Sonic ambiances through fundamental needs
An approach on soundscape interventions for intensive care patients

Louwers, Gijs; Pont, Sylvia; Gommers, Diederik; van der Heide, Esther; Özcan, Elif

DOI
10.1121/10.0030470

Publication date
2024

Document Version
Final published version

Published in
Journal of the Acoustical Society of America

Citation (APA)
Louwers, G., Pont, S., Gommers, D., van der Heide, E., & Özcan, E. (2024). Sonic ambiances through fundamental needs: An approach on soundscape interventions for intensive care patients. *Journal of the Acoustical Society of America*, *156*(4), 2376-2394. https://doi.org/10.1121/10.0030470

The Journal of the Acoustical Society of America

OCTOBER 11 2024

Sonic ambiances through fundamental needs: An approach on soundscape interventions for intensive care patients[a)]

Gijs Louwers ; Sylvia Pont ; Diederik Gommers ; Esther van der Heide ; Elif Özcan

J. Acoust. Soc. Am. 156, 2376–2394 (2024)
https://doi.org/10.1121/10.0030470

JASA ARTICLE

Sonic ambiances through fundamental needs: An approach on soundscape interventions for intensive care patients[a)]

Gijs Louwers,[1,2,b)] Sylvia Pont,[1] Diederik Gommers,[2] Esther van der Heide,[3] and Elif Özcan[1,2]

[1]*Faculty of Industrial Design Engineering, Delft University of Technology, Delft, The Netherlands*

[2]*Department of Adult ICU, Erasmus Medical Center, Rotterdam, The Netherlands*

[3]*EHM Research, Hospital Patient Monitoring, Philips, Eindhoven, The Netherlands*

ABSTRACT:
We explored the underpinnings of providing positive listener experiences for intensive care unit (ICU) patients with compositions of added sounds. Our objective was to derive an approach to such interventions based on soundscape perception and need fulfillment. In one study, we gathered qualitative empirical data about imagined soundscapes where nine fundamental needs were fulfilled. Hierarchical clustering and thematic analysis showed that imagined soundscapes clustered into four types of sonic ambiances, i.e., affective connotations with soundscapes: Comfortable, Pleasurable, Motivating, or Stimulating ambiances. We derived four design parameters to achieve these ambiances with sound compositions: eventfulness, sonic ambiance qualities, narrative structure, and sound distribution. A sound artist was asked to use these parameters to create sound compositions. In a listening experiment, we examined their effects on the perceived pleasantness and eventfulness of soundscapes and on listeners' experienced pleasure and arousal. Soundscapes were perceived as pleasant with varying eventfulness in line with our structured approach. We found a strong correlation between pleasantness and with listener's pleasure and a moderate correlation between eventfulness and with listener's arousal. Finally, we suggested that in future research, three sonic ambiance types should be considered rather than four. Concluding, we showed that our need-driven approach could form a promising way to support ICU patients.

 https://doi.org/10.1121/10.0030470

(Received 23 May 2024; revised 23 August 2024; accepted 19 September 2024; published online 11 October 2024)

[Editor: Francesco Aletta] Pages: 2376–2394

I. INTRODUCTION

Since the days of Florence Nightingale, intensive care units (ICUs) evolved into highly advanced and complex care environments, increasing the chances of survival of the critically ill (Kelly *et al.*, 2014). Nevertheless, an estimated 50% of patients survive their ICU stay with lasting psychological impairments such as post-traumatic stress disorder and anxiety (Geense *et al.*, 2021). A well-known risk factor for the development of these symptoms is stress experienced while in the ICU (Lee *et al.*, 2020). Sub-optimal environmental conditions are known to contribute to this stressful experience (Darbyshire *et al.*, 2019). Among environmental stressors, patients, relatives, and clinical staff rank sound among the highest in perceived severity (Krampe *et al.*, 2021). Listening to sounds caused by other patients, staff conversations, alarms, or machinery (Xie *et al.*, 2009) causes sleep disruptions (Elbaz *et al.*, 2017) and loss of orientation (Ballard, 1981). As a result, ICU soundscapes, i.e., the acoustic environment as perceived or experienced by a person or people in context (ISO, 2014), are experienced negatively (Johansson *et al.*, 2012). The elevated sound levels associated with ICUs are widely documented, amounting to 50 dB(A) LAeq, with peaks of over 100 dB(A) (Darbyshire and Duncan Young, 2022).

Some hospitals responded by introducing single-patient room layouts as part of noise reduction strategies, which positively affected patient and staff comfort (Luetz *et al.*, 2019; Vreman *et al.*, 2023; Delaney *et al.*, 2019). However, while solving the initial problem of sound level (Özcan *et al.*, 2024), we discovered that the seclusion of patients to single-patient rooms could also lead to new issues. In a previous qualitative investigation, we found that patients in single-patient ICU rooms experienced the soundscape as alienating, unvaried, unfamiliar, and disruptive (Louwers *et al.*, 2024). Medical alarms, sound-proofed doors, and a lack of variety in room soundscapes negatively impacted patients' experiences, resulting in wakefulness, anxiety, and disorientation.

There are opportunities to utilize the soundscapes of secluded single-patient rooms as a source of restoration and other positive user experiences. In a collaborative workshop with ICU stakeholders (Louwers *et al.*, 2024), we developed concepts for hospital soundscape interventions (Busch-Vishniac and Ryherd, 2023) for ICUs that provide patients with compositions of sounds inside their rooms. Other studies have shown the merit of providing such interventions for comparably vulnerable patients (in dementia care) to evoke

[a)]This paper is part of a special issue on Advances in Soundscape: Emerging Trends and Challenges in Research and Practice.

[b)]Email: g.l.m.louwers@tudelft.nl

positive associations (Devos *et al.*, 2019; De Pessemier *et al.*, 2023). In single-patient ICU rooms, a soundscape augmentation could evoke various familiar, positive associations through meaningful sensory representations (Özcan and Van Egmond, 2007) of added sound compositions that are not provided by the existing soundscape. For example, providing physical access to nature is not feasible for ICU patients, with some exceptions such as a rooftop terrace provided to ICU patients by Rijnstate Hospital (Rijnstate, 2023). By adding natural sounds to existing pediatric ICU soundscapes, significant improvement on perception of pleasantness of the soundscape was achieved in an experimental set up (Özcan *et al.*, 2023).

This positive effect could be explained by the affective evaluation associated with the soundscape, which we will refer to as the *sonic ambiance*. Previous research established that perceived affective meanings of soundscapes can affect listeners' valence and arousal (Russell, 2003; Fan *et al.*, 2015). Given these effects, sonic ambiances could serve as functions of ICU soundscapes to address the needs of patients. As product functions are commonly developed to address specific user needs (Hassenzahl and Diefenbach, 2012; Wiklund-Engblom *et al.*, 2009), sonic ambiances should be dependent on the auditory needs of the listener, such as safety or information (Van den Bosch *et al.*, 2018). However, due to recent trends towards lighter sedation, ICU patients are awake more than before (Holm and Dreyer, 2017). This requires the consideration of a more comprehensive view of needs, such as pleasure, dignity, or a sense of purpose (Özcan *et al.*, 2020).

While patients may seem to have different motivations than healthy individuals, studies into psychological needs and well-being have shown that in essence the same needs are present for everyone and exist regardless of culture, age, or lifestyle (Sheldon *et al.*, 2001; Tay and Diener, 2011). We assume that patients, like healthy individuals, listen with varying intent (Tuuri and Eerola, 2012; Özcan *et al.*, 2022) for auditory cues to fulfill their psychological needs. For example, patients find reassurance by listening to the footsteps or voices of nurses coming in from the hallway. Since these needs, such as reassurance, are present in every individual, they are considered *fundamental* to human experience. Revising earlier fundamental need typologies, researchers created a design-focused framework made up of thirteen fundamental human needs: the needs for *Autonomy*, *Beauty*, *Comfort*, *Community*, *Competence*, *Fitness*, *Impact*, *Morality*, *Purpose*, *Recognition*, *Relatedness*, *Security*, and *Stimulation* (Desmet and Fokkinga, 2020). Naturally, the manifestations of these needs (i.e., sub-needs) for patients and healthy individuals (Huang and Desmet, 2023) may be different depending on the situation.

Here, we address the question of whether soundscapes are need-specific and distinctive. For example, would soundscapes that provide distraction during painful care procedures (e.g., Stimulation) have different characteristics than soundscapes that provide reassurance during long stretches of time without visitation (e.g., Relatedness)? There are many ways to compare these characteristics of soundscapes. They could be compared in terms of their psychoacoustic indicators, such as loudness or sharpness (Engel *et al.*, 2021). However, co-existing with the more objective characteristics of sound, the subjective features of hospital soundscapes may be equally important (Mackrill *et al.*, 2013). For example, they could be compared by their sonic

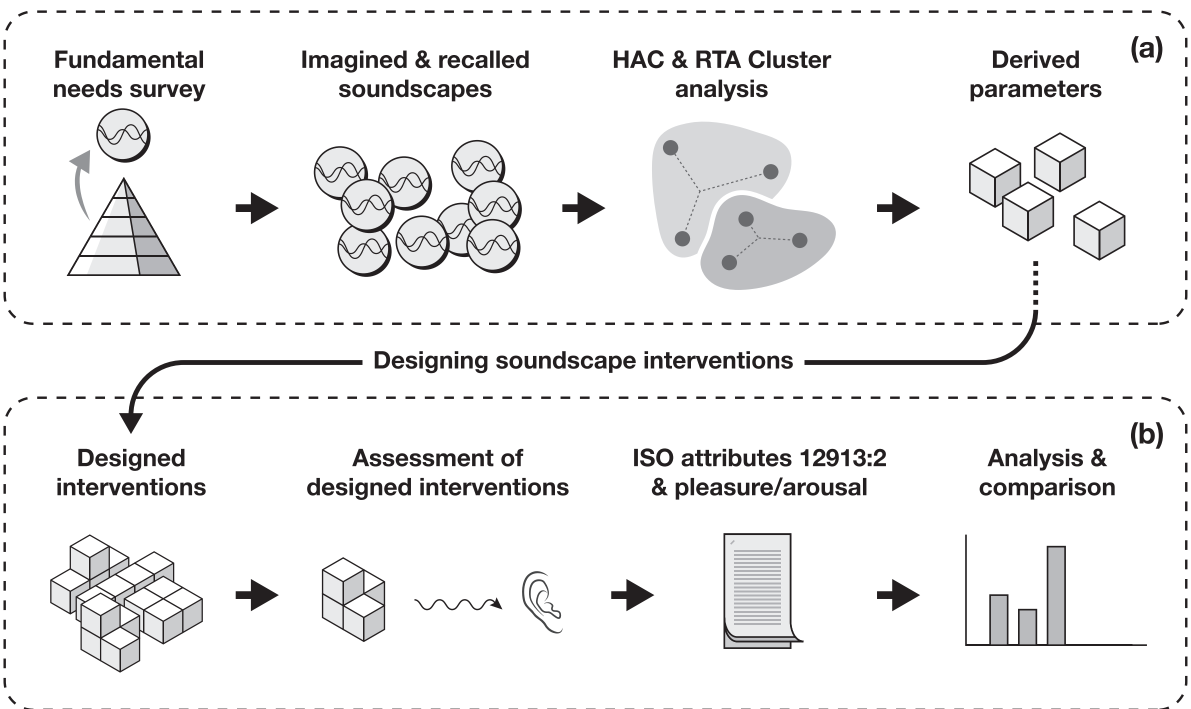

FIG. 1. Flow diagram of steps taken in Study 1 (a) and Study 2 (b).

https://doi.org/10.1121/10.0030470

ambiance qualities (e.g., distracting/reassuring), sound sources (Lenzi *et al.*, 2021), or spatial-temporal organization of elements (Çamci, 2022). Alternatively, soundscapes can be compared in terms of perception. Semantic perceptual dimensions such as pleasantness and eventfulness are used to measure soundscape perception in outdoor environments (Davies *et al.*, 2014; Aletta *et al.*, 2016). Comfort and content are generally used for indoor residential environments (Torresin *et al.*, 2020; Torresin *et al.*, 2023). Last, they can be compared in terms of their effect on listeners in terms of their emotional state: pleasure and arousal (Fiebig *et al.*, 2020).

In the present paper, we investigated the perceptual, qualitative, and emotional relationships between fundamental needs and soundscapes. Specifically, our objectives were to derive an approach for designing sound compositions based on soundscape perception and fundamental need fulfillment and to assess its effectiveness in a lab ICU setting. We therefore performed two studies with two independent participant populations, see Fig. 1.

In Study 1 [Fig. 1(a)], we developed our design approach. We gathered qualitative and quantitative data via a survey and conducted a hierarchical agglomerative clustering (HAC) and reflexive thematic analysis (RTA). On the basis of the results, we derived four design parameters based on perceptual (i.e., pleasantness/eventfulness) and qualitative (i.e., sonic ambiance qualities, narrative structure, sound categorization) characteristics of soundscapes that we found to be related to the fulfillment of specific needs. Next, a sound artist designed various sound compositions based on these design parameters, which are included in the supplementary material.

