality as close as possible to how humans perceive and interpret it. Identifying sound sources becomes more relevant when combining objective measures (i.e., acoustic and psychoacoustic metrics, sound event detection) with self-reported subjective and perceptual experiences (i.e., the perceived affective quality of a soundscape). However, ethical issues arise when the identification of sound events becomes the goal of the study, as daily sounds based on human-environment interactions need to be recorded, listened to and analysed in an ecologically relevant way.

1.2 The ethical problem in listening to the hospital

If, on one side, audio data intelligence promises to bring a reliable picture of the acoustic quality of the ICU environment, on the other side, it raises significant ethical issues [16]. Listening in highly functional environments is an individual experience and is influenced by hearing function, physical position and role in the environment, and the task at hand. In the case of ICUs, two main categories of sound sources can be identified: non-human and human. The first group refers to the sources emitted by technological instruments that enable the operability of the room through air circulation, heating and cooling systems. The noise of these systems depends on the type of HVAC, but in most cases, the inlet and outlet terminals have the main impact on the noise generation. Another technological system is the medical devices that continuously monitor patients' vital parameters and communicate information to nurses, alerting them through audiovisual alarms. Among these systems, it is possible to identify other medical equipment that supports the patients' vital functions, rather than monitoring their vital signs (i.e, infusion pumps).

The other category of sound sources concerns human activities. Patients who require assistance can generate sounds from caregiving activities such as daily grooming, communication, and education provided by healthcare teams and family members [17]. Among these activities, incidental events can occur. The involuntary hitting of an object (e.g., a pen dropping to the floor), the rubbing of objects on sheets, or the door opening or closing characterise the acoustic environment. Sounds related to the human voice include talking, singing, laughing, crying, screaming, shouting, humming or yelling. Among them, intelligible conversations raises the main ethical issues in audio recording.

Even if the existing studies aim to analyse acoustic quality in ICU with several methodologies, considerations about ethical problems are missing, and lack of know-how may limit the data collected and its analysis, hindering any improvement of the quality of ICU soundscapes. This paper aims to identify the ethical risks associated with audio recording for participants in ICU spaces. Below, the paper presents the feedback collected through expert interviews on data ethics in design, medical, and research contexts. The results are processed considering the main ethical risks posed by measurements of both qualitative and quantitative data, as well as the process of listening.

2. EXPERT INTERVIEWS

Due to the paper's exploratory aim, a qualitative approach was adopted to uncover hard-to-quantify phenomena, such as ethical issues caused by audio recording [18]. Expert interviews and thematic analysis were used to gather diverse perspectives on ethical sound data collection in ICUs. They provide valuable insights into varied opinions, highlighting both similarities and differences in the participants' experiences, enabling assessment from multiple perspectives. In this study, one-to-one interviews were conducted with experts to discuss and define the concept of data ethics and then understand how it can be applied for the purpose of this research. This approach seeks

to maintain an open view towards new data while also drawing valuable insights through a thematic perspective, enhancing the overall understanding of audio data ethics.

2.1 Methodology and Participants

Experts were selected through purposive sampling based on their knowledge of data collection and ethics in the human-centred design, medical context and acoustics. In qualitative research, purposive selections are made to align the sample with the specific context and goals of the study as a more viable alternative to random sampling. Experts make intentional selections to target specific areas of interest, bolstering the reliability of the opinions collected through their experience and knowledge.

In representation of the three mentioned domains, we chose to include Jos Kraal (abbr. JK), Assistant Professor of Health Behaviour Change and member of the Human Research Ethics Committee (HREC) at TU Delft; Mathieu van der Jagt (abbr. MvJ), Intensivist and Associate Professor at the Adult Intensive Care Department and member of the Medical Ethics Review Committee (METC) at Erasmus MC Rotterdam; and Thomas Deacon (abbr. TD), Research Fellow in Design Research for Sound Sensing at the University of Surrey involved in the project "AI for Sound". Semi-structured interviews were conducted with each participant, either in person or online, in March 2025. The duration of each interview was approximately 40 minutes. The session was moderated by the first author based on questions shared prior to the interview.

