Using psychoacoustic parameters to select suitable sounds to augment soundscapes for people with dementia.

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ABSTRACT

People with dementia have difficulties identifying time and space, and any disturbing noise or unfamiliar sound can be agitating and annoying for them. Sound augmentation as an intervention was shown to improve mood and cognitive behaviour in people. In addition, this approach has a positive effect on reducing anxiety, stress, and agitation and improving sleep quality in people with cognitive disabilities. In the soundscape approach, people have agency in evaluating their sonic environment. This method is hardly possible when designing for people with dementia, as the severity of the disease makes communication incomprehensible in most cases. Therefore, caregivers and nurses are the best sources of evaluation; their familiarity with residents and their knowledge of residents' behaviour and psychology are crucial in evaluating the soundscape.

This research uses feedback data from the caregivers and psychoacoustic parameters of sound to find ways to select suitable sounds that positively affect people with dementia. A logistic regression model with a single independent variable demonstrated the chance of a positive outcome (sound) versus a continuous indicator value (psychoacoustic parameter). The result shows that specific psychoacoustic indicators, such as sharpness, percentiles, and centre of gravity (COG), can result in a positive evaluated response in sound augmentation.

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1. INTRODUCTION

The effect of soundscape on people with dementia has been studied [1], and the relation between soundscape and BPSD (behavioural and psychological syndrome of dementia) is well known [2]. Sound is an essential sensory stimulus, especially for people with cognitive difficulties. Sound is significant in making people aware of their environment [3]; also, sound gives the "sense of place" [4]. However, when the sonic environment is unfamiliar, it adds to the anxiety of those who receive the sound, making the situation annoying and unpleasant. People with dementia feel isolated, lost, and lonely, and any unfamiliar sound or disturbing noise can be agitating and disturbing. Dementia is a broad name for symptoms caused by brain disorders. "Symptoms commonly include loss of short-term and long-term memory, judgment and reasoning, and changes in mood, behaviour and the ability to communicate" [5]. Symptoms of dementia affect a person's ability to be socially active, work and perform daily tasks.

Dementia is known to be more common in older adults. As a result, people with dementia either live in long-term care (LTC) facilities or have to relocate to LTC to reduce care responsibilities from their families. LTC facilities feel unfamiliar and usually are not customized for individual needs, making them more agitating and disturbing, especially for people with mental illnesses. Residents typically have a private room (or a room to share with a roommate). Still, all other activities happen in shared spaces, from dining and social events to taking showers which usually take place in a shared (not private) facility. These spaces are designed commonly to be functional and are not intimate. Sensory perception in these spaces is unfamiliar for residents: light, sound, temperature, and smells may differ from the familiar setting of one's home. Strange sensory stimuli add to the anxiety and annoyance of residents. Sound after smell is the most potent sensory stimulus [6] in changing mood, so it is essential to design a soundscape that promotes a positive attitude. Vulnerable populations are usually affected by their environment; the sense of place directly relates to auditory information and clarifies the location and situation [4].

The soundscape [7] is the acoustic environment perceived and experienced by a person in a specific context [8]. This phenomenon depends on individuals' listening habits and their relation to the environment; different people in the same environment may have a contrasting relationship to the soundscape [9] and, therefore, entirely different emotional responses to the same soundscape [10]. Research has shown the positive effect of natural and non-natural soundscape on people with severe or profound intellectual disabilities [11]. The same study also showed that natural sounds such as those found in forests and near beaches promote relaxation and interest in people with severe cognitive disabilities. Sound also generates a feeling of safety [11], influencing moods and triggering a specific action [12]. Augmenting soundscape for this purpose can improve the behaviour; adding (human-preferred) sound to the acoustic environment indicates "augmented soundscape" [13]. Soundscape can be seen as a positive environmental factor in improving health and well-being.

Research shows the effect of natural sound on attention restoration [14] and the importance of sound in making sense of place [15]. Memory plays an essential role in soundscape perception and reflects the interaction between a person and their environment [16]. Designing soundscapes for people with cognitive difficulties is challenging and requires an understanding of sound characteristics and human interaction with their sonic environment.

People with dementia may not be able to communicate their feeling verbally; nurses and caregivers are the best sources as they have a good understanding of non-verbal reactions and the state of residents. This paper looks at a sound selection method to augment a suitable soundscape for people with dementia, using the feedback data from the nursing home as the source of evaluation. In a study by Devos et al. [1] at Flanders nursing home, a designed soundscape intervention was delivered through speakers at a specific time during the day. The soundscape was a combination of different natural and human-made sounds chosen by soundscape researchers. Then the nursing staff evaluated the effect of the soundscape on residents through feedback buttons.