In Study 2 [Fig. 1(b)], we evaluated the effectiveness of our approach in a lab ICU setting. We evaluated the effects of the designed sound compositions on perceptual (i.e., pleasantness and eventfulness (ISO, 2018), emotional (i.e., pleasure and arousal), and qualitative (i.e., sonic ambiance quality and sound distribution) levels. In our analysis, we compared these effects to the intended design parameters.

Hence, the research questions addressed in this paper were the following:

(i) Can perceptual and qualitative characteristics of soundscapes be related to the fulfillment of different fundamental needs and serve as design parameters for creating need-based sound compositions? (Study 1.)
(ii) To what extent do these sound compositions have an effect on the perceived pleasantness and eventfulness of soundscapes and the pleasure and arousal of the listener? (Study 2.)
(iii) Are the effects of sound compositions measured in Study 2 similar to the effects described in Study 1, and do listeners perceive the characteristics of the sound compositions as we designed them?

II. STUDY 1

In Study 1 we performed an online survey study to evaluate whether and how the fulfillment of different psychological needs related to the perceptual and qualitative characteristics of imagined or recalled soundscapes. We adapted this methodology of recalling or imagining soundscape characteristics from other qualitative methods related to soundscapes, such as narrative interviews (Schulte-Fortkamp and Fiebig, 2006; Aletta *et al.*, 2016).

A. Methods

1. Participants

A total of 34 healthy volunteers (17 male, 17 female) in the age of 23 to 56 participated. Participants originated from Western-Europe (31), Southern Europe (two), and Asia (one), and all resided in the Netherlands. Participants had no experience with staying or working in an ICU. Exclusion criteria were not being proficient in English and hearing impairments. After giving informed consent, participants received an English online survey by email. They did not

TABLE I. Nine fundamental needs and corresponding need-specific feelings.

Need	Need-specific feeling
Autonomy	Being the cause of your actions and feeling that you can do things your own way, rather than feeling as though external conditions and other people determine your actions.
Beauty	Feeling that your environment is a place of elegance, coherence, and harmony, rather than feeling that it is disharmonious, unappealing, or ugly.
Comfort	Having an easy, simple relaxing life, rather than experiencing strain, difficulty, or overstimulation.
Competence	Having control over your environment and being able to exercise your skills to master challenges, rather than feeling that you are incompetent or ineffective.
Fitness	Having and using a body that is strong, healthy, and full of energy, rather than having a body that feels ill, weak, or listless.
Recognition	Getting appreciation for what you do and respect for who you are, instead of being disrespected, under-appreciated, or ignored.
Relatedness	Having warm, mutual, trusting relationships with people who you care about, rather than feeling isolated or unable to make personal connections.
Security	Feeling that your conditions and environment keep you safe from harm and threats, rather than feeling that the world is dangerous, risky, or a place of uncertainty.
Stimulation	Being mentally and physically stimulated by novel, varied, and relevant impulses and stimuli, rather than feeling bored, indifferent, or apathetic.

https://doi.org/10.1121/10.0030470

receive financial compensation. The study protocol was approved by the ethics committee of the Delft University of Technology on the 21st of October 2021.

2. Materials

Following consensus between the authors and ICU staff at an academic hospital, nine fundamental needs from the typology of Desmet and Fokkinga (2020) were selected: the needs for *Autonomy*, *Beauty*, *Comfort*, *Competence*, *Fitness*, *Recognition*, *Relatedness*, *Security* and *Stimulation*, see Table I.

These needs were deemed most relevant with regard to current patient experiences on ICU wards, and thus were used in the online survey. For each of those nine needs, participants were asked to think of a soundscape where they felt that the need in question was fulfilled. We did this in three steps. First, participants were asked to describe the environment they thought of. With this question, a description of a related need-specific feeling was shown, i.e., a positive experience associated with pleasurable and meaningful events that satisfy the need in question (Sheldon *et al.*, 2001). The descriptions of these feelings were sourced from the typology by Desmet and Fokkinga (2020), see Table I. Second, participants were asked which events took place in the described environment. Third, we asked them which sounds they connected to those events.

We will refer to these responses as Environments (question 1), Events (question 2), and Sounds (question 3), which together form an *imagined soundscape*: an ideal, imagined or recalled sound environment where a particular need is fulfilled. An example is shown in Fig. 2.

We also asked participants to rate every imagined soundscape in terms of pleasantness and eventfulness on 7-point semantic scales, ranging from 'Unpleasant' to 'Pleasant' and 'Uneventful' to 'Eventful.' We familiarized participants with these four attributes at the start of the survey.

3. Procedure

We used Qualtrics (www.qualtrics.com) to distribute and conduct the surveys through email invitation. Participants were recruited through professional mailing lists at Delft University of Technology. Participants were asked to fill in the survey by themselves, in one sitting, in a quiet environment where they felt at ease. The survey consisted of two parts, (1) demographics and (2) imagining and rating of their nine imagined soundscapes. The order in which the nine needs were presented to the participants was randomized. Participants' responses to multi-line, open-ended questions and rating data were exported from Qualtrics and saved on faculty servers for analysis.

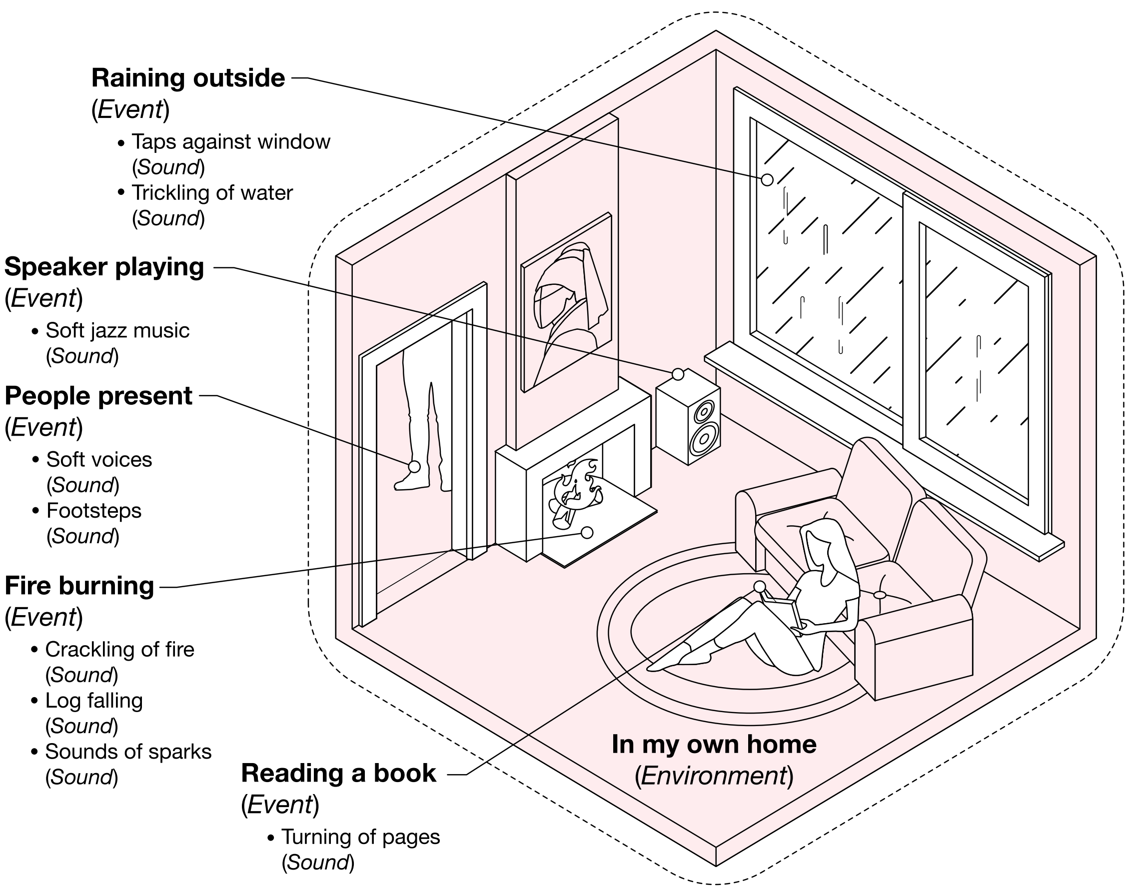

FIG. 2. (Color online) example elements of imagined soundscapes for the need for Comfort.

TABLE II. Examples of participant (P20) responses for needs for Beauty and Security to the three consecutive open-ended questions: describe an environment that makes you feel a sense of [need-specific feeling] (Environment), which events are happening in that environment (Events), which sounds would those events make (Sounds)?

Need	Environment	Events	Sounds
Beauty	Beach with waves clashing at the shore and a strong wind.	Waves clashing at the shore. Sitting at the cliff. Drinking a beer.	The sound of the waves and the wind whooshing. Maybe some seagulls.
Security	At home, comfortable on the couch when it is raining outside.	I am sitting on the couch. There are other people around me. It's raining outside. We have lit a fire.	Rain. Fire place crackling. Soft sound of voices/people talking.

4. Data analysis

We did a quantitative analysis of pleasantness and eventfulness ratings to assess differences in these ratings between imagined soundscapes of different needs. We tested for statistical differences with two separate one-way repeated measures analysis of variances (ANOVAs) with pleasantness and eventfulness as dependent variables and different needs as within-subjects factor. We followed up with *post hoc* tests (with an adjustment for multiple comparisons using a Bonferroni correction) to determine significant differences between imagined soundscapes for need pairs. Next, we did a hierarchical agglomerative clustering (HAC) analysis using Ward's Linkage (Ward, 1963) to determine whether imagined soundscapes could be grouped together.

After this quantitative analysis, we did a qualitative analysis of the imagined soundscapes belonging to each cluster discovered in HAC. The responses in terms of Environments, Events, and Sounds were grouped per cluster and imported into Atlas.ti (www.atlasti.com). We analyzed the data with reflexive thematic analysis (RTA) and held to its quality guidelines (Braun and Clarke, 2021). First, researchers (GL, EÖ) coded (parts of) responses where participants mentioned qualities of the imagined soundscape (e.g., harmonious). Second, the qualities were discussed among researchers (GL, SP, EÖ) and reduced in number through elimination and combination of identical or related qualities. Third, researchers (GL, SP, EÖ) determined whether these qualities formed a pattern that might represent an overarching theme about the cluster. We also searched statements for characteristics of narrative structure and sound category distributions.

B. Results

The survey took about 60 min (mean, M = 53.2, standard deviation SD = 24.3) to complete. In Table II, examples of a participant's imagined soundscapes are shown, in terms of their responses to the three open-ended questions (i.e., Environment, Events, Sounds) repeated for each of the nine needs considered.

Two participants (P18/34) were removed from the sample because of the number of missing responses (6 and 9, respectively, out of 27) in their surveys. Another participant (P23) only had missing responses for one need and thus remained in the sample. Ratings for this need were replaced by the mean of the respective rating per item. With jackknife (or leave-one-out) resampling (Efron and Stein, 1981) for both pleasantness and eventfulness ratings separately, we identified three further participants (P26, P32, P33) as outliers, and their entries were removed from the set. The remaining sample ($N = 29$) was further analyzed. As each participant provided nine imagined soundscapes, we collected 261 imagined soundscapes in total.

1. Quantitative analysis

For each of the nine needs, we calculated means and standard deviations for pleasantness and eventfulness (see the supplementary material). Results of one-way repeated measures ANOVAs showed significant main effects in pleasantness [$F(8, 224) = 6.475$, $p < 0.001$, $\eta^2 = 0.188$] and in eventfulness [$F(8, 224) = 9.308$, $p < 0.001$, $\eta^2 = 0.249$] between needs. In *post hoc* analysis, we conducted pairwise comparisons for mean differences (see supplementary material). Pleasantness ratings for Beauty soundscapes were significantly higher than for those for Stimulation ($p = 0.027$), Competence ($p < 0.001$), Fitness ($p = 0.027$), and Recognition ($p = 0.007$); they were also significantly higher for Comfort soundscapes than those for Competence ($p = 0.006$), and Recognition ($p = 0.034$); those for Security soundscapes were rated significantly higher than those for Competence ($p = 0.030$); those for Relatedness were also rated significantly higher than those for Competence ($p = 0.011$); participants rated those for Autonomy soundscapes significantly higher than those for Competence ($p = 0.046$). In terms of eventfulness ratings, participants rated those for the need for Stimulation soundscapes significantly higher than those for Beauty ($p < 0.001$), Comfort ($p < 0.001$), Security ($p < 0.001$), Competence ($p = 0.013$), Relatedness ($p = 0.043$), and Autonomy ($p = 0.003$); those for Fitness soundscapes were rated significantly higher than those for Comfort ($p = 0.006$) and Security ($p = 0.024$); those for Recognition soundscapes were rated higher than those for Comfort ($p = 0.004$) and Security ($p = 0.010$). Effects between the unmentioned pairs were not significant.