Before the interviews, participants received details about the purpose of the study and the interview process. Interviews began after participants had agreed to allow to record and quote their opinions in this paper. At the beginning of each interview, the experts were provided with a brief overview of the research concept and objectives. All interviews were recorded, and their content was transcribed automatically with the Microsoft Teams application. The questions were framed according to the three categories defined by Floridi: ethics of data, ethics of algorithms, and ethics of practices [19, 20]. The ethics of data address ethical challenges related to collecting and analysing large datasets that derive from human-centric data. The ethics of algorithms addresses issues posed by the increasing complexity and autonomy of algorithms broadly understood (e.g. including artificial intelligence and machine learning). Nevertheless, it regards the moral responsibility and accountability of the researchers to unforeseen undesired ethical risks. The ethics of practices addresses the pressing questions concerning the responsibilities and liabilities of researchers in charge of data processes that may ensure ethical practices fostering both the progress of data science and the protection of the rights of individuals.

Thematic analysis was applied to the transcriptions and notes to identify, analyse, and present patterns of meaning for a detailed organisation and explanation of the collected expert opinions [21]. The analytical process began with data discretisation (or coding), i.e., organising excerpts based on themes using a semantic approach. An example of the process leading from coding to theme formation is provided in Table 1

Table 1. Example of coding process for Theme 1.

Example of excerpt	Code	Theme
"The main risk ...[is]... identification of individuals and situations." "To avoid this kind of risk [identification), it is essential to have a plan developed in collaboration with a data expert, also known as a data steward. "	necessity to provide high degree of privacy	trade-off between ethics and science
"Data ethics concerns the quality of data and who handles it to ensure good, high-quality research." "The research often requires double-checking processes of investigation. This may necessitate knowing who the patient is, as most data is gathered from medical records. "	reliability of data collection	

2.2 Results

Through the thematic analysis of the interviews, two main themes have been identified: informed consent and trustworthiness in research, and the trade-off between ethics and science. While these are distinct lines of research, the ethics of data, algorithms, and practices are intertwined. This is why it may be preferable to speak in terms of three axes defining a conceptual space within which ethical problems can be represented as points identified by three values each. Most of them do not lie in one of the three categories. The results highlight the emerging topics

by using direct interviewees' quotes.

2.2.1 *Informed consent and trustworthiness in research beyond the ethical practice codes*

Informed consent plays a crucial role among the strategies for managing ethical risks. Strategies that clarify the process of gathering information from involved users are essential. Nevertheless, traditional informed consent is not always the best solution. In the case of audio data collection in the ICU:

"The informed consent procedure needs to account for more than individual people, so it's the idea that audio captures shared environments. So, the informed consent needs to also have a social aspect to it. [A simple version of..] *The informed consent should consider eventual visitors... This can lead to a hierarchy that should be reflected in the size of the informed consent."* (TD)

This can lead to adaptive informed consent (consent that can be tailored by participants' preferences while ensuring encrypted sensitive data) or multiple versions of the informed consent in the case of multiple users, providing the opportunity to choose when to take measurements. This could work for patients and their families, but for the healthcare team, may require a different approach.

"In the healthcare context, it could be important to be more creative. This method should respond to the question: So how do you adapt that trust process to a rolling recruitment process in a way that that would be the interesting bit of work to do there?" (TD)

The sense of trust in audio data collection and its processing must be built with the healthcare team through open discussions, such as *workshops*, prior to obtaining informed consent.

During the workshop, *"The involved users had the option to query and question about the research in a clear sense. Create a participatory space to make sure they understand and agree in a discursive way."* (TD)

The style of language used in both informed consent and the workshop must make the process comprehensible to the participants. Trust is based on clear goals and avoiding excessive technical language. In particular, the anonymisation process and the mitigation strategies developed to reduce privacy risks must be clearly explained. As researchers, it is important to give an evidential commitment that can be kept based on what is written in the informed consent.

"During the research process, ensure that the donor is aware of the research and their role in it. Provide an informed consent explanation detailing the aim, the process, and the outlook of the project. Respecting donors' trust and privacy should be viewed not just as a personal responsibility but as a representation of the ..[TU Delft].. community." (JK)

Allowing for adaptation of the sound and acoustic measurements to fit the situation can be another strategy to enhance trust in the research and achieve a higher number of signed informed consents. However, this approach may compromise dataset consistency (e.g., collect the right amount of informed consent).

