Sound augmentation for people with dementia: Soundscape evaluation based on sound labelling.

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Abstract: Researchers increasingly look at augmenting soundscapes to reduce Behavioural and Psychological Syndrome of Dementia (BPSD). However, methods to select suitable sounds still need improvement. This study proposes a sound selection methodology to augment the soundscape in nursing homes to lower BPSD, using sound characteristics and recognition methods. To uncover the underlying characteristics of sounds that trigger a positive response, added sounds previously used in nursing homes in Flanders were re-analyzed using a wide range of acoustic and psychoacoustic indices. The results highlight the sound characteristics that lead to positive responses and the need for further studies to understand the sounds most suitable for people with dementia. Results showed that sharpness and high-pitch sounds, such as animal localization or crickets, create a higher chance of a positive response. High-pitched sounds have a higher emergence in a typical nursing home sonic environment, increasing the possibility of being noticed. Sounds recognized as music, however, had a lower chance of a positive response and should be used cautiously. Interestingly, although bird vocalizations are often highly rated in other contexts, the ones considered in the current dataset did not lead to a positive response, highlighting the need for further studies to understand better which sounds are most suitable for people with dementia."

Keywords: soundscape; dementia; sound augmentation; sound labelling; behavioural and psychological symptoms of dementia (BPSD); sonic environment

1 Introduction

The term "soundscape", introduced by Canadian composer R. Murray Schafer (Schafer R. M., 1977) and subsequently defined in ISO-12913, refers to an acoustic environment as perceived, experienced and interpreted within a specific context by a person or people (ISO12913-1, 2014). Therefore, soundscape can be considered a valuable environmental factor in enhancing health and well-being. A well-designed soundscape can improve the quality of life and create a positive health impact (Schulte-Fortkamp, 2021). Research also shows the effect of natural sound on attention restoration (Ratcliffe, 2021b) and the importance of sound in making sense of place (Adams et al., 2006).

Sound is an essential sensory stimulus that gives people a sense of time and place (Talebzadeh et al., 2023; van den Bosch et al., 2016). While an unfamiliar and chaotic sonic environment can increase the anxiety and stress of those perceiving it, making the experience annoying and unpleasant, a well-designed soundscape can avoid such adverse effects. Expectation is essential in perceiving and understanding the sonic environment (Bruce & Davies, 2014). Expectation violation may cause annoyance, but mild expectation violation that does not jeopardize instantaneous intentions may make the experience more appealing and engaging. In mixed sonic environments, the expectation may also affect which sounds are attended to (Filipan et al., 2017).

Research also shows the positive effect of natural and non-natural soundscapes on people with severe intellectual disabilities (Andringa & Van Den Bosch, 2013). Sound can generate a feeling of safety (Van Den Bosch & Andringa, 2014) by influencing mood and triggering a specific action (Devos, Aletta, et al., 2019 a). Memory plays a vital role in soundscape perception and reflects the interaction between a person and their environment (Guastavino, 2006). Especially for people with cognitive decline, such as dementia, sounds become even more critical in their everyday lives (Guastavino, 2006).

Dementia is a neurodegenerative disorder that reduces memory and cognitive abilities, mobility and balance, mood and sleep quality. Behavioural and psychological symptoms of dementia (BPSD) refer to a group of noncognitive behaviours associated with dementia (Petrovic et al., 2007) that affect the prediction and control of dementia.

Currently, more than 55 million people live with dementia worldwide, and nearly 10 million new cases are diagnosed with dementia every year. Dementia is among the top seven causes of death among all diseases and a significant cause of disability and dependency among older adults globally. Dementia has social, psychological, and economic impacts, not only on the people living with dementia but on their caregivers, the healthcare system and society (World Health Organization, 2021). People with progressive cognitive illness need special care, which burdens their family members and caregivers. At some point, they commonly move to nursing homes and long-term care facilities and, in the case of dementia, memory care units. However, care facilities are often not customized for individual needs. Most of the activities in care units happen in shared environments with no sense of agency, as these spaces are commonly designed to function and are not intimate. Sensory perception of these spaces is unfamiliar for residents, adding to their anxiety and distress. People with dementia feel isolated, lonely and confined (Victor et al., 2020), and unfamiliar sounds can aggravate and disturb them.

Nursing homes' sonic environment can become a form of environmental pollution. Sudden noises, such as slammed doors or dropped equipment, can cause a startle reflex, which not only causes physiological responses in the person with dementia but can also increase the sense of disorientation and insecurity (Dewing, 2009). Exposure of individuals with severe dementia to high noise levels may increase confusion and trigger fear or other negative feelings, resulting in reduced social interaction (Garre-Olmo et al., 2012). Because dementia reduces the effects of sensory stimuli, it changes how a person perceives the external stimuli, leading to a greater risk of falls through loss of balance and sense of orientation (Hayne & Fleming, 2014). As van den Bosch et al. mention, when a person is unable to ignore or escape a sound; for example, in people with mobility restrictions in care facilities, what started as an annoyance would become a source of stress and agitation (van den Bosch et al., 2016). Also, people with dementia may have a limited capacity to understand their environment (Hayne & Fleming, 2014) and the relation between sound and the source of sound, which adds to their confusion.

Although hearing loss is common in older adults, significant hearing loss affects around 40% of adults over 65 with cognitive impairment and dementia (Hardy et al., 2016). Research shows a correlation between hearing loss and dementia. Hearing loss may not be the reason behind cognitive impairment; however, it brings social isolation and excess cognitive load that may accelerate cognitive decline.

BPSD includes agitation, depression, apathy, repetitive questioning, psychosis, aggression, sleep problems, wandering, and socially inappropriate behaviours (Kales et al., 2015). Apathy is one of the most common factors in BPSD (Massimo et al., 2018), and environmental stimuli are one of the triggers (Jao et al., 2019). Sound, as an effective factor, therefore, needs attention. As Jao et al. mentioned, tailoring environmental stimuli based on a personal life history, cognitive level, and functional capacity can help reduce BPSD (Jao et al., 2019).

The effect of the soundscape on people with dementia has been studied (Aletta et al., 2017, 2018; Janus et al., 2021; Talebzadeh et al., 2023; Thomas et al., 2020; van den Bosch et al., 2018) and the relation between soundscape and BPSD is becoming clear (De Pessemier et al., 2022; Devos, Thomas, et al., 2019 b). Adding a positive sound to the environment for this purpose improves the behaviour and lowers BPSD (De Pessemier et al., 2022; Kosters et al., 2022). Adding (human-preferred) sound to the acoustic environment creates an “augmented soundscape” and improves the overall perception of the environment, e.g., an urban park (Van Renterghem et al., 2020, p. 1).

Soundscape perception and experience depend on people’s listening habits and their relationship to the environment; different people in the same environment may have a contrasting relationship to the same soundscape (Truax, 1984) and, therefore, entirely different responses (Cain et al., 2013). The ability to control the soundscape gives people a sense of agency and power, even inside a confined environment.