We performed HAC to further analyze the two-dimensional distribution of the data. The clustering steps of the nine different needs are shown in a dendrogram [Fig. 3(a)]. The related agglomeration table is included in the supplementary material. The impact of the clustering steps on distance coefficients between clusters is depicted in an elbow diagram [Fig. 3(b)]. In the elbow diagram, the coefficients in the agglomeration table are plotted for each

JASA
https://doi.org/10.1121/10.0030470

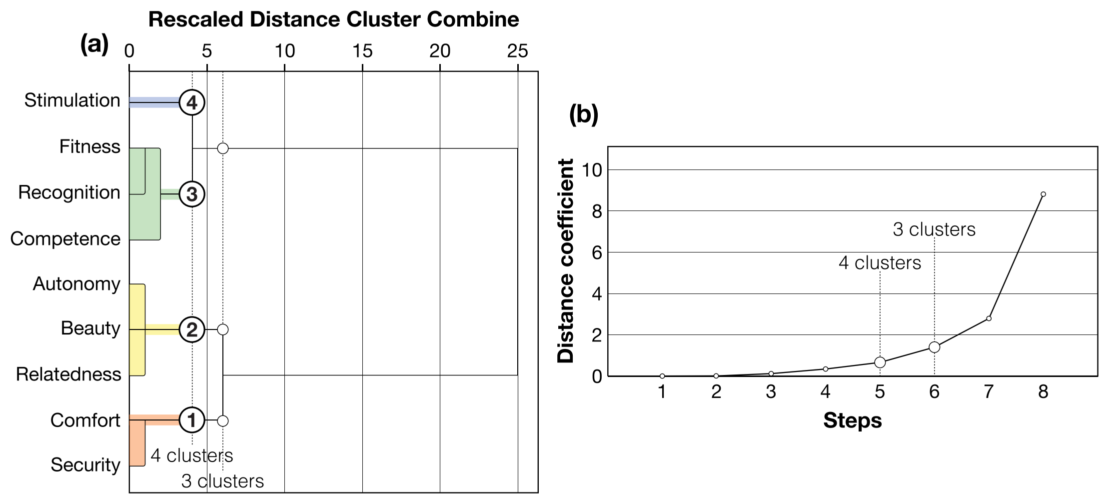

FIG. 3. (Color online) (a) Dendrogram with clustering steps of the HAC for a three/four-cluster solution; (b) elbow diagram of distance coefficients in agglomeration schedule.

combination step. The elbow method (Thorndike, 1953) suggests that the ideal stopping point would be at step six/seven or five/six Fig. 3(b), located at the elbow of the graph.

Given the significant differences found in *post hoc* analysis, we chose the four-cluster solution for further analysis. Cluster one consisted of Comfort and Security soundscapes, cluster two of Relatedness, Autonomy, and Beauty soundscapes, cluster three of Competence, Fitness and Recognition soundscapes and a fourth cluster comprised of Stimulation soundscapes. The clusters were numbered in ascending order of eventfulness, where cluster one was the least eventful, and cluster 4 the most eventful, see Table III. The means in pleasantness and eventfulness with 50th percentile contour plots for the four clusters were plotted in Fig. 4.

2. Qualitative analysis

In our analysis of the qualitative results, we found that the sonic ambiance qualities we coded corresponded to distinctive sonic ambiance *types* for each cluster. Cluster 1 (Security, Comfort) included descriptions that featured a *Comfortable* sonic ambiance type, characterized by ambiance qualities that were called *familiar*, *safe*, and *relaxed*. In cluster 2, (Relatedness, Autonomy, Beauty) imagined soundscapes had a *Pleasurable* ambiance type. Ambiance qualities were called *harmonious*, *momentous* (i.e., not every day), and *engaging*. Cluster 3 (Competence, Fitness, Recognition) involved descriptions that had a *Motivating* sonic ambiance type and qualities that were called *energetic*, *focused*, and *positive*. Finally, in cluster 4 (Stimulation) descriptions of imagined soundscapes had a *Stimulating* sonic ambiance type, characterized by ambiance qualities that were called *vibrant* and *inspirational*. These four different sonic ambiance types are presented in Table IV with their qualities. In the Appendix, Table VI, the qualities are shown with example quotes.

TABLE III. Mean pleasantness and eventfulness of combined needs in clusters from HAC.

	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Pleasantness	6.33	6.29	5.29	5.44
Eventfulness	3.64	4.71	5.36	6.34

Aside from finding recurring patterns within clusters regarding sonic ambiance qualities and types, we found that the participants' descriptions of imagined soundscapes followed a specific organization regarding the Environment, Events, and Sounds. In each description, we found that the individual events and sounds that took place in the imagined soundscapes were bound up together in a *narrative*:

"I imagine this environment as picturesque English countryside in late summer. It is evening, just before sunset, when the sky becomes hazy and pink. I am meandering

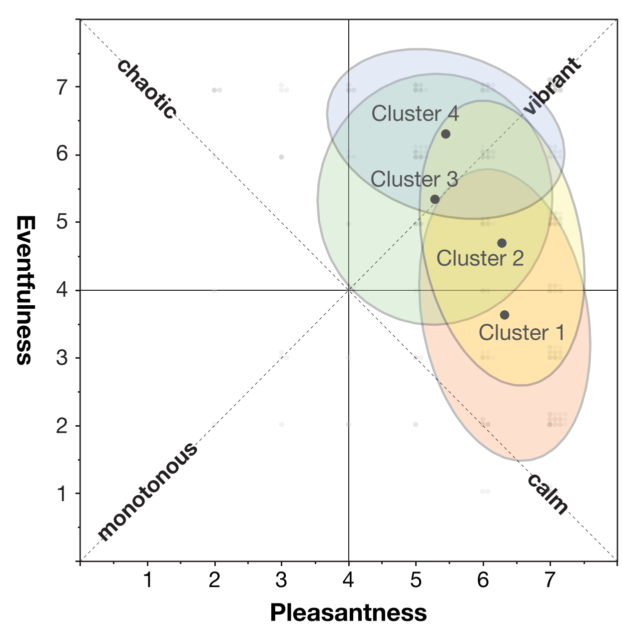

FIG. 4. (Color online) Means of clusters from HAC in pleasantness and eventfulness. Colored ellipses indicate 50th-percentile density contours.

TABLE IV. Clusters from HAC with needs, ambiance types, and qualities.

Cluster	Needs	Sonic ambiance type	Sonic ambiance qualities
1	Security Comfort	Comfortable	Familiar Safe Relaxed
2	Relatedness Autonomy Beauty	Pleasurable	Harmonious Momentous Engaging
3	Fitness Competence Recognition	Motivating	Energetic Focused Positive
4	Stimulation	Stimulating	Vibrant Inspirational

through a field next to a river that's flowing under an old stone bridge. There's a collection of birds—sparrows, blackbirds and house martins—flitting about in the trees and hedges. Grass and earth rustling beneath my feet, birds' wings flapping, bird calls (each one distinguishable by the type of bird), water flowing gently, maybe church bells occasionally in the distance" (Beauty, P24).

Within this narrative, the components of the imagined soundscapes and the participant's position relative to the sounds and events were organized in space, such as in terms of *characterizing location* (e.g., picturesque English countryside) or *figure-ground* (e.g., church bells occasionally in the distance). The narrative also followed a progression of time, i.e., *temporality* (e.g., first walking through the field, then hearing the river or birds in the trees), and defined the *listener's role* in the cause of the present sounds and events (e.g., "Grass and earth rustling beneath my feet"). We thus concluded from the qualitative responses that the narratives were organized by a (1) characterizing location, (2) figure-ground relationships, (3) temporality, and (4) listener role.

Furthermore, we found that differences existed between the four clusters in terms of sound category distributions of sound sources. In a previous study, we labeled, counted, and compared the distributions of sound categories between the nine needs (Louwers *et al.*, 2022). We created a taxonomy

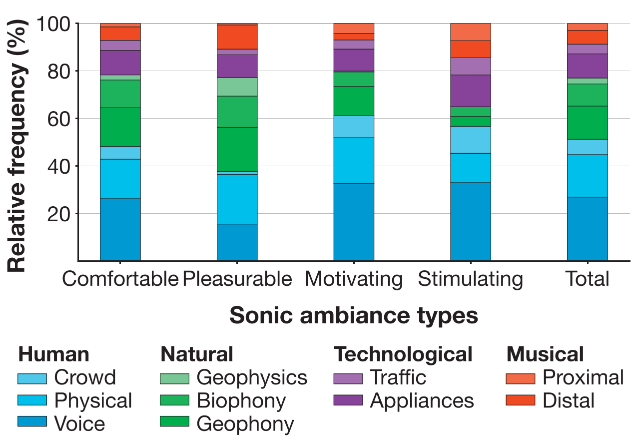

FIG. 5. (Color online) Distributions of super-ordinate and basic sound descriptions for four types of sonic ambiances.

of four super-ordinate (i.e., human, natural, musical, technological) and ten basic sound categories, which was based on earlier categorizations (Gaver, 1993; Axelsson *et al.*, 2010; Özcan *et al.*, 2014; Lenzi *et al.*, 2021). The relative distributions of these sound categories across participants for the four sonic ambiance types are graphically illustrated in Fig. 5.

We used this taxonomy to compare the sound category distributions between Pleasurable, Comfortable, Motivating, and Stimulating ambiance types with a Chi-square test for independence. We found that there was a significant association [$X^2(9, N = 806) = 52.62, p < 0.001$] between sonic ambiance type and sound category. The contingency tables can be found in the supplementary material. Out of the four sound categories, as illustrated by the Total bar, we most frequently encountered human sounds (i.e., 51.2% of all sound labels) in responses for all types of sonic ambiances, followed by natural (25.8%), technological (14.3%), and musical (8.7%) ones. In 209 out of 261 (80.1%) imagined soundscapes, at least one human sound label was counted.

C. Discussion

In Study 1 we evaluated whether characteristics of imagined soundscapes related to the fulfilment of different fundamental needs could serve as design parameters for creating need-based sound compositions. We analyzed their perceptual characteristics, i.e., pleasantness and eventfulness, and qualitative characteristics, i.e., sonic ambiance qualities, narrative structure, and sound categorization. Based on our findings, we propose four design parameters for designing sound compositions for fundamental need fulfillment.

The level of eventfulness of sound compositions was defined as our first design parameter. The substantial variation in eventfulness between the four clusters implied that it could play a role in defining the sonic ambiance. Events or activities that fulfill fundamental needs are experienced as pleasurable (Sheldon *et al.*, 2001), which could explain the lower variation in pleasantness between clusters. We therefore disregarded the level of pleasantness of sound compositions as a possible design parameter but rather considered the positive level of pleasantness of sound compositions as a prerequisite of the design process. The level of pleasantness and eventfulness of sound compositions could thus direct existing soundscapes towards a desired quadrant, e.g., from monotonous to vibrant (Cain *et al.*, 2013).

We defined sonic ambiance quality as our second design parameter. Depending on the need-profile of the listener, i.e., the grouping of needs in varying saliency (Hassenzahl and Diefenbach, 2012), ambiance qualities define the desired experience of the sonic ambiance. The narrative structure of sound compositions was defined as a third design parameter. Characterizing locations, different figure-ground relationships, changes in temporality, and listener roles were encountered as characteristics of narratives in imagined soundscapes. This suggested that in designed

https://doi.org/10.1121/10.0030470

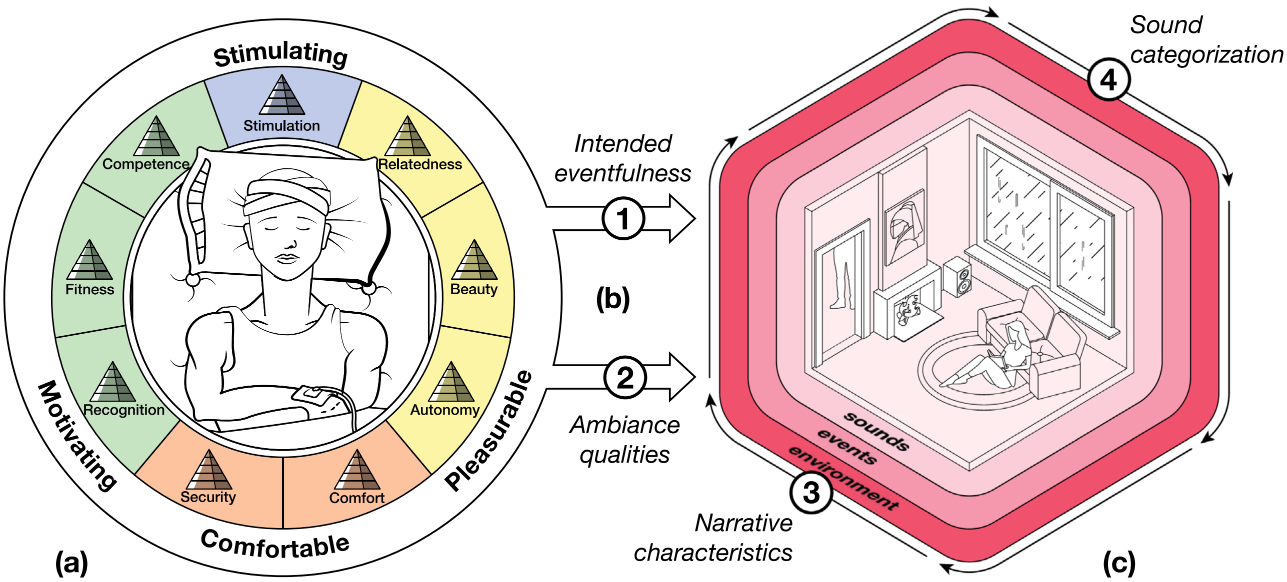

FIG. 6. (Color online) Process of conceptualizing pleasant sound compositions based on fundamental need fulfilment.

sound compositions, individual sounds could be organized in space and time according to those same narrative characteristics. Since auditory order and variation are important indicators of eventfulness (Aletta *et al.*, 2014; Fiebig *et al.*, 2020), the narrative structure could therefore be manipulated to attain the desired levels of eventfulness. Also, this parameter could serve to achieve the desired sonic ambiance qualities, as emotional responses are heavily influenced by the narratives constructed while listening (Juslin and Vastfjall, 2008).