2.2.2 *Trade-off between ethics and science*

The reliability of a dataset is crucial, and it is essential to balance ethical considerations with the objectives of the research project.

"Data ethics concerns the quality of data and who handles it to ensure good, high-quality research." (MvJ)

To find a trade-off between navigating the degree of harm and achieving research targets, a sound data collection strategy must avoid over-collection. Statistical methods help create balanced samples in certain areas with the purpose of removing redundant data.

"You know where you say we've got all these different rooms with these different acoustic conditions. We need at least 12 hours per room to do our data modeling. OK, how do we get 12 hours? We don't just record 12 hours. Let's record 36 or create a 36 hour window where we can record so that we can let deletions be included in as redundancy in the system. " (TD)

At the same time, sound detection can lead to the identification of activities and individuals.

"The first important ethical value is privacy." (MvJ)— *"The main risk ...[is]... identification of individuals and situations."* (JK)

To mitigate risks, academic institutions have created a checklist to support risk management during the research application phase. In human-centred design involving expert participants, the personal data workflow guide stresses the importance of protecting subjects when data comes from interviews, surveys, product testing, social media, or third parties. It highlights the need to assess potential harm if participants' identities are linked to their data, even after publication. One interviewee identified that it is crucial to develop strategies to mitigate the risks and communicate them to the data donor:

"The data management protocol within that then becomes an important evident aspect for you to supply to gain access, which is and has to be adhered to as well. So

these are the pipelines of data in processing—we'll call it anonymisation and transcription." (TD)

Nevertheless, anonymisation does not always fulfil the needs of research in the medical context.

"The research often requires double-checking processes of investigation. This may necessitate knowing who the patient is, as most data is gathered from medical records. Research may require checking more than one entry in a dataset, and sometimes, this may mean stepping back to the raw data. In this case, informed consent is the tool used to explain the process."(MvJ)

Fulfilling checklists and tools required by ethics committees is necessary, but perceptions differ when comparing design and medical contexts. In the human-centered design context, which incorporates expert participation, an extensive guide with more than 30 answers is perceived as exhausting and identified as a limitation by researchers.

"Most of the research developed at IO-Delft (TU Delft Faculty of Industrial Design Engineering) *focuses on design processes, typically yielding tangible outcomes. Completing the checklist and responding to committees takes time. The concept of the ethical risk process as a limited step in the research may depend on several aspects, including the need for practical output, which leads to the challenge of balancing good practice with good research."* (JK)

In the medical context, ethics risk assessment is more accepted, and this step is planned in every research project schedule.

"The administrative work required for research is quite impressive, time-consuming, counterproductive, etc., but necessary." (MvJ)

Informed consent became the main instrument to make the process clear to the participants and avoid decreasing trust in scientific research.

3. DISCUSSION: ETHICAL RISKS AND MITIGATION STRATEGIES

Our discussion below focuses on developing a framework for understanding and assessing the ethical risks associated with sound and audio data collection used to develop algorithms and systems to monitor and assess the quality of the acoustic environment, tailored to the needs of ICUs.

3.1 Ethical risks and mitigation strategies for quantitative and qualitative data

A-weighted sound pressure levels are calibrated to align with human ear responses and are the standard for indoor measurements [22]. Data can be stored on a hard drive and then downloaded at the end of the measurement without disrupting ICU staff activities. Raw data is processed to output acoustic descriptors (LA_{eq}, LA_{peak}, and L_{90}) in both frequency and time domains, as well as psychoacoustic parameters (loudness, sharpness, psychoacoustic tonality, roughness, and fluctuation strength). Informed consent from patients and families is crucial, as it involves explaining the measurement process and building trust in this complex discipline. The consent also outlines the ethics code approved by the hospital's ethics committee. Workshops for the medical team can enhance the understanding of acoustic measurements.

Ethically, sound pressure levels pose minimum risk as they measure the adequate sound wave pressure relative to a reference (20 μPa), which makes them incapable of identifying specific activities, particularly speech. Measures are provided to give participants adequate comprehension over the process with informed consent (for the patient and family) and specific communication for the healthcare team. In the ethics of algorithms, the risks are negligible because a strong anonymisation process is applied, ensuring that the data are not traceable to an individual. Regarding the ethics of practice, donors have adequate control over their data since they are aware that they are not providing personal data as specified in the informed consent. The reliability of the process is established because the latter specifies the ethical commitments the researchers are fulfilling. In this case, the trade-off between the ethical respect for the participants and the purposes of the research is balanced, as the probability of harmful events is negligible. Moreover, the informed consent with accessible language (also in Dutch) allows to obtain a long period of measurement.