Augmenting sonic environments for people with dementia can help them navigate in space and be aware of time. However, sound augmentation is challenging for people with memory loss, as sounds may trigger specific reactions. The soundscape design, therefore, requires an understanding of sound characteristics and human interaction with their sonic environment. Sound impacts memory and can be a powerful trigger for positive and negative emotional experiences, including trauma, as the brain can make a strong connection between trauma and the sound present at the time of the event. People who have experienced trauma may be especially susceptible to sound triggers. These triggers can lead to various responses, including anxiety, fear, panic attacks, or dissociation. Therefore sound selection plays an essential role in augmenting a soundscape. Some sound or sound characteristics may be beneficial for most people; however, knowing people's interests and preferences would be helpful in selecting the sounds.

Previous studies (De Pessemier et al., 2022; Devos, Thomas, et al., 2019 b) looked at the effect of personalized soundscape on people with dementia. In typical soundscape studies, people personally evaluate their sonic environment (ISO/TS12913-2, 2018);

however, communication impairment is common for people with dementia (Banovic et al., 2018) and is often one of the earliest symptoms. Nurses and caregivers are trained to communicate with residents and comprehend their reactions and needs. The day-to-day interaction between nurses and residents in nursing homes makes them the best source of understanding the participant's reactions and interests. Therefore, nurses are an indirect source of information on the effect of soundscape on the residents as they understand non-verbal responses and the states of residents. As researchers increasingly look at designed soundscapes to reduce BPSD (De Pessemier et al., 2022; Talebzadeh et al., 2022; Talebzadeh & Botteldooren, 2022; Thomas et al., 2020), finding methods to select the sounds for soundscape augmentation is needed.

This research aims to find practical methods for selecting sound in designing soundscape for people with severe dementia. The selected sounds were based on the soundscape player in the study by de Pessemier et al. (De Pessemier et al., 2022), and the feedback given by the caregivers from that study was used to find a correlation between the selected sounds and participants' responses. The correlation between the soundscape evaluation data and the characteristics of the sounds was used to introduce methods for future sound selection for augmentation without human biases.

In the design of this study, we first selected a set of sounds to be used in the soundscape design (sections 2.1 and 3.1). Then, the soundscape was implemented in a few nursing homes and evaluated through a feedback system operated by caregivers. As we explain later, caregivers in nursing homes are very familiar with the residents and aware of their reactions and needs (sections 2.4 and 3.2). We then use a sound recognition system to dive deeper into the sound fragment.

Finally, we used statistical analysis to evaluate the feedback data to find a correlation with a sound recognition approach (sections 2.3 and 3.3). The aim was to evaluate the sound selection method by finding a correlation between the caregiver's feedback and the acoustic indicators for a chance of a positive outcome for each sound segment.

2 Materials and Methods

Our research design started with sounds selected by the research team. Then, the soundscapes were implemented in nursing homes. During the implementation, the feedback system personalized the soundscape based on the participants' interests. The feedback gave us an understanding of preferred sounds. We asked nurses and caregivers to evaluate the sounds based on the participants' reactions. Then we used a sound recognition system to understand the sound segment of each selected sound.

2.1 Sound Selection by Experts

The research team selected the preferred sounds for the designed soundscape through ethnographic research in two nursing homes (Talebzadeh et al., 2023) and multiple co-design sessions with nursing home residents' caregivers and family members (Devos et al., 2018). Two hundred and eighteen sounds were collected from open-source databases (191 sounds) and on-location recordings (27 sounds). The existing open databases were FreeSounds (137 sounds), BBC sound effects (27 sounds), MusOpen (21 sounds), BenSound (3 sounds), YouTube (2 sounds) and ElectroBel (1 sound). This collection includes natural sounds, anthropogenic sounds (from human activities) and music. All sounds are subcategorized/labelled into:″ animals″,″ birds″,″ weather″,″ water″,″ wind″,″ environment night″ in the case of natural sounds, and″ clock″,″ wind chime,″ and″ transport″ in the case of anthropogenic sounds. The music was carefully selected to remain in the background avoiding recognizable songs. All selected sounds had either non-compressed (wav) or compressed formats (mp3) and were converted into two-ƒchannel MPEG-1 layer three files “mp3 “joint “stereo”) at a sample rate of 44.1 kHz with a constant bit rate (CBR) of 192 kbps using Adobe Audition software.

A team of six researchers (AT, TVM, DVV, PDV, PD, and DB) reviewed and rated each sound for its ability to augment the soundscape during specific activities. Three team members (TVM, DVV and PDV) have clinical backgrounds specialized in geriatric psychology, dementia healthcare management and occupational therapy, with an understanding of soundscape. AT has an architecture background, designing memory care units, senior housing and long-term care facilities and studying soundscapes for people with dementia. The other two persons involved (PD and DB) are engineers with signal processing and soundscape research backgrounds.

The team evaluated the suitability of each sound for 17 different activities by rating them 0, 1, or 2 (Not suitable ‘0’, maybe ‘1’, and suitable ‘2’). The activities were defined based on a typical day in nursing homes, from waking up and getting ready for breakfast, having breakfast, lunch and dinner time, actional activities such as taking medication, taking showers, going to the bathroom and resting activities such as sleeping, resting, and getting ready to sleep. The list of activities originated from previous research in Flanders nursing homes (Devos, Aletta, et al., 2019 a) and was then tailored to be used in the personalized soundscape.

Two activities were eliminated during the evaluation as they received very little ratings (doing a social activity and having a visitor in the room), which emphasizes the difficulty of choosing one specific suitable sound for these activities.

To choose a suitable sound, the team used 40% and 60% as benchmarks for the impact of each sound. Although these numbers may seem arbitrary, they gave the researchers a starting point to design the soundscape as they refer to a moderate level of selection between six researchers. The average rating for sounds per activity was then calculated. Sounds with an average of >1.2 were selected for level 2, and those with an average rating of >0.8 (and below 1.2) were chosen for level 1. Level 2 sounds would be a priority to play for a specific activity and were used when the experiment started. Based on the caregivers’ responses, alternative sounds were occasionally selected automatically to be used the next day. These alternatives can be selected from categories 1 as well as from 2.

The selection of sounds by the research team may potentially introduce a “sample selection bias” (Cuddeback et al., 2004). However, the team rated sounds for their suitability of each activity and the teams' diverse background; demographic (gender, ethnicity, age) and professional (acoustic, design, psychology and care) made the selection diverse and gave credit to their evaluation. Within the framework of this study, this method helped design a soundscape.

2.2 Sound Features

To uncover the underlying characteristics of sounds that trigger a positive response in persons with dementia, all sounds (De Pessemier et al., 2022) were analyzed using a wide range of acoustic and psychoacoustic indices. It should be noted, however, that the sounds used for augmenting the soundscape are not heard by themselves but as part of a composition with the sounds that are naturally present in the nursing home. Indeed, the sound was played at a level to only weakly emerge above the expected background, and hence they may attract attention occasionally, but they were not dominant. The goal was to blend the augmentation into the existing acoustic environment, not sounding too invasive or artificial. Also, for those with hearing impairment, whether they use hearing aids or not, the system was designed to their preference. The system has an option for residents with hearing impairment; by choosing the option, the system adjusts the volume of the soundscape. This option is adjustable for each activity since residents may use the hearing aid only during certain activities (De Pessemier et al., 2022, p.10).