Last, variation in sound distribution was defined as the fourth design parameter. The positive potential of natural sounds is widely accepted (Alvarsson *et al.*, 2010; Ratcliffe *et al.*, 2013; Medvedev *et al.*, 2015). However, the large proportion of human sounds counted in each cluster implied that other sounds, such as the background murmur in a café, could also play a role in designing sound compositions for need fulfillment. This design parameter relates to the personal preference for certain sounds, or the appropriateness of soundscapes, in a given context (Jo and Jeon, 2020). Elements of need-based sound compositions could therefore be selectively sourced from these four major sound categories to personalize and contextualize content. For example, being deprived of most categories of sound in single patient ICU rooms, patients might experience listening to sound compositions with appropriately balanced human, natural, technological, and musical elements as a positive addition.

In Fig. 6, we have outlined the process of conceptualizing pleasant, need-based sound compositions based on these four design parameters. This process is aimed at improving patients' experiences of ICU stays through need fulfillment by added sound compositions to the existing soundscape. It illustrates an approach that starts by picking a need that should be addressed from the context [Fig. 6(a)]. Then, the sonic ambiance type can be identified. Based on this, the eventfulness of the sound composition and the ambiance qualities can be derived [Fig. 6(b)]. Then [Fig. 6(c)] the sound composition can be designed with those in mind by manipulating the narrative characteristics and sound category distribution.

III. STUDY 2

In Study 2, we used the design parameters from Study 1 to create sound compositions which were tested in a simulated ICU lab setting. We evaluated to what extent designed sound compositions had an effect on soundscape descriptors and emotional state. Also, we compared whether the effects of the sound compositions measured in Study 2 were similar to the effects described in Study 1 and whether listeners perceived the characteristics of the designed sound compositions as we designed them. All sound compositions were intended to address fundamental needs. Hence, their perceived level of pleasantness was considered a prerequisite of the design process.

A. Methods

1. Participants

We recruited 30 healthy individuals (11 male, 19 female) of mixed nationalities at Delft University of Technology through academic mailing lists and posters. None of the participants of Study 1 participated in Study 2. Inclusion criteria were adults (age 28.9 ± 5.9 years), proficient in English, and reported no hearing impairments. Participants gave written informed consent prior to participation and were financially compensated for their time. Similar to Study 1, participants had no experience with staying or working in an ICU. The study ran from the 5th of December 2023 until the 18th of January 2024. The protocol of the study was approved by the ethics committee of Delft University of Technology on the 18th of August 2023.

TABLE V. Sixteen variations of sound compositions created by the sound artist with the design parameters.

Ambiance type	Intended eventfulness[a]	Keynote	Natural	Musical	Human	Technological
Comfortable	Uneventful	Rain	Fireplace	Home office	Synthesized	Train compartment
Pleasurable	Somewhat uneventful	Flowing water	Forest	Terrace	Strings	Urban backyard
Motivating	Somewhat eventful	Wind	Park	Beach	Melodic	Boats
Stimulating	Eventful	Traffic	Countryside	Market	Rhythmic	City

[a]Relative eventfulness within the dominant sound category.

Participant responses were anonymized through assigned case numbers.

2. Sound compositions

A conservatory trained, experienced sound artist designed sound compositions in Ableton Live at a sampling rate of 44.1 kHz stereo with 16-bit depth, together with one of the authors. They used the design parameters and workflow for creating sound compositions as presented in Fig. 6. This resulted in sixteen sound compositions, see Table V. In their design, the sound compositions were intended for playback through a set of mounted speakers as a patient intervention in ICU rooms. Playback through speakers was preferred over headphones due to hygienic and nurse workflow advantages. The sound compositions were used in Study 2 as stimuli. Samples of the sound compositions and spectrograms are available in the supplementary material. In Table VII in the Appendix, psychoacoustical indicators are shown for each sound composition.

The eventfulness and sonic ambiance qualities of pleasant sound compositions were derived from the four sonic ambiance types. As was shown in Table III, eventfulness gradually increased from Comfortable (cluster 1), Pleasurable, (cluster 2), Motivating (cluster 3), and Stimulating (cluster 4) ambiance types. The sound artist layered keynote and signal sounds to model the respective sonic ambiance quality after the qualities defined in Study 1 and presented in Table IV (e.g., a Motivating sound composition would be experienced as energetic, focused, and positive). Keynote sounds are sounds heard by people often enough that they can form the background against which other sounds are perceived, such as a hum, rain or ventilation (Truax, 1999). Sound signals represent sounds in the 'foreground' and are treated in relation to the keynote's context, similar to figure-ground relationships in visual perception. Similarly, the sound artist designed the respective eventfulness with layered keynote and signal sounds from four major sound categories also presented in Study 1: natural, human, musical, and technological sounds. The designed sound distribution was dependent on each of the four sound categories but had one dominant sound category, i.e., a type of sound most prevalent or prominent within the designed sound composition.

Different characterizing locations were chosen for each sound composition based on the sonic ambiance qualities and dominant sound category. The sound artist chose a keynote sound to fit those qualities and the relative eventfulness belonging to the sonic ambiance type. For continuity, the chosen keynote sounds were repeated for each sound composition belonging to that sonic ambiance type, regardless of the dominant sound category. The four keynote sounds (i.e., rain, flowing water, wind, and traffic) formed the basis for the sound compositions. Signal sounds were added in accordance with the characterizing location and sound-producing events, to attain the level of desired eventfulness of the sonic ambiance type.

We relied on the sound artist's creative freedom in terms of narrative structure because experienced sound designers are trained to consider and balance these kinds of relationships in sound design activities (Dunne and Gaver, 1997; Collins, 2008). The narrative characteristics were thus used as tools by the sound artist to organize keynote and signal sounds in time and space to achieve the relative eventfulness and sonic ambiance quality.

3. Experimental setup

We used a box shaped lab-space with dimensions of 5.3 m (length), 3.2 m (width), 2.6 m (height) at Delft University of Technology [see Fig. 7(a)] with a patient bed (a), bedside table (b), and closed curtain (c) to simulate a clinical setting that approximated the conditions of a single patient ICU room. Participants (d) were in the middle of the bed, at 2 m from the opposing wall, and 1.2 m from the sidewall. Two Genelec 8020DPM studio monitors (e) were placed on stands outside of view. A researcher (f) facilitated the experiment from the other side of the curtain. A 19" LCD monitor (g) was placed next to participants to time the measurements. Participants gave ratings on a 13" iPad Pro (h) in front of them. Sound compositions were played to the speakers from the sound card of a MacBook Pro 13" (i) on a constant level. Together with the sound artist, the sound levels of the designed stimuli were calibrated in the lab-space according to the intended sound levels while designing. In pilot testing, these sound levels were confirmed as being at a comfortable level. Participants did not have control over the sound level. The speakers were positioned at equal distances from the participants. The acoustical axes were positioned at the participants' ear-height ($h = 120$ cm). The speakers were rotated to the estimated position of the ears of the participant at approximately 80 cm [Fig. 7(b)], as indicated in monitor placement documentation for the respective monitors (Genelec, 2017). Aside from the sound compositions, no other sounds (e.g., no medical alarms or other ICU sounds) were introduced in the space.

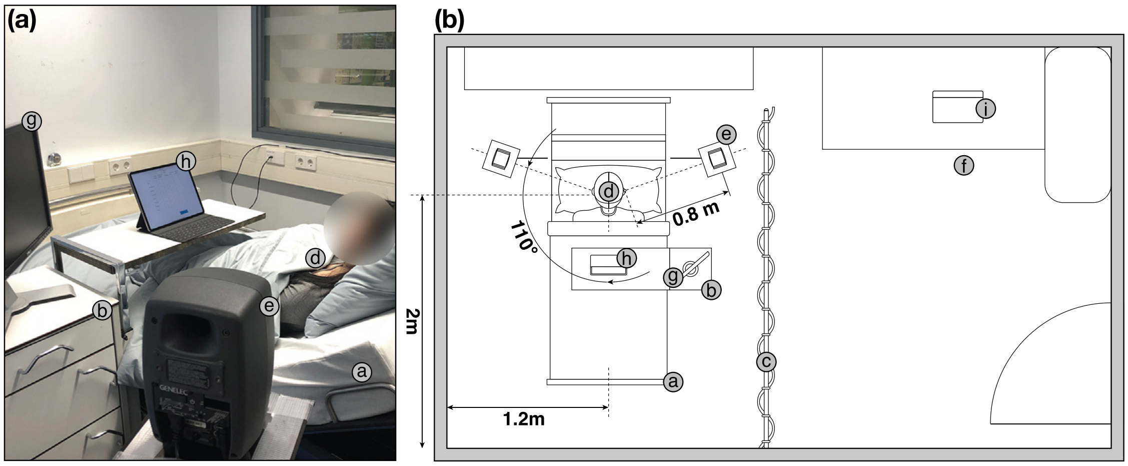

FIG. 7. (Color online) (a) Experimental setup of the clinical setting in lab-space at Delft University of Technology, with participants in a hospital bed. (b) Schematic illustration of speaker rotation.

Acoustical measurements were performed with 1/2 in. Microphone type 4189, on a two-channel Brüel & Kjaer type 2270 Sound Level Meter (Brüel & Kjaer, Naerum, Denmark) calibrated at 94 dB sound pressure level (SPL) 1 kHz with a Brüel & Kjaer type 4231 Acoustical Level Calibrator. We measured the A-weighted equivalent continuous sound pressure level of the background for 30 min ($L_{A,eq,30min}$) in the room in the midpoint between the speakers at ear-height on two weekdays, resulting in $L_{A,eq,30min} = 30.1/30.3$ dB(A). The level ($L_{A,eq,90s}$) of sound compositions measured at the position of the participant ranged between 30 and 45 dB(A) (see the Appendix, Table VII). All acoustical measurements are included in the supplementary material.

4. Experimental procedure

The study tasks took about 45 min to complete and were divided into two parts: rating tasks (1) and forced-choice tasks (2).

In the first part, participants listened and assessed the soundscape of the lab-space at different points in time. At each timepoint, participants evaluated their perception of the soundscape and the resulting emotional state. The former was measured by the extent to which eight descriptors (i.e., vibrant, calm, pleasant, annoying, monotonous, chaotic, eventful, uneventful) applied to the soundscape they were listening to with 5-point Likert scales ranging from *Strongly disagree* to *Strongly agree*. This method was based on international standards on how soundscape data should be collected and analyzed (ISO, 2018). The latter was measured with affective sliders for pleasure and arousal (Betella and Verschure, 2016). Both were documented on a tablet device using Qualtrics. Participants first heard five seconds of pink noise, thus acting as a cue for the start of a new trial. They then listened to the soundscape for 90 s. After 30 s of free listening, a 60-s timer showed on the monitor. Participants were instructed to rate the descriptors and affective sliders before the timer ran out. When it ran out, the screen faded to black and pink noise played, indicating the next trial. This cycle was repeated for every trial. The designed sound compositions were played in pseudo-randomized sequences (see supplementary material). Both before and after this sequence, we asked participants to rate their perception and emotional state as a result of the lab-space soundscape without sound compositions (i.e., the baseline), thus resulting in two baseline-measurements. Participants practiced the procedure of rating their soundscape perception and emotional state once while listening to Mozart's Eine Kleine Nachtmusik K. 525: Allegro prior to the first measurement. This first part of the study lasted 30 min.

In the second part, we conducted forced-choice tasks to determine whether listeners perceived the design parameters of the sound compositions as intended. We first played groups of four 30-s sound compositions, grouped in pseudo-randomized order in terms of their common sonic ambiance type. After listening, participants were asked to choose which of the four ambiance types (i.e., Comfortable, Pleasurable, Motivating, Stimulating) the grouped sound compositions had in common. This was repeated four times (once for each sonic ambiance type). The same task was employed for the sound compositions now grouped in terms of their dominant sound category (i.e., natural, human, musical, technological). This was also repeated four times (once for each sound category).