Although the feedback data is subjective, the nursing staff were encouraged to focus on residents' reactions and not their own when evaluating the soundscape.

2. METHODOLOGY

2.1. Sound Selection

For making the sound database for this research, 218 sounds were collected either by on-location recording (27 sounds) or existing sound databases (191 sounds). The existing databases are FreeSounds (137 sounds), BBC sound effects (27 sounds), MusOpen (21 sounds), BenSound (3 sounds), YouTube (2 sounds) and ElectroBel (1 sound).

This collection of sounds includes natural sounds, anthropogenic sounds (from human activities) and music. In the preliminary stage, all sounds are labelled based on three categories of nature, man-made and music. This initial categorization is meant to be used as meta-information to validate the characterization of the sound database. Furthermore, all sounds are subcategorized into animals, birds, weather, water, wind, environment night for nature, clock, wind chime and transport for anthropogenic sounds. Music stayed as one general category. All selected sounds had either non-compressed (wav, ac) or compressed formats (mp3) and were converted into two-channel MPEG-1 layer three files (mp3 "joint stereo") at a sample rate of 4000 Hz with a constant bit rate (CBR) of 192 kbps using Adobe Audition software.

2.2. Sound Analysis

The sounds were analyzed using acoustic and psychoacoustic metrics. The sounds were characterized in terms of level for Z, A, C-weighting, including continuous equivalent sound pressure (L_{eq}, LA_{eq}, LC) and percentiles L_x with x= 5, 10, 25, 50, 75, 90, and 95, where L_5 and L_{10} are the usual estimates of maximum level and L_{90} and L_{95} of minimum level.

All metrics were obtained from the full-duration sounds (not excluding the background noise). For psychoacoustic metrics, loudness, fluctuation strength, roughness and sharpness were analyzed. In addition, saliency, music likeness, the centre of gravity, number of events above LA_{50}, danceability, beats per minute, and spectral complexity were analyzed.

Music Likeness (ML) is a metric that defines whether a sound is likely to be "musical" based on a low-frequency analysis. Saliency or sensory saliency is related to how much a sound stands out from a surrounding environment. The centre of gravity corresponds to the frequency that divides the spectrum into two halves such that the amount of energy in the top half (higher frequencies) is equal to that in the bottom half (lower frequencies). A sound with much high-frequency energy will have a significant value for the centre of gravity. The number of events above LA_{50} is defined as the number of events 3-dB above the median A-weighted level for at least 3s. Danceability is a parameter estimated from the slope of the transients present in an audio signal.

2.3. Sound Evaluation

To choose suitable sounds for the personalized soundscape, six soundscape researchers (geriatric psychologist, occupational therapist, acoustic engineer, bioacoustics engineer and architect) reviewed a set of 218 sounds. The researchers evaluated the suitability of each sound for 17 different activities by rating them 0 (not suitable), 1 ("maybe"), or 2 (suitable). Also, they rated the degree of suitability of the sound for safety-enhancing, mood changing, or triggering behaviour on a five-point scale ranging from "not at all" to "very much."

2.3.1 List of Activities

Tale 1 shows the list of activities used for the evaluation of sounds.

wake up	wash & dress	have breakfast
go to the toilet	take medication	eat lunch
drink coffee (coffee time)	dinner	fall sleep
sleeping	rest or sleep	take a bath or shower
expect social activities	doing social activities *	expect visitors in the room
having a visitor in the room*	perform personal activities	

Table 1: List of Activities

Two activities (*) were eliminated during the evaluation as there received almost no ratings. The average rating for sounds per activities then calculated. Sounds with an average of >1.2 were selected for level 2, and those with an average rating of >0.8 were chosen for level 1. Level 2 sounds would be a priority to play for a specific activity.

The team was aware of their biases during the rating process. None of the experts were diagnosed with cognitive disorders (such as dementia), and they listened to sounds in their comfort place, mainly through headsets. However, the diversity of their age, gender, ethnicity, professional background, knowledge of soundscape and dementia, and years of studying the effect of soundscape on people and perception of the sonic environment gave credit to their evaluation. In the end, 101 sounds were selected for this study.

2.4. Sound Player System

1. A dedicated sound playing device with a remote connection to the server to receive updated soundscape daily based on the feedback loop.