Nevertheless, it would have been highly beneficial to record the overall sound environment during the augmentation phase and use this for further analysis. However, privacy regulations and ethical boundaries did not allow us.

A wide range of acoustic and psychoacoustic metrics was calculated as a starting point for the statistical analysis. Firstly, classical total sound pressure levels were calculated without frequency weighting (L_{eq}) and with A and C weighting (LA_{eq}, LC_{eq}). Temporal characteristics were analyzed using percentiles L_x with x= 5, 10, 25, 50, 75, 90, and 95, where L_5 and L_{10} are commonly used to indicate peak levels while L_{90} and L_{95} are representative of the continuously present background noise. These metrics were included because of their common use, not because they were necessarily expected to be good indicators to assess the effect of sound augmentation. All metrics were calculated over the full duration of the fragments.

For psychoacoustic metrics, Zwicker loudness (ISO 532-1-2017, 2017; Zwicker & Fastl, 2007), fluctuation strength, roughness, and sharpness (DIN 45692, 2009) were analyzed. Their average value over the fragment and their main percentiles were also included. In addition, more explorative metrics that emerged recently in soundscape research, such as saliency, music likeness, the spectral center of gravity, the number of events above LA_{50}, danceability, beats per minute, and spectral complexity, were included.

Saliency or sensory saliency relates to how much a sound stands out from a surrounding environment (Filipan et al., 2019). Music Likeness (ML) is a metric that defines whether a sound resembles music based on the self-organizing complexity of its temporal behaviour both in amplitude and in pitch changes (Botteldooren et al., 2006). The “Center of Gravity” (Kazazis et al., 2022) corresponds to the frequency that divides the spectrum into two halves such that the amount of energy in the top half (at higher frequencies) is equal to that in the bottom half (at lower frequencies). The number of events above LA_{50} is defined as the number of events at least 3 dB above the median A-weighted level for at least 3s. Spectral complexity (Laurier et al., 2010) is a metric based on the number of peaks in the amplitude spectrum.

It was previously observed that psychoacoustic metrics could not be used across distinct categories of sounds as they would, in such a case, merely be a proxy for the sound recognition. E.g., the “sharper” sounds in a wide sound collection may correspond to bird vocalizations (Benocci et al., 2021), and thus a preference for sharp sounds could potentially indicate a preference for bird sounds.

2.3 Sound Recognition

To identify the recognizable sounds present in each fragment, an automatic sound labelling system (Kong et al., 2019) that was trained on AudioSet (Gemmeke et al., 2017; Hou et al., 2022) was used. The labelling resulted in 527 classes of sounds. Every second, the probability of identifying a sound belonging to each class was obtained. Then, these probabilities were aggregated over the full duration of the sound fragment. 27 classes of sounds. Every second, the probability of identifying a sound belonging to each class was obtained. Then, these probabilities were aggregated over the full duration of the sound fragment.

For this, two strategies were followed:

1) the probabilities that were higher than 10% were averaged; this can be interpreted as the percentage of the time that the sound event was prominent

$$\text{mean}\ ((\max\ (0, \text{label\_probability} - 0.1)/\ (1.0\text{-}0.1))$$

2) the logarithm of the probabilities per second was averaged; this can be interpreted as an indication that the sound is always there, the background

$$\text{mean}(\log(1+\text{label\_probability})/\log\ (2))$$

2.4 Push button evaluation by caregivers

Caregiver’s feedback was collected using a five-category push button. The Ethics Committee of Ghent University approved the study with B.U.N.(Belgian unique number): B6702020000597 and date: 21/8/2020. All participants or their representatives signed an informed consent. The buttons were used several times throughout the day to evaluate the sound as part of the soundscape system (De Pessemier et al., 2022). Although this information is primarily used for automatically modifying the playlist, it can also be used to classify the sounds that were used for augmentation with respect to their impact on the overall state of the person with dementia. Push button responses are less reliable than detailed questionnaires commonly used in soundscape studies. However, the number of responses allowed us to obtain more substantial statistical power on a sound-by-sound basis. Moreover, the workload of caregivers is such that answering several questions on top of their daily routine is unfeasible.

During the experiment in the nursing homes, caregivers evaluated the effect of specific sounds on the participant’s behaviour and mood by pressing feedback buttons. Nineteen residents participated in the study (7 male and 12 female, with a mean age of 85, SD=6.43). The sounds were played during 8 weeks in total (2 weeks of pre-soundscape phase, 4 weeks of soundscape phase and 2 weeks of post-soundscape) (De Pessemier et al., 2022, p.16). Caregivers are very close to the residents and aware of their reactions and are thus well suited to understand residents’ responses to the environment, especially their agitation and stress. The feedback system uses a 5-point colour scale (green, yellow, orange, red, and black), where “green” should be used for strongly positively evaluated sounds and “black” for the non-desirable (disturbing) sounds. In addition, a white button was used to mute the system when residents were too agitated or when different activities were happening simultaneously (doctor visits, incidents or emergencies). The algorithm adjusts based on the feedback system; if the feedback is negative, the system chooses another sound. The system keeps the sound on the playlist for a specific activity when the input is positive or when there is no feedback.

Caregivers were reminded throughout the research that the assessment must be based on the residents' reactions, not their own; however, caregivers' cognitive biases may affect the evaluation. During the study, nurses were directed to use the same knowledge and expertise in evaluating BPSD to evaluate the effect of the augmented sound on the participants. Most dementia evaluation tools are based on behavioural changes and not through direct verbal communication. Evaluation tools, such as the Pittsburgh Agitation Scale (PAS), are based on direct patient observation and designed to monitor the severity of agitation associated with dementia. The same techniques were used in evaluating the effect of each segment and using the feedback system.

The data from the feedback buttons should mainly demonstrate the overall suitability of the sounds from the residents' perspectives. Nonetheless, it cannot be excluded that the caregiver's perception and mood can affect the evaluation.