5. Data analysis

As proposed in the standard ISO 12913: part 3 (ISO, 2019), we reduced the eight soundscape descriptors into bivariate distributions of primary pleasantness and eventfulness as continuous variables between –1 and 1. This was done using a trigonometric transformation based on the 45° relationship between the diagonal axes (i.e., monotonous-vibrant and chaotic- calm) and horizontal axes (i.e., annoying- pleasant and uneventful-eventful) (Mitchell *et al.*, 2022). Pleasure and arousal scores (measured using sliders with 100 steps) were also normalized between –1 and 1. We first performed one-way repeated measures ANOVAs for pleasantness and eventfulness to assess the main effects of sonic ambiance type and sound category. This was followed by *post hoc* tests with a Bonferroni correction for multiple comparisons to determine significant differences. We tested for significant effects of the sound compositions on pleasantness and eventfulness of the lab-space soundscape compared to the baseline with one-way repeated measures ANOVAs and *post hoc* tests. These effects were visualized in relation to the baseline in 50th percentile density plots (Mitchell *et al.*, 2022). To further evaluate their effects in terms of eventfulness, we performed an independent two-way repeated measures ANOVA with sonic ambiance type and sound category of sound compositions as within-subjects factors and eventfulness as a dependent variable, followed by *post hoc* analysis. The accuracy of the forced-choice tasks was calculated by dividing the number of trials with correct judgments by the number of trials. Sound level measurements were imported and processed in Brüel & Kjaer Measurement Partner Suite BZ-5503 (Brüel & Kjaer, Naerum, Denmark). We calculated the loudness and sharpness of sound compositions with a MATLAB-based toolbox for quantitative sound quality analysis (Greco *et al.*, 2023).

B. Results

1. Effects of the sound compositions

We calculated the means and dispersion of responses across sonic ambiance types and sound category (i.e., for pleasantness, eventfulness, pleasure, and arousal), see Figs. 8(a) and 8(b). For pleasantness, we found no significant main effect between sonic ambiance types [$F(3, 357) = 2.637$, $p = 0.05$, $\eta^2 = 0.02$]. For eventfulness, we did find a significant main effect [$F(2.8, 335.9) = 53.728$, $p < 0.001$, $\eta^2 = 0.31$]. *Post hoc* analysis (see supplementary material) showed that eventfulness increased as designed with each sonic ambiance type. These increases were significant except between Motivating and Stimulating sound compositions ($p = 0.549$).

For pleasantness, we found a significant main effect between sound categories [$F(3, 357) = 15.088$, $p < 0.001$, $\eta^2 = 0.11$]. In pairwise comparisons (see supplementary material), we found that pleasantness for the natural sound compositions was significantly higher than for human ($p = 0.007$) and technological ($p < 0.001$) ones. For musical sound compositions, pleasantness was also significantly higher than for human ($p < 0.001$) and technological ($p < 0.001$) ones. For eventfulness, we also found a significant main effect [$F(2.8, 333.5) = 26.775$, $p < 0.001$, $\eta^2 = 0.18$]. In *post hoc* analysis we found that eventfulness was significantly higher for the human sound compositions than all others. We also found that eventfulness for natural sound compositions was significantly higher than for musical ones ($p < 0.001$). Following these analyses, we evaluated the effects of each sound composition by comparing the resulting soundscape's pleasantness and eventfulness scores to those of the baseline soundscape. Paired samples t-tests indicated that the two baseline measurements (i.e., before and after the sequence) did not significantly differ in pleasantness [$t(29) = 1.595$, $p = 0.12$] nor in eventfulness [$t(29) = 1.397$, $p = 0.17$]. An average baseline score was thus computed for each participant for pleasantness and eventfulness. In Fig. 9, we plotted the responses of participants in terms of pleasantness and eventfulness per resulting soundscape, and the baseline soundscape. The density of scores is indicated by 50th percentile contours.

Comparing the 16 resulting soundscapes and one baseline soundscape (Fig. 9), we found significant main effects for both pleasantness [$F(8.7,251.3) = 9.3$, $p < 0.001$, $\eta^2 = 0.242$] and eventfulness [$F(8.5,246.4) = 37.7$, $p < 0.001$, $\eta^2 = 0.565$]. In *post hoc* analyses for pleasantness (see supplementary material), we found that six soundscapes were rated as significantly more pleasant than the baseline (see Fig. 9, indicated by asterisk). We also found that all resulting soundscapes were significantly more eventful than the baseline except one [Fig. 9(m)]. Most sound

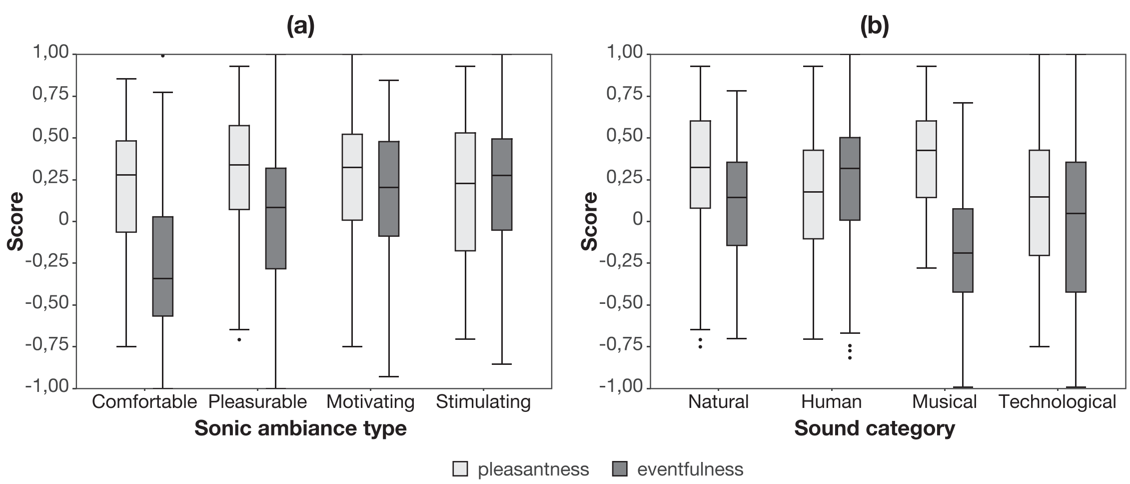

FIG. 8. Central tendency and dispersion for pleasantness and eventfulness as boxplots for levels of (a) sonic ambiance type and (b) sound category.

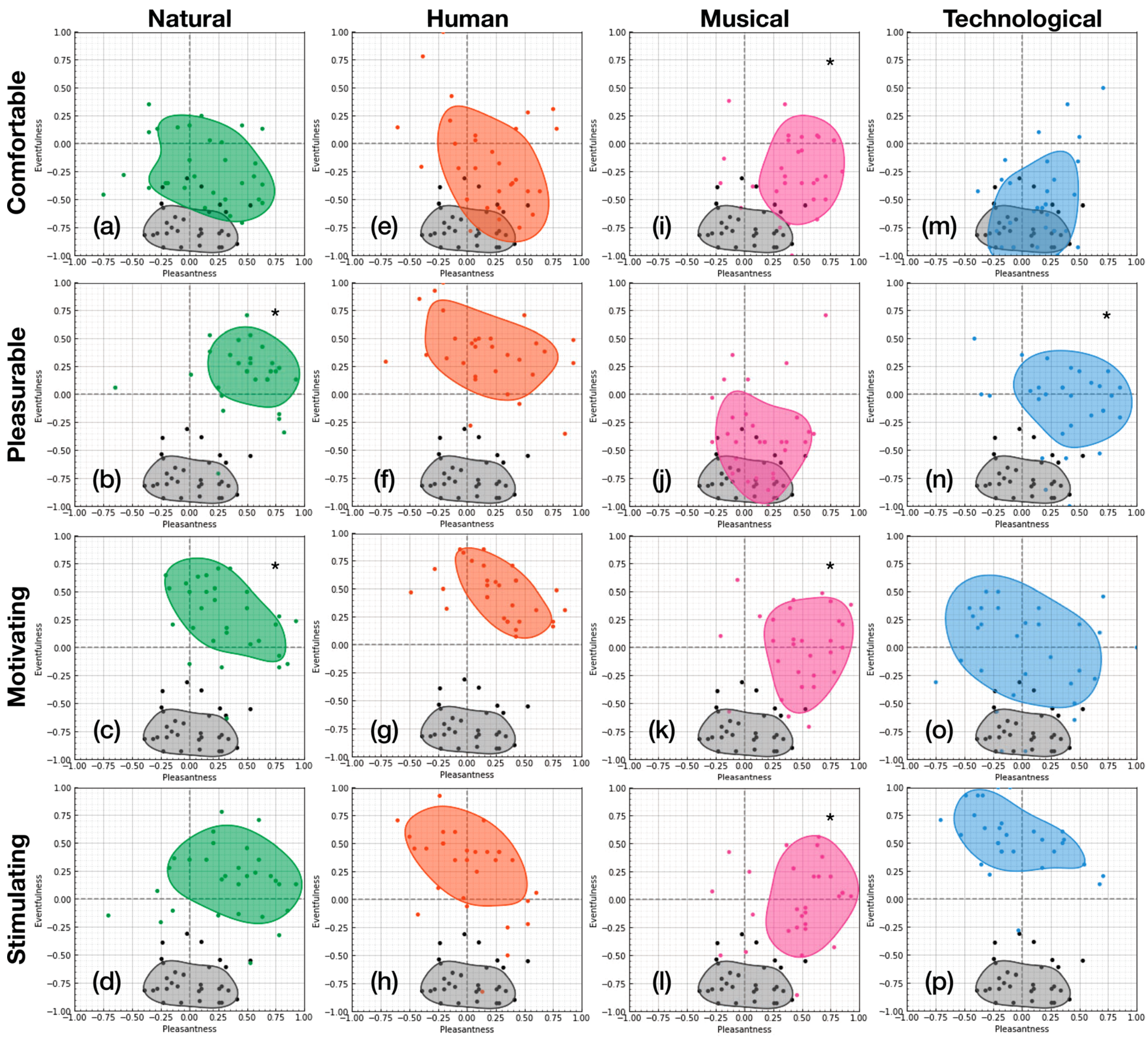

FIG. 9. (Color online) 50th percentile contours of sound compositions versus the baseline. (*) Indicates significant differences in pleasantness.

compositions moved the soundscape from the 'neutral' (i.e., neither annoying nor pleasant) and uneventful baseline soundscape towards pleasant and eventful (i.e., calm or vibrant) quadrants in the circumplex model of soundscape perception (Axelsson *et al.*, 2010). However, with some human and technological variations [Figs. 9(h), 9(o), and 9(p)] the average position moved towards negative quadrants.

We evaluated the effects of the soundscapes on emotional state by considering the correlation between soundscape descriptors and experienced pleasure and arousal. We thus conducted a correlation analysis to explore the relationships between soundscape pleasantness and experienced pleasure, and soundscape eventfulness and experienced arousal, see Fig. 10. We found a strong positive correlation ($r = 0.829$, $\rho = 0.827$, $p < 0.001$) between pleasantness and pleasure [Fig. 10(a)]. This suggested that the effects of the sound compositions on these two measures were highly congruent with one another. For eventfulness and arousal [Fig. 10(b)], we found a moderate correlation ($r = 0.586$, $\rho = 0.594$, $p < 0.001$), suggesting that in our sample the relationship between these two variables was moderately congruent.