2. Feedback buttons with wireless connection for sound evaluation. A panel of 5 feedback buttons for rating the participant's behaviour by the staff and an additional snooze button to mute the sounds when necessary.

3. The web-interface gives access to the overall soundscape control. It allows for the initial composition of the soundscape and the daily schedule of the different soundscape player systems. The interface connects to a cloud-based server and provides site-level control of the system, allowing the

activation and deactivation of the players. This software program delivers the soundscape and uses the feedback from the button panel to personalize the soundscape.

The system is designed to obtain a personalized soundscape based on staff feedback through the button panel, which is transferred to the remote server. This server has the function to recommend improved sounds to be played the next day(s).

2.5. Feedback Evaluation by Caregivers

During the experiment in the nursing homes, caregivers evaluated the effect of specific sounds on the participants by pressing feedback buttons. Caregivers are very close to the residents and aware of their reactions and are thus well suited to assess residents' 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. The algorithm adjusts based on the feedback system; if the feedback is negative, the system chooses another sound. The system continues playing the same sound when the input is positive or there is no feedback. The data from the feedback buttons should mainly demonstrate the overall suitability of the sounds from the residents' perspective. However, it cannot be excluded that the caregiver's perception and mood can affect the evaluation.

3. RESULT & DISCUSSION

Caregivers' feedback was used to evaluate the sounds based on residents' reactions, monitor the sounds that are the best received, and for any adverse effects of the sounds. The result of the five-button feedback system is demonstrated in Figure 1. Each column refers to a particular sound. Colours are based on a feedback system with off-white representing mute action.

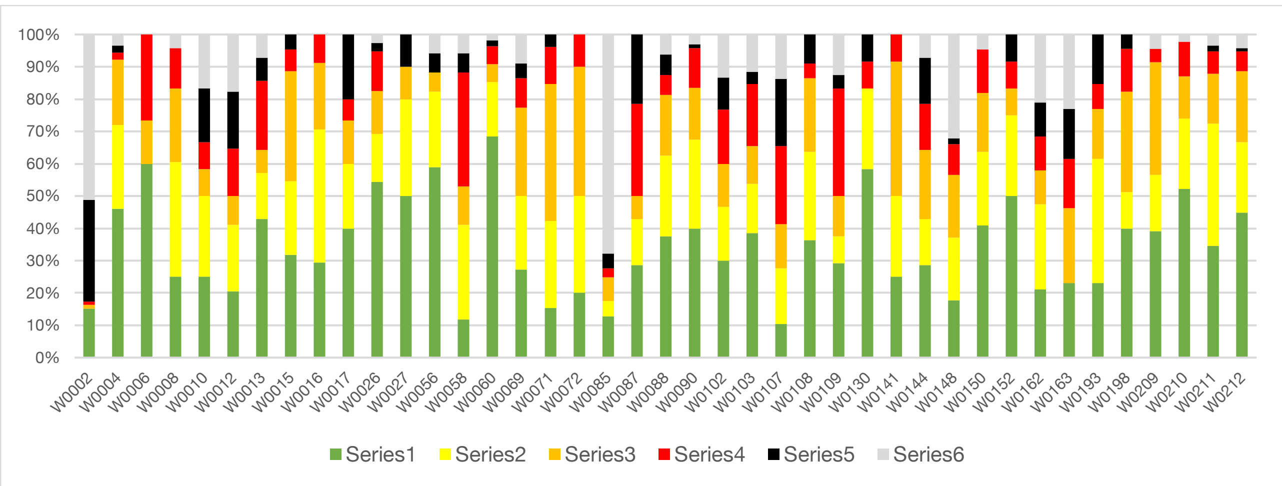


Figure 1: Caregivers' Feedback

The data from the feedback system was used to find a correlation between the characteristic of the sound and their effects on people. (Figure 2)

For a start, a minimum number of buttons pressed per sound was set to 5; otherwise, the sound is disregarded.