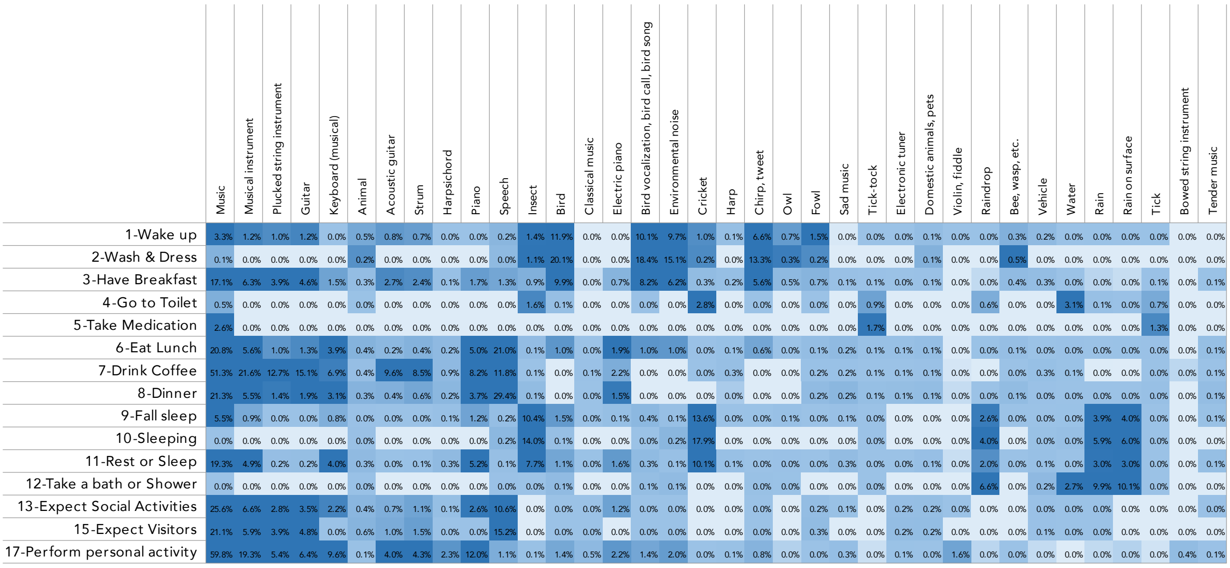
In brief, the caregivers' feedback was used to evaluate the sound selection based on residents' reactions, monitor the best-received sounds, and for any adverse effects of the sounds.

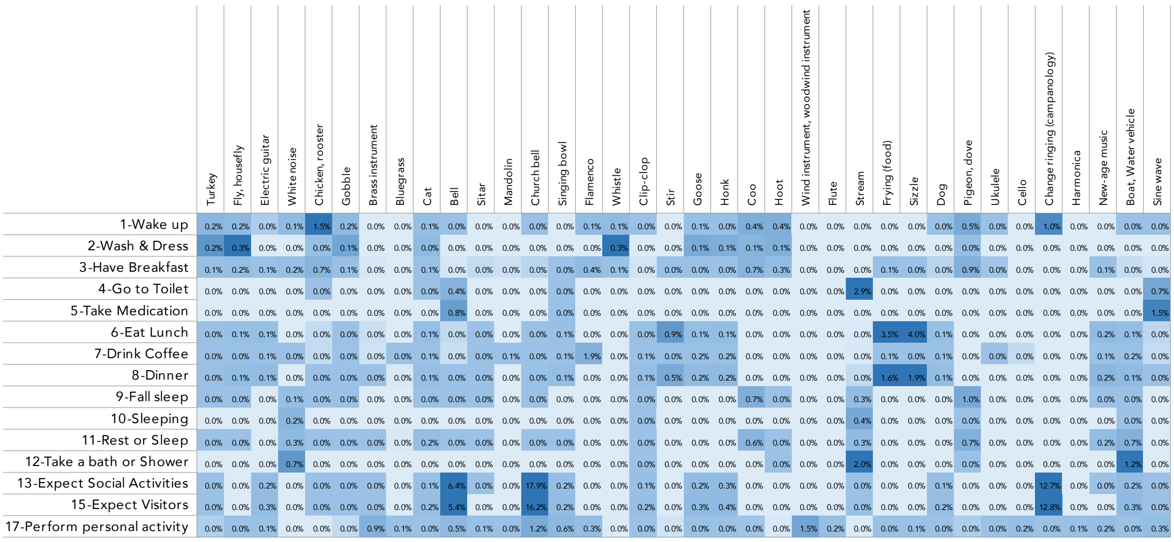
3 Results

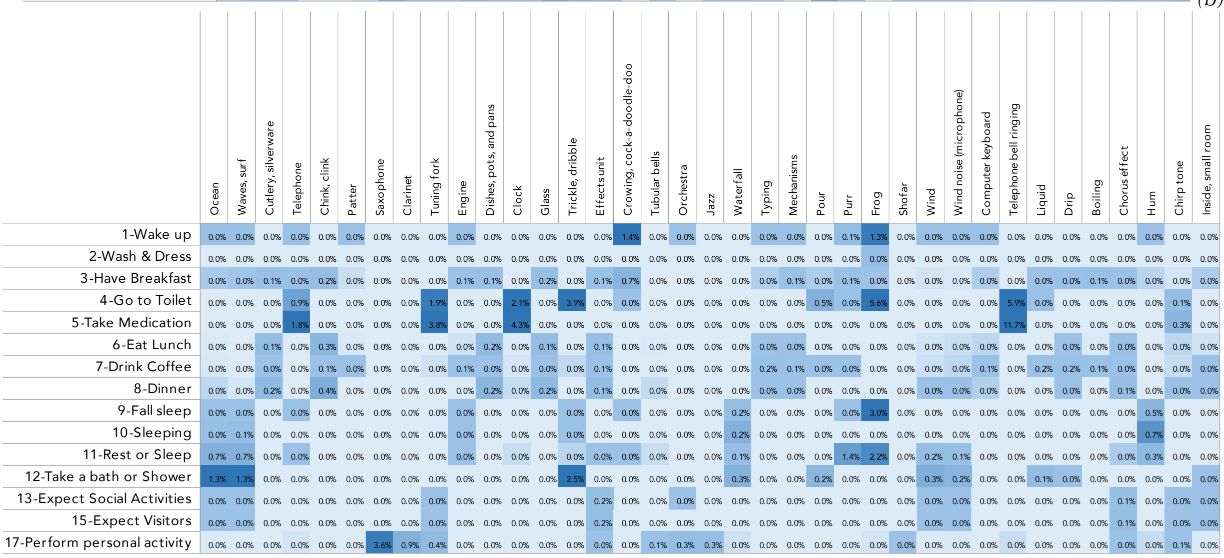
3.1 Expert Selection

For each fragment selected by the experts as appropriate for a specific activity (label "2", see Section 2.1), automatic sound recognition was used to identify the type of sounds that were present in that fragment (background aggregation). This sound recognition allows for investigating whether the experts have selected fragments due to recognizable sounds. For this purpose, probabilities for a particular sound to occur for an activity were averaged over all fragments selected for that activity.

Table 1 shows the probability of segments per activity using a percentile colour scale. Music has the largest probability of being selected by the expert panel for most of the activities, followed by "bird", "bird vocalization" for morning activities and "cricket" for resting and sleeping activities. Human-based sounds such as "typing", "speech", "telephone" and others have staggered probability through almost all activities. Looking at the table, for example, the bird's sound received the highest probability for both "wake up" and "wash and dress." Cricket sound has the highest probability for "falling asleep" and "sleeping". However, music has the highest probability for "resting." Rain sounds were often recognized in fragments selected for resting and sleeping, but in a trivial way, it is also associated with taking a bath or a shower. Some extremely specific and recognizable sounds such as "bells", "church bells", and "telephone ringing" were present only in fragments that were related to "take medication," "expect social activities," or "expect a visitor".