2. Comparison Study 1 and Study 2

In Study 1, we found that Comfortable, Pleasurable, Motivating, and Stimulating ambiance types ascended in terms of mean eventfulness (see Fig. 4) which also suggested that eventfulness might be relevant as a design parameter for sound compositions. In Study 2, we found a similar distribution of mean eventfulness for the four sonic ambiance types, as can be visually inspected in Fig. 11. In order to compare the eventfulness (i.e., as a function of sonic ambiance type) revealed in Study 1 to the measured eventfulness in Study 2, we performed an independent samples Mann-Whitney U test. With this test, we assessed the

https://doi.org/10.1121/10.0030470

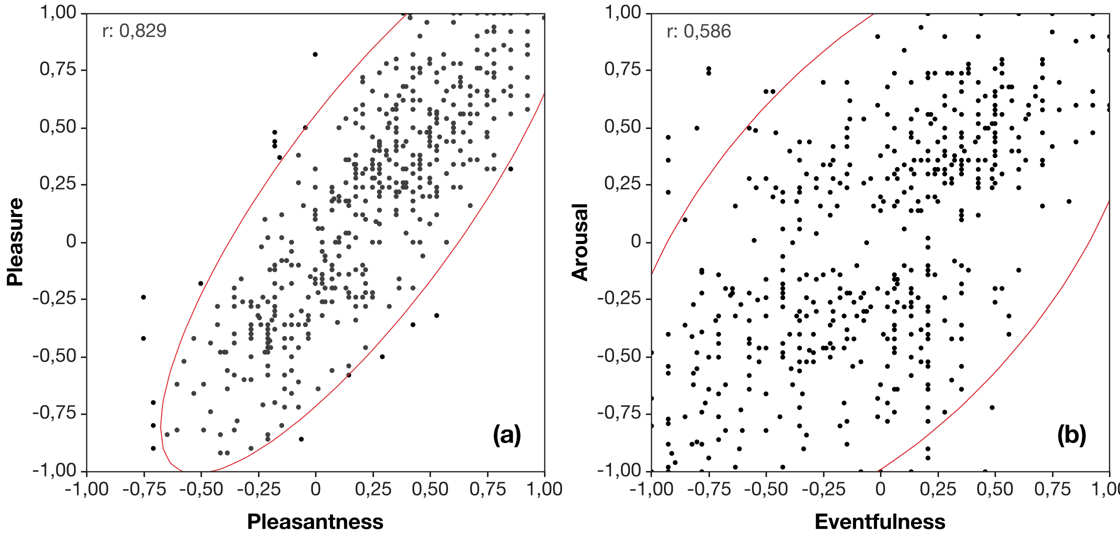

FIG. 10. (Color online) Correlation plots for (a) pleasantness and pleasure and (b) eventfulness and arousal, with 95% confidence ellipses.

differences between Study 1 and Study 2 in terms of mean-rank ordered eventfulness. This resulted in a non-significant difference between the two studies ($U = 4$, $p = 0.343$), indicating that the null hypothesis, i.e., that the distribution of mean eventfulness is the same across the different levels of sonic ambiance type between the two studies, could be retained.

This finding implied that eventfulness could be confirmed as a fitting design parameter to elicit desired effects on the listener. However, the density contours of Fig. 11 suggested that there were large variations in eventfulness scores within sonic ambiance types. We investigated these variations by comparing the sound category variants per sonic ambiance type in terms of measured eventfulness. To assess the effects of both factors on eventfulness, we conducted an independent two-way repeated measures ANOVA with sound category and sonic ambiance type as within-subjects factors (both with four levels) and eventfulness as the dependent variable. We determined that there was a significant interaction effect between the factors [$F(5.8, 168.4) = 13.07$, $p < 0.001$, $\eta^2 = 0.31$]. This suggested that the effects of the sound compositions per sonic ambiance type changed depending on the dominant sound category. We plotted the estimated marginal mean eventfulness for each sound category and sonic ambiance type to visualize this interaction effect (Fig. 12).

Last, we assessed whether the sonic ambiance type and dominant sound category were perceived as designed. In Fig. 13, the accuracy (i.e., correct observations divided by total observations) of the forced-choice tasks is shown for sonic ambiance type [Fig. 13(a)] and sound category [Fig. 13(b)]. As indicated by this graphic, accuracy for sonic

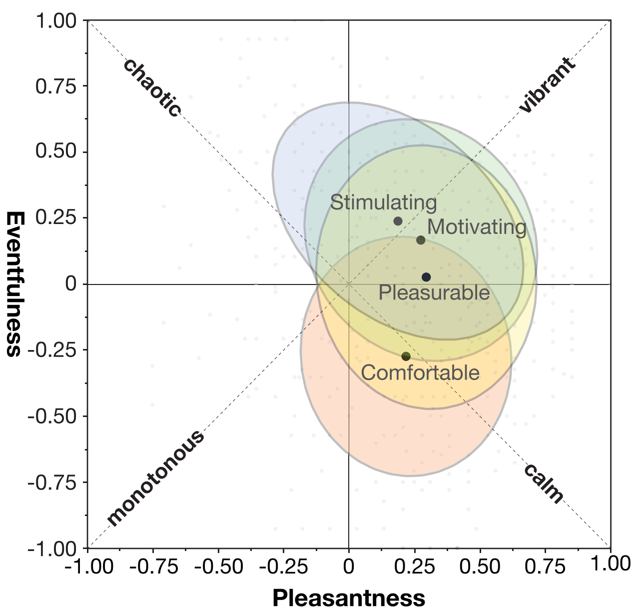

FIG. 11. (Color online) Means of measured pleasantness and eventfulness of four sonic ambiance types across sound category variants. Colored ellipses indicate the 50th percentile density contours.

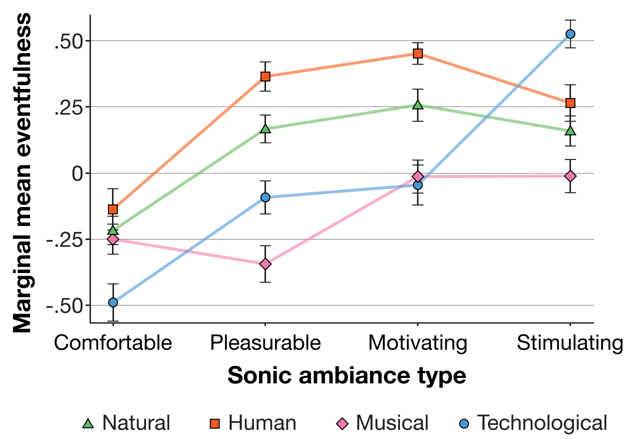

FIG. 12. (Color online) Interaction effects between sonic ambiance type and sound category in estimated marginal means of measured eventfulness. For sonic ambiance type, intended eventfulness gradually increases from Comfortable (uneventful) to Stimulating (Eventful). Error bars represent +/- 1 standard error.

JASA

https://doi.org/10.1121/10.0030470

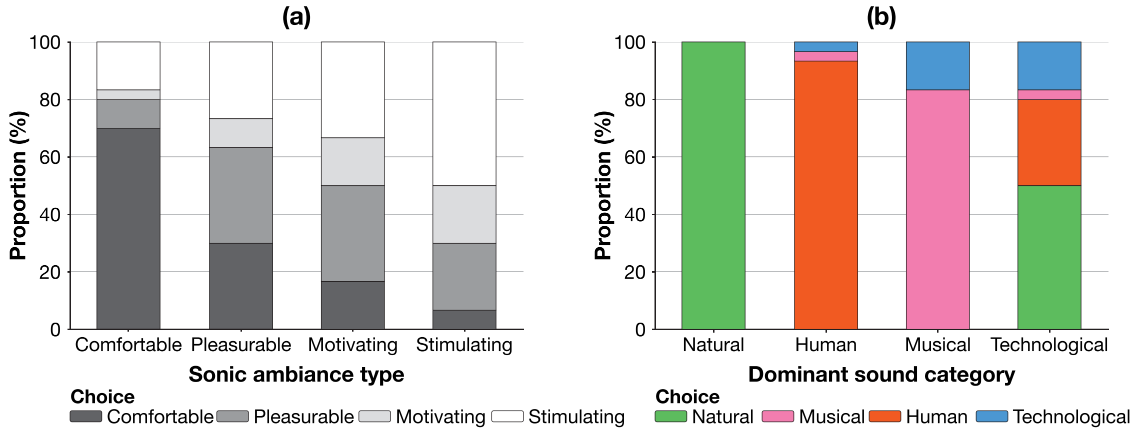

FIG. 13. (Color online) Accuracy in terms of proportions of correctly chosen sonic ambiance types (a) and sound categories (b).

ambiance type was highest for Comfortable (70%), followed by Stimulating (50%), Pleasurable (33.3%), and Motivating (16.7%) ambiances. This suggested that the sonic ambiance type associated with these sound compositions was roughly perceived as such for Comfortable and Stimulating ambiances, while others were not. Accuracy for sound category was highest for natural (100%), human (93.3%), and musical (83.3%), and a low accuracy for technological (16.7%) were found. This suggested that for the technological category, the dominant sound category was less perceivable.

C. Discussion

In Study 2, we evaluated the effectiveness of designing need-based sound compositions with our framework of four design parameters—eventfulness, sonic ambiance qualities, narrative structure, and sound distribution—in a simulated ICU setting. Sixteen sound compositions were created by a sound artist to evaluate their effects on soundscape pleasantness and eventfulness, and listeners' pleasure and arousal, and to evaluate whether these effects were congruent and as designed for.

Most importantly, we found that designed sound compositions affected the perceived pleasantness and eventfulness of the lab-space soundscape considerably. Achieving pleasant soundscapes was considered a prerequisite to our approach. The data confirm this, as sound compositions resulted in similarly pleasant soundscapes. However, considering pleasantness between dominant sound categories revealed that there were differences in perceived pleasantness. This suggested that not every dominant sound category affected the perceived pleasantness of the soundscapes to the same extent. The natural and musical sound compositions led to more pleasantly perceived soundscapes than technological and human ones. The decrease in the soundscape's pleasantness with respect to human sound compositions was in line with previous work, where increases in human activity had negative consequences for the soundscape's perceived pleasantness (Lenzi *et al.*, 2021). This phenomenon has been accredited to feelings of either safety or vigilance when listening to (un)pleasant sounds in the fore- or background (Andringa and Lanser, 2013). As human and technological sound compositions featured human activity both in the fore- and background this could explain our observed differences in pleasantness. Thus, the choice of individual sounds (i.e., sound distribution) as well as their organization (i.e., narrative structure) could play an important role in moderating pleasantness.

In terms of eventfulness, resulting soundscapes followed the expected ordering of our approach described in Study 1; that is, Comfortable sonic ambiance types were perceived as the least eventful followed by Pleasurable ones. Motivating and Stimulating sonic ambiance types were roughly equally judged to be the most eventful of the four. As auditory order and variation are important indicators of eventfulness (Aletta *et al.*, 2014), it can be said that the density of sound events in time and space (e.g., car sounds, bicycle bells, dogs barking, and an ambulance siren occurring all at the same time) but also the types of sound in the sound compositions contribute to the eventfulness of a soundscape. Our study showed that the human sound compositions added the most to the perceived eventfulness of resulting soundscapes, while musical sound compositions added the least. One possible explanation for the low eventfulness with regard to musical sound compositions could be found in grouping principles in Gestalt, such as streaming (Bregman, 1990). When presented with complex stimuli, such as musical compositions with multiple instruments or musical acts, individuals perceive them as unified wholes rather than as their individual components.

For most individual sound compositions, we found that the soundscape's position was moved from the baseline to vibrant and calm quadrants of the circumplex grid. These shifts were in line with previous research, where it was suggested that deliberate modifications to existing (urban) soundscapes could change their position to more positive quadrants (Cain *et al.*, 2013). In particular, our inspection compared to the baseline soundscape revealed that six sound compositions significantly affected the perceived pleasantness, and nearly all sound compositions significantly affected the perceived eventfulness of the soundscape. For Comfortable sound compositions, the effect in eventfulness was consistently mild, whereas for other sonic ambiance types, this effect became gradually stronger as designed. Only the perceived eventfulness as a result of musical sound compositions appeared to be inconsistent with this trend between sonic ambiance types.

Furthermore, we confirmed that our design approach for creating pleasant and varyingly eventful soundscapes evoked the desired affective response in listeners. That is, the perceived pleasantness and eventfulness of soundscapes matched the listeners' basic affective experience in terms of pleasure and arousal. Although the correlation between eventfulness and arousal was significant, it was less pronounced than that between pleasantness and pleasure. While pleasantness and pleasure may be more steadily aligned due to common, pre-existing associations regarding pleasant sounds (Andringa and Lanser, 2013), we currently lack a definitive explanation for the difference between the correlations. In previous work, regarding such relationships (Fiebig *et al.*, 2020) it was stated that emotional responses to soundscapes not only depended on the stimuli but also on the individual. The moderate correlation between eventfulness and arousal may thus be related to individual differences between participants. Since listening is a context-dependent, active process of action-based meaning-creation, the degree of arousal could be dependent on the listener's intentionality toward the perceived events (Tuuri and Eerola, 2012). In other words, the extent to which someone will feel activated by listening to a certain soundscape will likely depend on the need(s) of the listener. With our designed sound compositions in a lab-context, these needs may have been latent.

From Study 1 we concluded that need-based sound compositions would inherently be perceived as pleasant, and will differ in terms of eventfulness based on the need(s) of the listener. In Study 2 we confirmed this, as our design approach was effective in achieving equally pleasant soundscapes, which spanned the same range of eventfulness as described in Study 1. Our findings thus indicated that eventfulness was a viable design parameter for creating a varying range of sound compositions. However, as we discovered a significant interaction effect between the sonic ambiance types and dominant sound categories, the effective application of eventfulness as a design parameter needs to be explored further. For example, while human and natural sound compositions overall led to the most eventful soundscapes, perceived eventfulness was significantly less for their Stimulating variant. The musical sound compositions similarly had a negative difference between some sonic ambiance types, while technological sound compositions showed a considerable positive difference in eventfulness for the Stimulating variant. These interaction effects demonstrated that there is no single formula (yet) to describe this interplay and that a delicate balance is required while choosing and organizing sound events from certain sound categories to create eventfulness.