Among the qualitative methods for evaluating soundscapes, considering the architectural characteristics of an ICU room (a small space with, at most, one bed), the questionnaire defined in Method A (ISO/TS 12913-3:2019) is the most appropriate. The questionnaire responses, which comprise four parts (sound source identification, perceived affective quality on eight different scales, surrounding sound environment, and appropriateness of the surroundings), report numerical evaluations that are converted into points on a two-dimensional model through mathematical processing. The risk of identification is minimized by deleting personal data (e.g., name, age) and timestamps after processing. Questionnaire explanations are provided in the informed consent, shared with patients and families, and discussed in workshops for medi-

cal staff. Data is aggregated using a mathematical method to capture perceived affective attributes. Ethical standards are upheld through clear consent procedures and workshop discussions. A high response rate supports data reliability, and the absence of ethical risks does not compromise the results. Trustworthiness is gained thanks to a clear informed consent and explanation of the answers' processing.

3.2 Ethical risks and mitigation strategies for sound event detection and classification

Sounds must be identified and annotated to describe how they contribute to a soundscape, via methods including manual ratings through listening tests [23] and categorisation based on perceived similarities [13]. Annotation procedures are, in fact, essential for training an automatic sound event detection/classification model able to automatically classify different types of sound events [4]. A large number of examples for each sound source type is necessary to cover acoustic variability as a result of factors such as instance-related influences (e.g., similar sounds caused by different people) and environmental influences such as non-predictable situations. To measure the highest number of events possible, day-long measurements have to be set. Non-experts (i.e., people who are not involved in the ICU activities) should be involved in the raw audio data slicing task so that all sound events are safely separated from their audio context. Sound excerpts can then be categorised by experts (i.e., nurses) using a similarity sorting task and labelled as categories according, e.g., to the categories idenfied in Section 1.2. These sound excerpts are further analysed to extract standard acoustic features to feed machine learning algorithms for detecting sound events. Furthermore, experts (i.e., nurses) can indicate the relevance of these sounds to the overall ICU context and their preferences to keep or discard these sounds to support the separation between 'useful' and 'harmful' sounds.

The slicing of raw audio could pose a significant ethical risk due to the type of data that is collected. The main concern is about recording conversation events, as this leads to the identification of the participants and the comprehension of the conversations themselves. The probability of these risks occurring is high, and if not properly mitigated, the impact could result in severe harm. Mitigation strategies must be developed according to the typology of sound sources, audio storage, recording methods, audio processing, and final usage .

The intent of SED is the identification of the occurrence of sound sources (human and non-human) and their contextual relevance rather than the identification of the participants through their speech and behaviours. For this reason, a pre-processing step should be added to the SED methodology in order to make conversations in audio files non-intelligible through a speech filtering algorithm. Speech filtering algorithms are techniques used to modify the quality and intelligibility of speech signals. Nevertheless, audio slicing should be carried out by non-experts who have no perception of the ICU context, while the sliced audio should be categorised by experts (i.e, nurses).

The research team demonstrates its commitment to previous mitigation strategies through strong data governance, including clear data management policies and ethical practices. Given the risk of data breaches, it's crucial to prevent unauthorized access to audio recordings. Using a secure digital research environment in the hospital, raw data is stored in the cloud and accessible only to authorized team members. Participants must be informed about the ICU recording process. Therefore, a tailored public communication strategy is needed, accounting for the diverse ways individuals may become audio donors. The healthcare team (for example, specialised doctors) and nurses contribute to the ICU's acoustic environment through conversations with patients, external visitors, and among themselves, as well as through physical interactions with the space. Given their permanent presence in the space, informed consent can be gathered at the beginning of the project. In case it is necessary, a specific workshop could help clarify the different aspects of the mitigation strategy for ethical risks. Patients, family members, and any other external visitors must be informed about the audio recording before entering the space. Nevertheless, in both previous cases, an adaptable system could be developed in order to stop the recording in case the participants did not intend to be recorded at a specific moment (Fig. 1).