Music
Musical instrument
Plucked string instrument
Guitar
Keyboard (musical)
Animal
Acoustic guitar
Strum
Harpsichord
Piano
Speech
Insect
Bird
Classical music
Electric piano
Bird vocalization, bird call, bird song
Environmental noise
Cricket
Harp
Chirp, tweet
Owl
Fowl
Sad music
Tick-tock
Electronic tuner
Domestic animals, pets
Violin, fiddle
Raindrop
Bee, wasp, etc.
Vehicle
Water
Rain
Rain on surface
Tick
Bowed string instrument
Tender music
1-Wake up
2-Wash & Dress
3-Have Breakfast
4-Go to Toilet
5-Take Medication
6-Eat Lunch
7-Drink Coffee
8-Dinner
9-Fall sleep
10-Sleeping
11-Rest or Sleep
12-Take a bath or Shower
13-Expect Social Activities
15-Expect Visitors
17-Perform personal activity
(a)


Turkey
Fly, housefly
Electric guitar
White noise
Chicken, rooster
Gobble
Brass instrument
Bluegrass
Cat
Bell
Sitar
Mandolin
Church bell
Singing bowl
Flamenco
Whistle
Clip-clop
Stir
Goose
Honk
Coo
Hoot
Wind instrument, woodwind instrument
Flute
Stream
Frying (food)
Sizzle
Dog
Pigeon, dove
Ukulele
Cello
Change ringing (campanology)
Harmonica
New-age music
Boat, Water vehicle
Sine wave
1-Wake up
2-Wash & Dress
3-Have Breakfast
4-Go to Toilet
5-Take Medication
6-Eat Lunch
7-Drink Coffee
8-Dinner
9-Fall sleep
10-Sleeping
11-Rest or Sleep
12-Take a bath or Shower
13-Expect Social Activities
15-Expect Visitors
17-Perform personal activity
(b)


Ocean
Waves, surf
Cutlery, silverware
Telephone
Chink, clink
Patter
Saxophone
Clarinet
Tuning fork
Engine
Dishes, pots, and pans
Clock
Glass
Trickle, dribble
Effects unit
Crowing, cock-a-doodle-doo
Tubular bells
Orchestra
Jazz
Waterfall
Typing
Mechanisms
Pour
Purr
Frog
Shofar
Wind
Wind noise (microphone)
Computer keyboard
Telephone bell ringing
Liquid
Drip
Boiling
Chorus effect
Hum
Chirp tone
Inside, small room
1-Wake up
2-Wash & Dress
3-Have Breakfast
4-Go to Toilet
5-Take Medication
6-Eat Lunch
7-Drink Coffee
8-Dinner
9-Fall sleep
10-Sleeping
11-Rest or Sleep
12-Take a bath or Shower
13-Expect Social Activities
15-Expect Visitors
17-Perform personal activity
(c)

	Pink noise	Male speech, man speaking	Female speech, woman speaking	Narration, monologue	Children playing	Buzz	Aircraft	Ratchet, pawl	Gears	Chewing, mastication	Biting	Heart sounds, heartbeat	Heart murmur	Organ	Gong	Chime
1-Wake up	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2-Wash & Dress	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3-Have Breakfast	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%	0.2%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
4-Go to Toilet	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5-Take Medication	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6-Eat Lunch	0.0%	0.2%	0.3%	0.9%	0.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
7-Drink Coffee	0.0%	0.1%	0.2%	0.4%	0.1%	0.0%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
8-Dinner	0.0%	0.3%	0.5%	1.3%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
9-Fall sleep	0.7%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	4.9%	3.1%	0.0%	0.0%	0.0%
10-Sleeping	1.1%	0.0%	0.0%	0.0%	0.0%	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%	7.3%	4.6%	0.0%	0.0%	0.0%
11-Rest or Sleep	0.9%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	3.7%	2.3%	0.0%	0.0%	0.0%
12-Take a bath or Shower	2.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
13-Expect Social Activities	0.0%	0.2%	0.2%	0.7%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
15-Expect Visitors	0.0%	0.3%	0.3%	1.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
17-Perform personal activity	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%

	Wind chime	Sailboat, sailing ship	Rowboat, canoe, kayak	Chopping (food)	Children shouting	Crowd	Cowbell	Croak	Coin (dropping)	Typewriter	Crunch	Throbbing	Cheering	Hammond organ	Jingle bell	Bicycle bell	Alarm	Alarm clock	Ding	Clang	Jingle, tinkle
1-Wake up	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2-Wash & Dress	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3-Have Breakfast	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4-Go to Toilet	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.7%	0.3%	2.7%	0.4%	0.2%	0.0%
5-Take Medication	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	18.0%	3.5%	0.7%	5.3%	0.8%	0.5%	1.1%
6-Eat Lunch	0.0%	0.0%	0.0%	0.1%	0.4%	0.4%	0.1%	0.0%	0.1%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
7-Drink Coffee	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
8-Dinner	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.1%	0.0%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
9-Fall sleep	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.8%	0.0%	0.0%	0.0%	0.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
10-Sleeping	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
11-Rest or Sleep	0.0%	0.2%	0.1%	0.0%	0.0%	0.0%	0.0%	0.6%	0.0%	0.0%	0.0%	0.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
12-Take a bath or Shower	0.0%	0.3%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
13-Expect Social Activities	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
15-Expect Visitors	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
17-Perform personal activity	0.2%	0.0%	0.0%	0.0%	0.2%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

(d)

Table 1 (a,b,c,d). Probability of appropriateness of a sound fragment for an activity. The colour scale from the 5th (light blue) to the 95th percentile (dark blue).

3.2 Evaluation via Pushbutton

The result of the five-button feedback system is demonstrated in Figure 1. Each column refers to a particular sound fragment. Colours are based on a feedback system, with off-white representing the mute action. The Wxxx number refers to the individual sound fragments used in this study. The list of fragments is shown in Table 2 (the label refers to the most dominant sound heard when listening to the fragment).

The sounds that were initially played are those that the experts selected as level 2 sounds. If, however, a sound was rated negatively very often, it was replaced by a level 1 sound matching that activity. In a previous paper (De Pessemier et al., 2022), it is explained how this rating evolved over time during the experiment. Also, the system adapts to the resident's preferences and therefore sounds which remained in the system received more positive ratings. These system characteristics explain why sounds are mostly rated green or yellow, with the exception of sounds W0002 (beep) and W00085 (solo acoustic guitar player). Nevertheless, the fact that sounds remained in the soundscape system and played for the period of the experiment emphasizes the positive impact of the augmented soundscape on residents.