Finally, we concluded that our choice of four sonic ambiance types may have been ambitious and that future use of our approach should be conducted with three sonic ambiance types instead: Comfortable, Pleasurable, and Stimulating. In the forced-choice tasks, we observed that the identification of dominant sound categories of sound compositions was mostly accurate, except for technological (i.e., 16.7%). This might be attributed to the categorization from existing sound taxonomies (Gaver, 1993). The label 'technological' thus may not reflect the reality of how listeners perceive and label sounds in their daily interactions. Perhaps, a more specific definition of technological sounds should be provided to listeners in future research. In contrast, participants only identified Comfortable and Stimulating sonic ambiance types somewhat accurately (i.e., 70% and 50%, respectively). The results of the forced-choice tasks therefore suggested that while participants could distinguish well between dominant sound categories, they were less able to do so for the four sonic ambiance types.

In part, this could be due to the hierarchical agglomerative clustering in Study 1. The elbow diagram [Fig. 3(b)] indicated that a more fitting stopping point may have been at the three-cluster solution. This implied that Motivating and Stimulating sonic ambiance types were perhaps too similar to separate, and should therefore be merged for future considerations. Also, the labels themselves may not have fully captured the meaning of the sonic ambiances. The labels of sonic ambiances might be more meaningful in the presence of the actual related needs that are unfulfilled. Thus, this part of the study should be further investigated in follow-up studies in a functional setting (e.g., a real ICU). Similar to user tests performed with a soundscape augmentation system for dementia patients (De Pessemier *et al.*, 2023), our sound compositions and related sonic ambiances should be tested on their functional role, e.g., to comfort the patient, to provide a pleasurable environment during long stretches of time without visitation, and to stimulate (i.e., distract) them during spontaneous breathing trials or early rehabilitative physiotherapy. For these types of situations in real ICUs, future research should investigate the provision of sound compositions based on our approach, also relative to the existing ICU soundscape.

D. Limitations and future steps

We can expect that clinical (e.g., severity of illness, pain) and psychological (e.g., stressors) factors impact patients' experiences of real ICUs. Further, ICU patients spend considerable portions of their stay in states of sedation (Pandharipande *et al.*, 2013). These factors are likely to influence need fulfillment and soundscape perception. However, as a first feasible step to develop our need-based approach, we included healthy people rather than ICU patients. In this light, future studies could include a longitudinal, clinical trial with patients in single-patient ICU rooms with follow-ups after discharge.

Further, the acoustical differences of real single-patient ICUs compared to our lab setting in Study 2 should be considered. In our lab setting, the sound level (without sound compositions) was $\pm$ 30 dBA, while in single-patient ICU rooms minima of 37–38 dBA were measured (Özcan *et al.*, 2024). Additionally, actual ICU soundscapes include alarm events, opening doors, and other sounds inherent to ICU stays. Thus, we propose that future studies should evaluate whether the insights of this paper can be replicated in acoustic environments of real ICUs.

Also, another limitation of the study was developing our approach for single-patient ICU rooms. Future studies could investigate whether our approach could benefit other ICU formats as well.

Finally, during the design process of the sound compositions, the sound artist retained creative freedom over the design parameter of narrative characteristics, such as figure-ground relationships and temporality between individual sounds. This design parameter might be investigated further in relation to soundscape perception and need fulfillment, and in relation to our need-based approach.

IV. CONCLUSIONS

While the chances of surviving critical illness have improved drastically due to intensive care units (ICUs), previous studies have shown that patients experience these environments as stressful. The alienating, disruptive, unvaried, and unfamiliar soundscapes that surround patients in single patient ICU rooms harm their fulfillment of basic, psychological needs, such as pleasure, comfort, or purpose. These negative experiences may lead to long-lasting psychological impairments after ICU discharge. In this paper, we studied the soundscape of an ICU room itself as a source of need fulfillment and positive listener experiences by adding sound.

Our results show that adopting a need-driven approach when designing soundscape interventions could form a beneficial new way of providing positive listener experiences for ICU patients. This approach is aimed at developing sound compositions that support nine fundamental human needs, by establishing four distinct types of sonic ambiances (i.e., affective connotations with soundscapes): Comfortable, Pleasurable, Motivating, and Stimulating ambiances. Based on soundscape perception and fundamental need fulfillment, we identified four design parameters that designers could use to create such sound compositions, from the starting point of a (set of) target need(s): eventfulness, sonic ambiance qualities, narrative structure, and sound distribution. The results of the two studies in this paper confirmed that sound compositions developed with our design approach had the desired effects on both the perception of resulting soundscapes, as well as on the emotional responses of listeners. As we set out to provide positive experiences based on the needs of listeners, our findings suggest that with our approach this could indeed become possible. This paper is complementary to previous research regarding the design of supportive soundscapes and environments for vulnerable listeners, adding a novel, need-driven perspective to the field. Provided that the designed sound compositions match the salient needs of patients in different situations, improved experiences with soundscapes of ICUs could contribute to stress reduction and possibly reduce the long-term incidence of PICS-related symptoms, thus forming a promising step in improving ICU stays.

SUPPLEMENTARY MATERIAL

See the supplementary material at for: (Study 1) dataset with qualitative and quantitative data, means and standard deviations of needs, agglomeration table, and contingency tables. (Study 2) spectrograms, (psycho)acoustical measurement dataset; quantitative dataset; 20-s samples of sixteen sound compositions.

ACKNOWLEDGMENTS

We would like to extend our gratitude to Dr. René van Egmond for assisting in the statistical analyses, and to Dr. Ela Fasllija for her assistance with the (psycho)acoustical aspects of this paper. Also, we would like to acknowledge the creative efforts and skill of sound artist/composer Willem van Erven Dorens in designing the sound compositions used in this study. We would also like to extend our gratitude to the funding parties involved in this project.

AUTHOR DECLARATIONS

Conflict of Interest

This study was part of the VitalSounds: Sounds for Clinical Well-being project at the Critical Alarms Lab of

TABLE VI. Ambiance types, qualities, and examples from qualitative responses.

Ambiance type	Ambiance quality	Example quote[a]
Comfortable	Familiar	“At home in the garden. A neighbor is mowing his lawn, fountain is spraying. Splashing, lawn mower (…)” (P6)
	Safe	“I’m inside on a cold, stormy night, cocooned in a thick blanket with a cup of tea. Rain on window, jazz (…)” (P24)
	Relaxed	“Sitting in a good chair, closed eyes, listening to music or an audiobook. Burning wood, vinyl player (…)” (P31)
Pleasurable	Harmonious	“A living room with close family. It has harmony, but still with freedom/spontaneity. Voices, whistling (…)” (P28)
	Momentous	“Walking up, looking around, sharing the moment with the person you’re walking with. Rustling trees, birds (…)” (P25)
	Engaging	“You are walking in a museum of art. Every few meters displays a new piece of art. Walking, whispering (…)” (P12)
Motivating	Energetic	“I am cycling on a spinning bike. The instructor is talking and playing music. Strong beat, panting. (…)” (P17)
	Focused	“I am talking, other people are listening. There is a sense of focus. Quiet, own voice. (…)” (P20)
	Positive	“My supervisor is telling me the doctors are very satisfied with my work. Shifting in chair, laughter (…)” (P21)
Stimulating	Vibrant	“A city center of a world metropolis abroad, with new sounds and cultural experiences. Honking, shouts (…)” (P6)
	Inspirational	“Looking at someone whenever they perform live, a musical, theater show or sport event. Murmur, laughter (…)” (P28)

[a]Summarized descriptions of imagined soundscapes (i.e., *Environment, Events, Sounds*).

TABLE VII. (Psycho)acoustic indicators per sound composition: measured sound level, $L_{Aeq,90s}$; Loudness $N_{R/L}$ (sone), Sharpness $S_{R/L}$ (acum) for right and left channels.

Sound composition	Sound category	Ambiance type	$L_{Aeq,90s}$	N_R	N_L	S_R	S_L
Fireplace	Natural	Comfortable	35.7	5.28	4.46	1.55	1.51
Forest	Natural	Pleasurable	37.8	5.66	5.66	1.68	1.69
Park	Natural	Motivating	41.0	8.31	6.38	1.51	1.42
Countryside	Natural	Stimulating	36.0	3.81	5.64	1.78	1.71
Home office	Human	Comfortable	33.7	3.78	4.57	2.16	2.24
Terrace	Human	Pleasurable	37.8	6.11	5.68	1.63	1.68
Beach	Human	Motivating	37.1	6.04	5.02	1.31	1.70
Market	Human	Stimulating	37.0	5.13	5.64	1.59	1.62
Synthesized	Musical	Comfortable	39.2	5.15	5.22	0.80	0.73
Strings	Musical	Pleasurable	30.5	0.74	0.82	1.05	0.83
Melodic	Musical	Motivating	43.8	5.37	5.57	0.93	0.97
Rhythmic	Musical	Stimulating	45.4	7.12	7.10	0.94	0.92
Train compartment	Technological	Comfortable	33.9	2.75	2.69	0.49	0.59
Urban backyard	Technological	Pleasurable	33.3	2.55	3.27	2.03	1.92
Boats	Technological	Motivating	31.5	2.41	2.46	1.53	1.52
City	Technological	Stimulating	42.0	6.71	6.59	1.15	1.19

Industrial Design Engineering TU Delft and the Department of ICU at Erasmus Medical Center. The project is funded by Philips and Holland High Tech (TKI-HTSM/20.0385).

Ethics Approval

For both studies, all participants gave informed consent. We received ethical approval for both studies included in this paper through the Human Rights Ethics Committee (HREC) of Delft University of Technology: Study 1, approved on the 21st of October 2021, ID#1847; Study 2, approved on 13th of July 2023, ID#3342.

DATA AVAILABILITY

The data that support the findings of these studies are available within the article and its supplementary material.

APPENDIX

Ambiance types, qualities, and examples from qualitative responses (Table VI). (Psycho)acoustic indicators per sound composition: measured sound level, $L_{Aeq,90s}$; Loudness NR/L (sone), Sharpness SR/L (acum) for right and left channels (Table VII).

Aletta, F., Axelsson, Ö., and Kang, J. (**2014**). "Towards acoustic indicators for soundscape design," in *Proceedings of the Forum Acusticum 2014 Conference*.

Aletta, F., Kang, J., and Axelsson, Ö. (**2016**). "Soundscape descriptors and a conceptual framework for developing predictive soundscape models," Landscape Urban Plann. **149**, 65–74.

Alvarsson, J. J., Wiens, S., and Nilsson, M. E. (**2010**). "Stress recovery during exposure to nature sound and environmental noise," Int. J. Environ. Res. Public Health. **7**(3), 1036–1046.

Andringa, T. C., and Lanser, J. J. L. (**2013**). "How pleasant sounds promote and annoying sounds impede health: A cognitive approach," Int. J. Environ. Res. Public Health **10**(4), 1439–1461.

Axelsson, Ö., Nilsson, M. E., and Berglund, B. (**2010**). "A principal components model of soundscape perception," J. Acoust. Soc. Am. **128**(5), 2836–2846.

Ballard, K. S. (**1981**). "Identification of environmental stressors for patients in a surgical intensive care unit," Issues Ment. Health Nurs. **3**(1–2), 89–108.

Betella, A., and Verschure, P. F. (**2016**). "The affective slider: A digital self-assessment scale for the measurement of human emotions," PLoS One **11**(2), e0148037.

Braun, V., and Clarke, V. (**2021**). "One size fits all? What counts as quality practice in (reflexive) thematic analysis?," Qual. Res. Psychol. **18**(3), 328–352.

Bregman, A. S. (**1990**). *Auditory Scene Analysis: The Perceptual Organization of Sound* (MIT Press, Cambridge, MA).

Busch-Vishniac, I., and Ryherd, E. (**2023**). "Chapter 10: Hospital soundscapes," in *Soundscapes: Humans and Their Acoustic Environment*, edited by B. Schulte-Fortkamp, A. Fiebig, J. A. Sisneros, A. N. Popper, and R. R. Fay (Springer, New York).

Cain, R., Jennings, P., and Poxon, J. (**2013**). "The development and application of the emotional dimensions of a soundscape," Appl. Acoust. **74**(2), 232–239.

Çamci, A. (**2022**). *The Cognitive Continuum of Electronic Music* (Bloomsbury Publishing USA, New York).

Collins, K. (**2008**). *Game Sound: An Introduction to the History, Theory, and Practice of Video Game Music and Sound Design* (MIT Press, Cambridge, MA).

Darbyshire, J. L., and Duncan Young, J. (**2022**). "Variability of environmental sound levels: An observational study from a general adult intensive care unit in the UK," J. Intensive Care Soc. **23**(4), 389–397.

Darbyshire, J. L., Müller-Trapet, M., Cheer, J., Fazi, F. M., and Young, J. D. (**2019**). "Mapping sources of noise in an intensive care unit," Anaesthesia **74**(8), 1018–1025.

Davies, W., Bruce, N., and Murphy, J. (**2014**). "Soundscape reproduction and synthesis," Acta Acust. united Ac. **100**(2), 285–292.