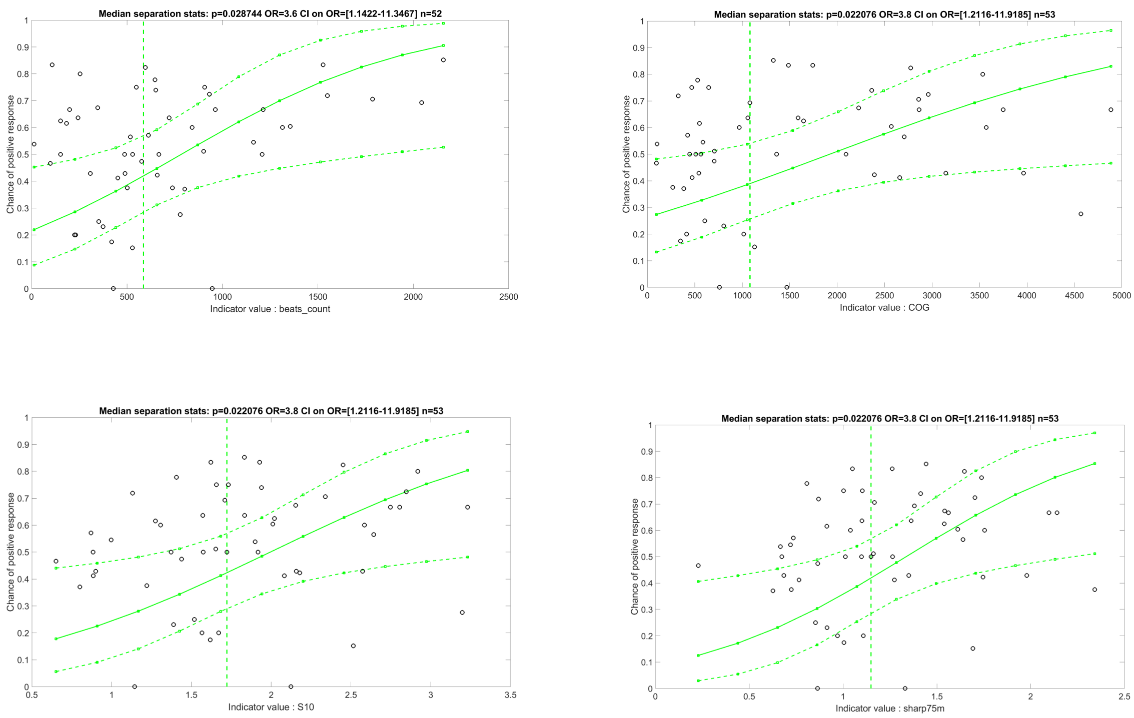
A "positive" sound is defined as the "Green + Yellow" buttons pressed at least 60%. Some sound indicators were disregarded due to missing values.

Outliers in the indicators have been removed (based on a normal distribution with $\rho = .01$, with a maximum of 5 removal points); this prevents a few extreme values from shaping the regression curve.

Odds ratios are calculated after pooling each indicator in two classes based on median (low value vs high value within the range of values present - shown by the vertical line in the graphs).

Logistic regression was used (outcome=positive sound or not) with a single independent variable (i.e. the psychoacoustic indicator, either continuous or dichotomous).

The result shows the potential of using sharpness, COG, and percentile to choose a suitable sound.



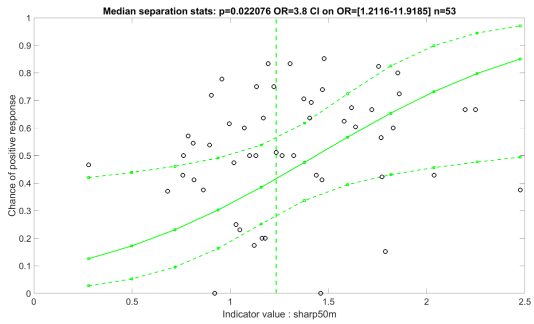


Figure 2: Chance that a specific psychoacoustic indicator results in a positively evaluated response in function of its value range. Only the indicators leading to a regression model statistically significant at the 5 % level are shown. The dashed lines show the upper and lower 95% confidence intervals. The open circles are the actual data points. In addition, the odds ratios are shown in the case of median separation (low vs high value) of the indicator. For example, a COG above about 1000 Hz is 3.8 times more likely to end up with a positive response than a COG lower than 1000 Hz.

4. CONCLUSIONS

People with dementia can benefit from augmented sonic environments since auditory stimulation can reduce agitation and anxiety and provide safety and familiarity. Using psychoacoustic parameters to select proper sounds for soundscape augmentation is a starting step in finding a suitable method for designing soundscapes in long-term care facilities and senior housing. This method eliminates the biases and assumptions and focuses on users' perceptions and interests. Finding a correlation between caregivers' feedback data and the characteristic of sounds helps augment a soundscape that fosters a healthier sonic environment for people who may feel confined inside their residential facilities. Although there is a need to study different contexts and diverse participants, the correlation result is promising. Psychoacoustic parameters might be the best characteristic of sound to design a suitable soundscape for people with cognitive difficulties.

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