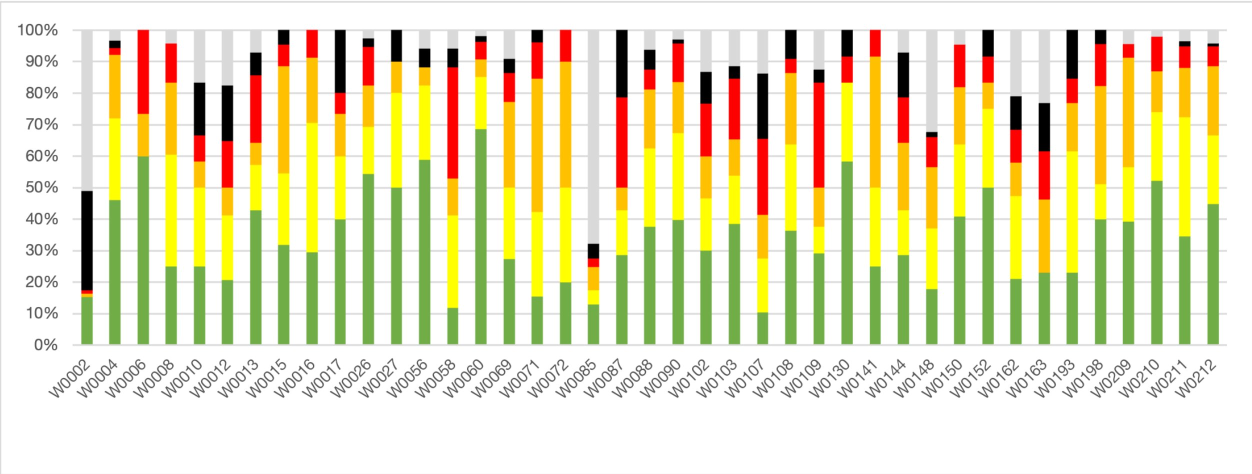


Figure 1. Feedback is based on five colour buttons and the mute button (grey).

W0002	Beep	W0060	Rain	W0130	Brewing coffee
W0004	Café- people talking	W0061	Music	W0141	Rooster
W0006	Cricket	W0069	Restaurant and conversation	W0144	Music
W0008	Birds and bees	W0071	Heavy rain	W0148	Music
W0010	Waves and wind	W0072	Birds	W0150	Cafe
W0012	Piano	W0085	Acoustic guitar	W0152	Birds
W0013	Piano	W0087	Water stream	W0162	Violin
W0015	Piano	W0088	Water stream	W0163	Violin
W0016	Birds	W0090	Cricket	W0193	Paragon
W0017	Kids playing in a park	W0102	Heartbeat	W0198	Café and conversation
W0026	Rain	W0103	Heartbeat	W0209	Birds
W0027	Birds	W0107	Cricket	W0210	Birds
W0056	Birds	W0108	Cricket, wind, and traffic	W0211	Birds
W0058	Birds	W0109	Cricket	W0212	Birds

Table 2. List of sounds based on the most dominant sound heard when listening to the fragment

3.3 Statistical Analysis

The statistical analysis of the relationship between button presses and the acoustic indicators introduced in Sections 2.2 and 2.3 included the following steps:

1) Retention of Sound Fragments:

Only sound fragments that have received evaluations from at least 5 buttons, either during or immediately after the fragment was played, were kept for analysis.

2) Binary Transformation of Button Scale:

The five-point button scale is transformed into a binary evaluation. Sound fragments that were rated as "Green + Yellow" at least 60% of the time are considered positive.

$$\text{Binary Evaluation} = (\text{Green} + \text{Yellow Count}) / \text{Total Evaluations} \geq 0.6$$

3) Removal of Outliers:

Outliers in the indicators have been removed based on a normal distribution with a threshold P=0.01 and a maximum of 5 removal points.

4) Calculation of Odds Ratios (OR):

Odds ratios are calculated after grouping each indicator into two classes based on the median. The classes are determined as low value vs. high value within the range of values present.

Odds Ratio (OR) = (*P* (high value) / (1 - *P* (high value))) / (*P* (low value) / (1 - *P* (low value)))

5) Logistic Regression Curves with Confidence Intervals:

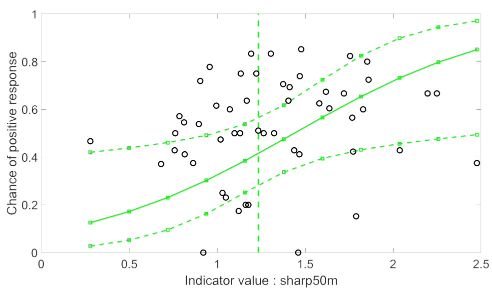
Logistic regression curves display the probability of a positive outcome against continuous indicator values. Dashed lines represent 95% confidence intervals on the regression curves.

Probability of Positive Outcome = 1. / (1 + exp (-(b0 + b1 * Indicator Value)))

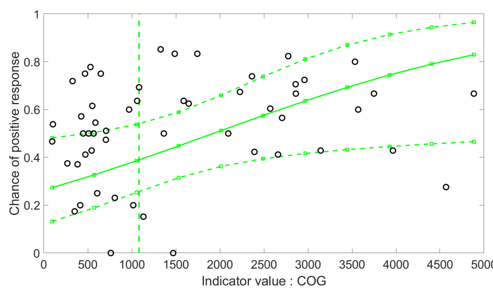
Odds Ratio (OR) = exp (b1)

In these explanations, "Green + Yellow" refers to the combined count of ratings in the "Green" and "Yellow" categories. "*P* ()" denotes the probability of an event occurring, and "exp ()" is the exponential function. The logistic regression formula represents how the probability of a positive outcome changes with the indicator value, where b0 is the intercept and b1 is the coefficient associated with the indicator value. The odds ratio formula calculates the ratio of the odds of a positive outcome between the high and low indicator value groups.

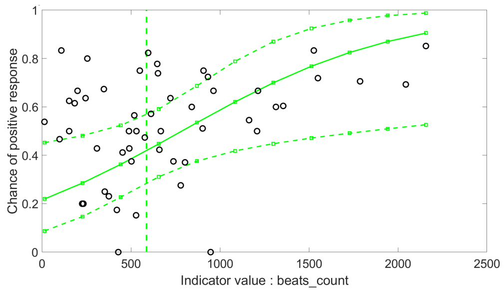
None of the level indicators have a statistically significant ($P < 0.05$) odds ratio or regression curve predicting the chance of a positive push-button response. This is unsurprising as the sounds were all played at the same loudness level. From the collection of psychoacoustic indicators, only increasing sharpness had a statistically significant effect on the chance of a positive rating (Figure 2a). Similarly, an increase in spectral centre of gravity showed a statistically significant positive effect on the chance of a positive evaluation (Figure 2b). Surprisingly, the increasing beat count also showed a statistically significant positive effect (Figure 2c). The reader should note that a software (Bogdanov et al., 2013) for music analysis was used whether a sound fragment contained music or not.



(a): Median separation stats: ρ =0.022076 OR=3.8 CI on OR= [1.2116-11.9185] n=53



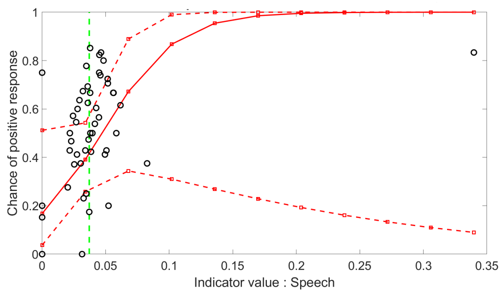
(b): Median separation stats: ρ =0.022076 OR=3.8 CI on OR= [1.2116-11.9185] n=53



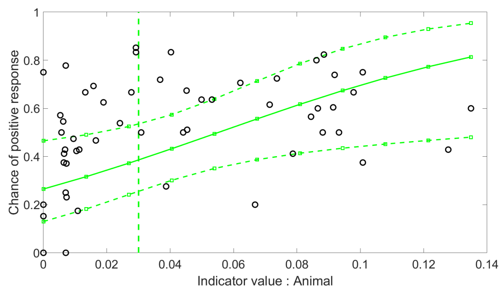
(c): Median separation stats: ρ =0.028744 OR=3.6 CI on OR= [1.1422-11.34671 n=52

Figure 2. Logistic regression on the chance of a positive effect; (a) for sharpness, (b) for the spectral centre of gravity, (c) for the beat count as an indicator.