4. CONCLUSIONS

This study presented ethical considerations related to sound and audio data collected in intensive care units (ICUs) in the wider frame of listening to hospitals. The findings are based on a thematic analysis of expert interviews and literature references with the primary aim of developing a matrix of ethics risk assessment. The key findings pertain to two key areas: 1) the identification of the main ethical risks and mitigation strategies for the categories of ethics of data, ethics of algorithm, and ethics

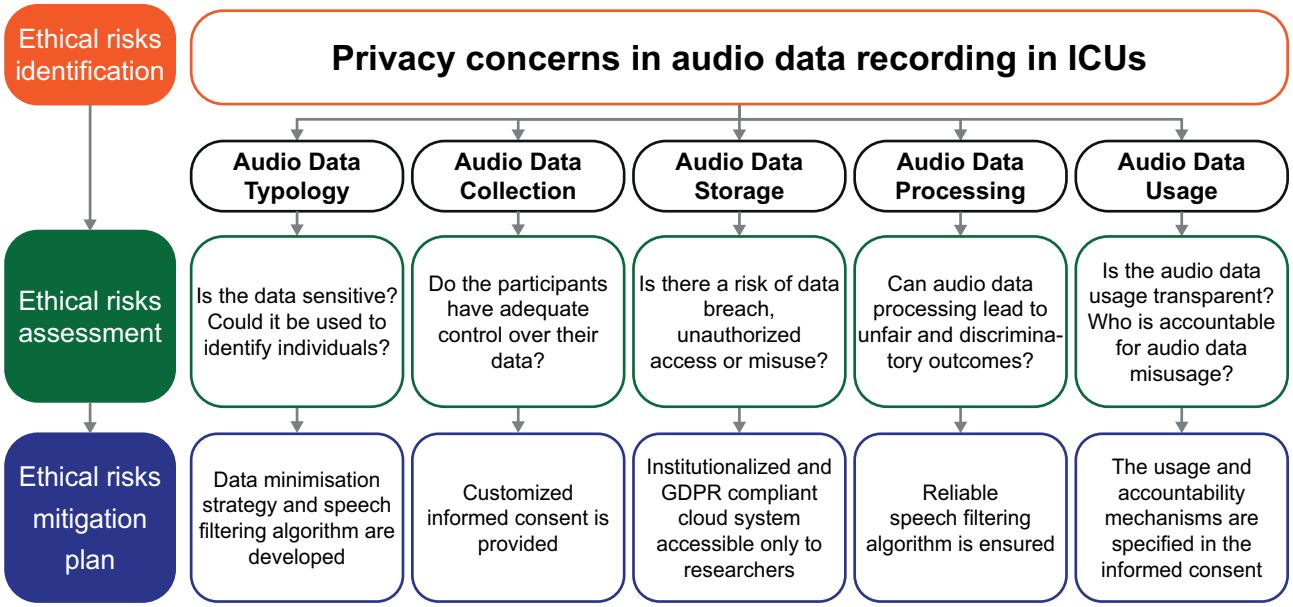

Figure 1. Ethical considerations on privacy in audio data recording in ICUs

of practice, and 2) the delineation of an operational guide associated with the specific data typology of ethics, risks, and mitigation strategies. The interviews have presented two main emerging topics: informed consent and trustworthiness, and the trade-off between ethics and science. The topics that emerged from the questions categorised according to ethics of data, ethics of algorithm and ethics of practice show strong intertwined relations among them. It is not possible to assess data collection without gaining trust from data donors (the ethics of data), providing mitigation strategies for anonymisation (the ethics of algorithm), and demonstrating researchers' competencies (the ethics of practice).

Based on these considerations, the ethics risks and mitigation strategies are developed and presented. It is evident that audio event detection and classification represent highly critical steps, as strong mitigation strategies for anonymisation must be developed to ensure privacy. Moreover, the measurement and collection of quantitative and qualitative data, even if it involves data with a low risk of harm, requires attention to create transparency and awareness amongst participants. The resulted considerations have to find consistency based on literature and experts' experiences. Nevertheless, its effective role will be tested in a real case study.

5. ACKNOWLEDGEMENT

This publication is part of the Auditory Footprints project which has received funding from the Dutch Research Council (NWO)'s Open Technology Programme under grant agreement No. 20853.

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