Delaney, L., Litton, E., and Van Haren, F. (**2019**). "The effectiveness of noise interventions in the ICU," Curr. Opin. Anesthesiol. **32**(2), 144–149.

De Pessemier, T., Vanhecke, K., Thomas, P., Vander Mynsbrugge, T., Vercoutere, S., Van de Velde, D., De Vriendt, P., Wout, J., Martens, L., Bottledooren, D., and Devos, P. (**2023**). "Personalising augmented soundscapes for supporting persons with dementia," Multimed. Tools Appl. **82**(9), 14171–14192.

Desmet, P., and Fokkinga, S. (**2020**). "Beyond Maslow's pyramid: Introducing a typology of thirteen fundamental needs for human-centered design," Multimodal Technol. Interact. **4**(3), 38.

Devos, P., Aletta, F., Thomas, P., Petrovic, M., Vander Mynsbrugge, T., Van de Velde, D., De Vriendt, P., and Botteldooren, D. (**2019**). "Designing supportive soundscapes for nursing home residents with dementia," Int. J. Environ. Res. Public Health **16**(24), 4904.

Dunne, A., and Gaver, W. W. (**1997**). "The pillow: Artist-designers in the digital age," in *Proceedings of CHI '97 Extended Abstracts on Human Factors in Computing Systems* (ACM, New York), pp. 361–362.

Efron, B., and Stein, C. (**1981**). "The jackknife estimate of variance," Ann. Stat. **9**, 586–596.

Elbaz, M., Léger, D., Sauvet, F., Champigneulle, B., Rio, S., Strauss, M., Chennaoui, M., Guilleminault, C., and Mira, J. P. (**2017**). "Sound level intensity severely disrupts sleep in ventilated ICU patients throughout a 24-h period: A preliminary 24-h study of sleep stages and associated sound levels," Ann. Intensive Care **7**, 25.

Engel, M. S., Fiebig, A., Pfaffenbach, C., and Fels, J. (**2021**). "A review of the use of psychoacoustic indicators on soundscape studies," Curr. Pollut. Rep. **7**, 359–378.

Fan, J., Thorogood, M., Riecke, B., and Pasquier, P. (**2015**). "Automatic recognition of eventfulness and pleasantness of soundscape," in *Proceedings of the Audio Mostly 2015 on Interaction With Sound*, Thessaloniki, Greece, October 7–9, pp. 1–6.

Fiebig, A., Jordan, P., and Moshona, C. C. (**2020**). "Assessments of acoustic environments by emotions—The application of emotion theory in soundscape," Front. Psychol. **11**, 573041.

Gaver, W. (**1993**). "What in the world do we hear?: An ecological approach to auditory event perception," Ecol. Psyhcol. **5**(1), 1–29.
Geense, W. W., Zegers, M., Peters, M. A., Ewalds, E., Simons, K. S., Vermeulen, H., van der Hoeven, J. G., and van den Boogaard, M. (**2021**). "New physical, mental, and cognitive problems 1 year after ICU admission: A prospective multicenter study," Am. J. Respir. Crit. Care Med. **203**(12), 1512–1521.
Genelec (**2017**). "Operating manual 8020D," https://edu.nl/n37gg (Last viewed May 1, 2024).
Greco, G. F., Merino-Martínez, R., Osses, A., and Langer, S. C. (**2023**). "SQAT: A MATLAB-based toolbox for quantitative sound quality analysis," in *Proceedings of the INTER-NOISE and NOISE-CON Congress and Conference Proceedings*, Tokyo, Japan, August 20–23, pp. 7172–7183.
Hassenzahl, M., and Diefenbach, S. (**2012**). "Well-being, need fulfillment, and experience design," in *Proceedings of the Designing Well-Being Workshop*, https://edu.nl/h8ere (Last viewed August 23, 2024).
Holm, A., and Dreyer, P. (**2017**). "Intensive care unit patients' experience of being conscious during endotracheal intubation and mechanical ventilation," Nurs. Crit. Care **22**(2), 81–88.
Huang, S., and Desmet, P. M. A. (**2023**). "Needs matter: A detailed typology of fundamental needs for human-centered design," in *Proceedings of the Creativity, Innovation and Entrepreneurship AHFE International Conference*, July 20–24, San Francisco, CA.
ISO (**2014**). ISO 12913-1:2014, "Acoustics—Soundscape—Part 1: Definition and conceptual framework" (International Organization for Standardization, Geneva, Switzerland).
ISO (**2018**). ISO/TS 12913-2:2018, "Acoustics—Soundscape—Part 2: Data collection and reporting requirements" (International Organization for Standardization, Geneva, Switzerland).
ISO (**2019**). ISO/TS 12913-3:2019, "Acoustics—Soundscape—Part 3: Data analysis" (International Organization for Standardization, Geneva, Switzerland).
Jo, H. I., and Jeon, J. Y. (**2020**). "Effect of the appropriateness of sound environment on urban soundscape assessment," Build. Environ. **179**, 106975.
Johansson, L., Bergbom, I., Waye, K. P., Ryherd, E., and Lindahl, B. (**2012**). "The sound environment in an ICU patient room—a content analysis of sound levels and patient experiences," Intensive Crit. Care Nurs. **28**(5), 269–279.
Juslin, P., and Västfjäll, D. (**2008**). "Emotional responses to music: The need to consider underlying mechanisms," Behav. Brain Sci. **31**(5), 559–575.
Kelly, F. E., Fong, K., Hirsch, N., and Nolan, J. P. (**2014**). "Intensive care medicine is 60 years old: The history and future of the intensive care unit," Clin. Med. **14**(4), 376–379.
Krampe, H., Denke, C., Gülden, J., Mauersberger, V. M., Ehlen, L., Schönthaler, E., Wunderlich, M. M., Lutz, A., Balzer, F., Weiss, B., and Spies, C. D. (**2021**). "Perceived severity of stressors in the intensive care unit: A systematic review and semi-quantitative analysis of the literature on the perspectives of patients, health care providers and relatives," J. Clin. Med. **10**(17), 3928.
Lee, M., Kang, J., and Jeong, Y. J. (**2020**). "Risk factors for post–intensive care syndrome: A systematic review and meta-analysis," Aust. Crit. Care **33**(3), 287–294.
Lenzi, S., Sádaba, J., and Lindborg, P. (**2021**). "Soundscape in times of change: Case study of a city neighbourhood during the COVID-19 lockdown," Front. Psychol. **12**, 570741.
Louwers, G., Özcan, E., Van Bommel, J., and Pont, S. (**2022**). "Sounds that satisfy: Describing the relationship between sound and need fulfillment," paper presented at DRS 2022, Bilbao, Spain, pp. 1–20.
Louwers, G., Pont, S., Van der Heide, E., Gommers, D., and Özcan, E. (**2024**). "Augmenting soundscapes of ICUs: A collaborative approach," in *Proceedings of DRS2024: Boston*, June 23–28, Boston, MA.
Luetz, A., Grunow, J. J., Mörgeli, R., Rosenthal, M., Weber-Carstens, S., Weiss, B., and Spies, C. (**2019**). "Innovative ICU solutions to prevent and reduce delirium and post-intensive care unit syndrome," in *Seminars in Respiratory and Critical Care Medicine* (Thieme Medical, New York), pp. 673–686.
Mackrill, J., Cain, R., and Jennings, P. (**2013**). "Experiencing the hospital ward soundscape: Towards a model," J. Environ. Psychol. **36**,1–8.
Medvedev, O., Shepherd, D., and Hautus, M. (**2015**). "The restorative potential of soundscapes: A physiological investigation," Appl. Acoust. **96**, 20–26.
Mitchell, A., Aletta, F., and Kang, J. (**2022**). "How to analyse and represent quantitative soundscape data," JASA Express Lett. **2**(3), 037201.
Özcan, E., Broekmeulen, C. L., Luck, Z. A., van Velzen, M., Stappers, P. J., and Edworthy, J. R. (**2022**). "Acoustic biotopes, listeners and sound-induced action: A case study of operating rooms," Int. J. Environ. Res. Public Health **19**(24), 16674.
Özcan, E., Rietdijk, W. J., and Gommers, D. (**2020**). "Shaping critical care through sound-driven innovation: Introduction, outline, and research agenda," Intensive Care Med. **46**(3), 542–543.
Özcan, E., Spagnol, S., and Gommers, D. (**2024**). " Quieter and calmer than before: Sound level measurement and experience in the Intensive Care Unit at Erasmus Medical Center," in *Proceedings of INTERNOISE*, August 25–29, Nantes, France, pp. 1–12.
Özcan, E., van der Stelt, B., Maljers, I., Jayaram, S., Brenes, S., van Twist, E., and Kuiper, J. W. (**2023**). "Nature sounds for the win: Influencing the pleasantness perception of PICU soundscapes," in *Proceedings of Forum Acusticum 2023*, September 23, Turin, Italy.
Özcan, E., and van Egmond, R. (**2007**). "Memory for product sounds: The effect of sound and label type," Acta Psychol. **126**(3), 196–215.
Özcan, E., van Egmond, R., and Jacobs, J. (**2014**). "Product sounds: Basic concepts and categories," Int. J. Des. **8**(3), 97–111.
Pandharipande, P. P., Girard, T. D., Jackson, J. C., Morandi, A., Thompson, J. L., Pun, B. T., Brummel, N. E., Hughes, C. G., Vasilevskis, E. E., Shintani, A. K., Moons, K. G., Geevarghese, S. K., Canonico, A., Hopkins, R. O., Bernard, G. R., Dittus, R. S., and Ely, E. W. (**2013**). "Long-term cognitive impairment after critical illness," N. Engl. J. Med. **369**(14), 1306–1316.
Ratcliffe, E., Gatersleben, B., and Sowden, P. (**2013**). "Bird sounds and their contributions to perceived attention restoration and stress recovery," J. Environ. Psychol. **36**, 221–228.
Rijnstate (**2023**). "Rijnstate opent uniek dakterras voor intensive carepatiënten" ("Rijnstate opens unique rooftop terrace for intensive carepatients"), https://www.rijnstate.nl/over-rijnstate/nieuws/2023/rijnstate-opent-uniek-dakterras-voor-intensivecare-patienten/ (Last viewed February 20, 2024).
Russell, J. A. (**2003**). "Core affect and the psychological construction of emotion," Psychol. Rev. **110**(1), 145–172.
Schulte-Fortkamp, B., and Fiebig, A. (**2006**). "Soundscape analysis in a residential area: An evaluation of noise and people's mind," Acta Acust. united Ac. **92**(6), 875–880.
Sheldon, K., Elliot, A., Kim, Y., and Kasser, T. (**2001**). "What is satisfying about satisfying events? Testing 10 candidate psychological needs," J. Pers. Soc. Psychol. **80**(2), 325–339.
Tay, L., and Diener, E. (**2011**). "Needs and subjective well-being around the world," J. Personality Social Psychol. **101**(2), 354–365.
Thorndike, R. (**1953**). "Who belongs in the family, Presidential address to the Psychometric Society," Psychometrika **18**(4), 267–276.
Torresin, S., Albatici, R., Aletta, F., Babich, F., Oberman, T., Siboni, S., and Kang, J. (**2020**). "Indoor soundscape assessment: A principal components model of acoustic perception in residential buildings," Build. Environ. **182**, 107152.
Torresin, S., Aletta, F., Oberman, T., Vinciotti, V., Albatici, R., and Kang, J. (**2023**). "Measuring, representing and analysing indoor soundscapes: A data collection campaign in residential buildings with natural and mechanical ventilation in England," Build. Environ. **243**, 110726.
Truax, B. (**1999**). *Handbook for Acoustic Ecology* (Cambridge Street Publishing, Cambridge, UK).
Tuuri, K., and Eerola, T. (**2012**). "Formulating a revised taxonomy for modes of listening," J. New Music Res. **41**(2), 137–152.
Van den Bosch, K., Andringa, T., Post, W., Ruijssenaars, W., and Vlaskamp, C. (**2018**). "The relationship between soundscapes and challenging behavior: A small-scale intervention study in a healthcare organization for individuals with severe or profound intellectual disabilities," Build. Acoust. **25**(2), 123–135.
Vreman, J., Lemson, J., Lanting, C., van der Hoeven, J., and van den Boogaard, M. (**2023**). "The effectiveness of the interventions to reduce

sound levels in the ICU: A systematic review," Crit. Care Explor. **5**(4), e0885.

Ward, J., Jr. (**1963**). "Hierarchical grouping to optimize an objective function," J. Am. Stat. Assoc. **58**(301), 236–244.

Wiklund-Engblom, A., Hassenzahl, M., Bengs, A., and Sperring, S. (**2009**). "What needs tell us about user experience," in *Proceedings of the Human-Computer Interaction–INTERACT 2009: 12th IFIP TC 13 International Conference*, August 24–28, Uppsala, Sweden, pp. 666–669.

Xie, H., Kang, J., and Mills, G. H. (**2009**). "Clinical review: The impact of noise on patients' sleep and the effectiveness of noise reduction strategies in intensive care units," Crit. Care **13**(2), 208–208.