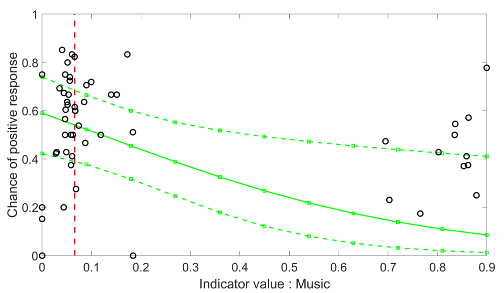
It was noted, however, that psychoacoustic indices such as sharpness could be an indicator of the sound type. Sounds with high-frequency components usually stay noticeable, resulting in positive or negative feedback compared with a sound with lower frequency content. Hence the probability of a sound being labelled with a specific label has also been used as a sound fragment indicator. First, the aggregation over time that leads to an evaluation of background sounds is considered. As many sounds regularly get assigned a small probability of being present by the sound recognition software, the analysis is limited to sounds for which the median indicator exceeds 0.01. Within this group, the presence of speech, animal sounds, and music had a statistically significant (r<0.05) effect on the chance of a positive response (Figure 3).



(a): Median separation stats: ρ=0.035179 OR=3.6 CI on OR= [1.093-11.85681 n=49



(b): Median separation stats: ρ=0.031191 OR=3.4545 CI on OR=[1.1185-10.6696] n=54



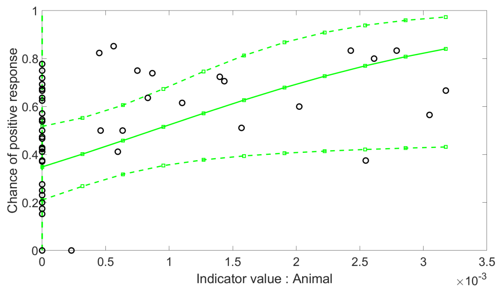
(c): Median separation stats: ρ=0.27522 OR=0.54622 CI on OR= [0.18433-1.6186] n=54

Figure 3. Logistic regression for the chance of a positive response as a function of the probability of recognizing specific sounds (background aggregation; (a) speech, (b) animal, (c) music.

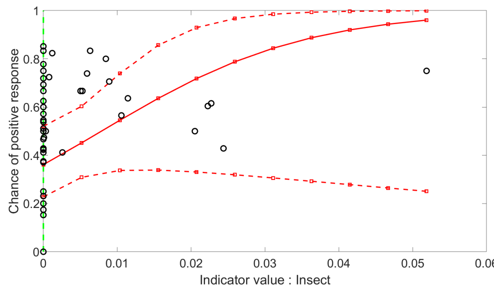
Speech is often recognized in the sound fragments (occasionally and in the background.) The OR is positive and statistically significant, but the logistical regression is not. Animal sounds (birds and dogs in the background could be found in the sound fragments) have a positive effect both in OR and logistic regression. Note that the system also recognizes a small probability of animal sounds in music fragments. Finally, music has a statistically significant negative effect. The negative effect of music is visible in the logistic regression and less in the dichotomized approach (OR) because the automatic subdivision of the x-axis seems unable to handle music fragments (very high values of music probability) and music-like sounds with a low probability of being recognized as music.

The same analysis is repeated using the strategy focusing on prominent sound events during aggregation over time. In this case, the sound of animals, insects, crickets, music, and musical instruments have a statistically significant (r<0.05) effect on the chance of a positive response (Figure 4). Also, animal sounds show a positive odds ratio and a statistically significant logistic regression here. The statistical significance of the OR and logistic regression for cricket sounds is stronger than for (general) insect sounds, which indicates that the cricket sounds in the sound fragments had a positive effect.

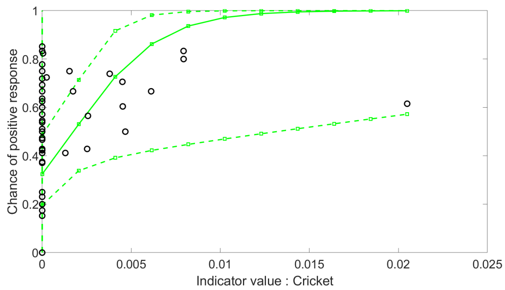
It should be noted that these sounds were played during rest and while going to sleep. Obviously, crickets are insects, and hence there is also a small positive effect for insect sounds. Once more, a sound recognized as music and musical instruments decreases the chance of a positive response.



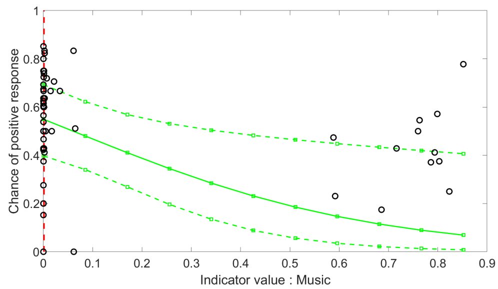
(a): Median separation stats: ρ=0.021626 OR=4.127 CI on OR=[1.2311-13.83481 n=49



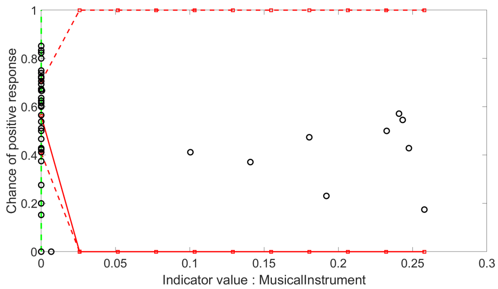
(b): Median separation stats: ρ=0.012815 OR=4.8889 CI on OR= [1.401-17.0595] n=49



(c): Median separation stats: ρ=0.0065982 OR=6.6 CI on OR=[1.6913-25.7552] n=49



(d): Median separation stats: ρ=0.27522 OR=0.54622 CI on OR= [0.18433-1.6186] n=54



(e): Median separation stats: ρ=0.015132 9R=0.070248 CI on OR=[0.0082422-0.59872] n=51

Figure 4. Logistic regression for the chance of a positive response as a function of the probability of recognizing specific sounds (event aggregation; (a) animal sound, (b) insect, (c) cricket, (d) music, (e) musical instrument.

Although these were less significant than animal sounds, bird vocalization also had a small effect on the chance of a positive response.

4 Discussion

This research looked at finding ways to select sounds to augment the soundscape for people with dementia without human intervention using sound recognition labelling and acoustic indicators.

Experts selected fragments that could – in their opinion – be suitable for augmenting soundscapes during different activities. Experts often picked fragments containing sounds easily recognized as music for various activities. This selection reflected some experts' opinion that music is the most prominent way to influence mood and behaviour. However, the evaluation by push button (feedback) showed that music does not work well when continuously present in the soundscape.

Apart from music, there is a tendency to select fragments containing bird sounds for morning activities such as waking up. It could be expected that they had augmented soundscapes with clear and dynamic sounds for activation in mind. For activities related to sleep and rest, white noise-like sound fragments that the automatic sound recognition categorized as containing crickets or rain were selected. Experts might have envisaged an augmentation that masks sound events from a distance in mind, possibly aiming at lowering arousal.

The results of the study of the field responses show that from the collection of psychoacoustic indicators (loudness, sharpness, roughness and fluctuation), only increasing sharpness had a statistically significant effect on the chance of a positive rating. Sharpness is a measure of the scaled centre of frequency of a sound (DIN 45692, 2009; Hugo Fastl & Eberhard Zwicker, 2006) emphasizing sounds with high-frequency content in relation to those with low-frequency content (Hales Swift & Gee, 2017). The sharpness perception, in general, influences the "pleasantness" of a sound (Hales Swift & Gee, 2017). Sharpness is a psychoacoustics metric that provides a numerical measure of sensation based on the number of high-frequency components in a sound. The high frequencies may trigger abruptness and, therefore, a mood change which results in a positive reaction. Also, sharpness makes sounds recognizable from the environment's background and brings attention to the sounds, which may be a reason for a positive rating. Loudness in this study is irrelevant, as all the sounds were calibrated to be perceived at the same level.

Sounds of animals had positive results; this is not a surprise as the positive effect of animal sounds was shown before in various research (Kariel, 1980; Ratcliffe, 2021a); based on attention restoration theory (Kaplan, 1995), animal sound as part of natural sounds helps in stress reduction and recovery (Kjellgren & Buhrkall, 2010; Ulrich et al., 1991).

However, automatic recognition of bird vocalization received a lower rating in this study, although an extensive number of studies emphasize that birds' sounds have a positive effect on soundscape perception. Research by De Coensel et al. (Coensel et al., 2011) showed that adding bird sounds to the urban park soundscape has a positive effect on pleasantness and eventfulness. In a study on auditory comfort in public spaces, Yang and Kang (Yang & Kang, 2005) showed that sound source type played a role in evaluations of comfort; introducing sounds to spaces that were considered pleasant (such as music and water), even rather loud ones, produced a considerable improvement in acoustic comfort. Along the same lines, evaluations of soundscapes dominated by road traffic sounds can be improved by adding sounds of natural origin (Van Renterghem et al., 2021), e.g. bird songs or water sounds. Others have studied how added sounds through the introduction of new amenities, like water features in public spaces, help reduce the impacts of traffic noise on space users (Galbrun & Ali, 2012; Jeon et al., 2012; Trudeau et al., 2020). We can closely examine the individual sound fragments to understand why bird vocalizations seem to be evaluated differently here. Fragment W0058, for example, is evaluated negatively (Figure 1) while having bird vocalizations 17% of the time. However, the spectral center of gravity is low, as is its music likeness and the sound is also recognized as a bird tweet or chirp. This sound is thus far from a bird chorus that might be more appreciated. This result calls for a more refined analysis with various fragments.(Galbrun & Ali, 2012; Jeon et al., 2012; Trudeau et al., 2020).

On the other hand, fragments in which cricket sounds are detected have a higher chance of a positive response (in both aggregation methods). Experts selected these fragments for rest and sleep periods. We do not know whether persons with dementia consider the fragments containing cricket sounds tranquil or if the continuous "noise" masks other unwanted sounds when added to the sonic environment. Such masking has been applied in many applications.

The experts also selected the sound of rain as appropriate for sleep and rest periods. Moreover, a similar masking effect could be expected for cricket sound. However, rain sound only had a marginally significant effect on the chance of a positive response. One can argue in favour of the hypothesis that persons with dementia still associate meaning to these sounds that are different from the meaning associated with cricket sounds. Rain and heavy rain may be a cause of worrisome and agitation.

Music, in general, received negative feedback in this study. Although the positive effect of music on people with dementia is well known, and music-based intervention has become part of the non-pharmacological treatment of dementia (McDermott et al., 2013, 2014; Vink et al., 2003; Weise et al., 2018), there is a need for more knowledge of the type of music or genre that works the best. Nevertheless, there are studies on making a preferred playlist for a person with dementia (Weise et al., 2018) or playing the music of interest based on cultural identity and background (McDermott et al., 2014).

The music used in this augmentation was purposefully improvised by the musician and recorded for this research to avoid copyright issues. The lack of residents' familiarity may be one reason for the absence of positive feedback.

5 Conclusion

Augmenting soundscape to reduce the behavioural and psychological syndrome of dementia has been studied, and sound augmentation as an environmental stimuli improvement was proven to be a positive for people with dementia. However, selecting suitable sound fragments to augment a soundscape for people with dementia is challenging as 1) People with dementia may have different interests, and 2) unbiased human selection is hardly doable.

In this paper, we looked at sound selection by experts for typical activities in nursing homes and the probability of each segment per activity using sound recognition software. We then looked at caregivers' feedback results on a five-colour feedback system that showed an overview of preference segments. Finally, we conducted a statistical analysis of the relationship between the button pressed and the acoustic indicators for a chance of a positive evaluation.

The presence of speech, animal sounds, and music through sound recognition software had a statistically significant ($r<0.05$) effect on the chance of a positive response. The chance of a positive response increased for speech and animal sounds, while it decreased for music. Similarly, an increase in spectral center of gravity showed a statistically significant positive effect on the chance of a positive evaluation. Surprisingly, the increasing beat count also showed a statistically significant positive impact. Also, sharpness and high pitch created a higher chance of a positive response.

In summary, these analyses of results from a previous study give us some good guidelines for selecting sound fragments. Further investigation based on this finding can increase the positive response and hence better outcomes in reducing behavioural and psychological syndromes in people with dementia.

6 Credit authorship contribution statement

Arezoo Talebzadeh: Conceptualization, Methodology, Writing - Original Draft Preparation, Visualization Preparation, Data Analysis. **Dick Botteldooren**: Conceptualization, Methodology, Software, Validation, Writing- Reviewing and Editing, Data Analysis. **Timothy Van Renterghem**: Conceptualization, Software, Writing- Reviewing and Editing, Visualization Preparation, Data Analysis. **Pieter Thomas**: Conceptualization, Writing- Reviewing and Editing, Data Analysis. **Tara VanderMynsbrugge**: Conceptualization, Data Collection. **Dominique Van de Velde**: Conceptualization, Data Collection, Writing- Reviewing and Editing. **Patricia De Vriendt**: Conceptualization, Data Collection. **Yuanbo Hou**: Sound Recognition. **Paul Devos**: Conceptualization, Writing- Reviewing and Editing, Data Analysis.

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8 Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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