Personalising augmented soundscapes for supporting persons with dementia

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Abstract The world population is aging and more and more people suffer from dementia, which makes remembering and orientation in time and space difficult. Moreover dementia has a strong negative effect on the quality of living of the people suffering from it, but also of their relatives. In this paper, we investigate if and how the playback of carefully chosen and recognizable sounds, such as music, a clock tower, or nature sounds, can help these people and have a positive effect on the behavioral and psychological symptoms of dementia (BPSD). The selection and playback of these sounds, augmenting the existing soundscape, is performed in a personalized manner, since sounds can elicit a different response in different people. Caregivers can provide feedback on the soundscape based on the resident's behavior and response to hearing the sounds. This allows a continuous adaptation of the soundscape. The soundscape system was tested with 19 people suffering from dementia and resident of 6 different nursing homes. Comparison of the nursing home environment before and after installation of the soundscape system showed

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that most residents (13/19) experienced this as an improvement of the sound environment.

Keywords soundscape · experience · personalized · dementia

1 Introduction

Dementia is a syndrome in which there is deterioration in cognitive function beyond what might be expected from the usual consequences of biological aging [34]. Dementia results from a variety of diseases and injuries that primarily or secondarily affect the brain, such as Alzheimer's disease. Alzheimer's disease is the most common form of dementia and may contribute to 60-70% of the cases [34]. Dementia affects thinking, memory, calculation, learning capacity, orientation, comprehension, language, and judgment. Consciousness is not affected, which is important for this study. The impairment in cognitive function is commonly accompanied, and occasionally preceded, by changes in behavior, mood, emotional control, or motivation. This makes it difficult for caregivers to interact appropriately with people suffering from dementia. Although dementia mainly affects older people, it is not an inevitable consequence of aging; but age is a risk factor.

Currently more than 55 million people live with dementia worldwide, and there are nearly 10 million new cases every year [34]. In Europe alone, 9.7 million people suffer from Alzheimer's disease and other forms of dementia [2]. By 2030, the number of patients is projected to rise to 14 million, and the cost of treating them will grow to €250 billion [22]. In Belgium -the target area of this study- the number of people with dementia has risen to 200,000, including 140,000 Alzheimer's patients on a population of 11.5 million people [27]. The number is almost 10% among the over-65s, 26% among the over-85s and more than 35% among the over-90s.

Currently, dementia is the seventh leading cause of death among all diseases and one of the major causes of disability and dependency among older people globally. Dementia has physical, psychological, social and economic impacts, not only for people living with dementia, but also for their carers, families and society at large [34]. To guarantee permanent care from accessible and supporting caregivers, people with dementia can reside in nursing homes. These nursing homes provide residential accommodation with supervision from nursing staff 24h a day, help with personal care needs, meals, and additional specialized services to older people [10]. These older people suffering from dementia staying in nursing homes are the target group of our research and the designed system.

Until today, there is no cure for dementia or Alzheimer's disease [22]. Diagnosing and treating the disease early — at the first onset of mild cognitive impairment — represents the best opportunity to meaningfully change the course of Alzheimer's disease [22]. Alzheimer's patients lose more and more grip on reality and their memory gradually disappears until nothing is left.

Moreover for caregivers, it is often difficult to deal with Alzheimer's patients and putting them at ease is important for their well being.

Fixed routine strengthens their sense of safety and security [28]. Recognizability of the environment is very important. In this study, preservation of these routines and the recognizability is stimulated by exposing the patient to sounds that remind him about activities or events that are characteristic for his daily routine. This will assist in the orientation in time and place. It makes the patient feel safe and reduces the behavioral and psychological symptoms of dementia (BPSD) [9]. For example, the sound of a clock tower can indicate every hour the current time. The sound of kitchen cutlery can remind the patient to come to the eating room at the right time. Previous research has proven that the sonic environment is an important aspect that can affect health and well-being, in particular for persons with reduced cognitive capabilities [10].

If these sounds are intelligently selected, timed for playback, and bundled, then this results into what is called a soundscape. There are similarities between the concepts of 'landscape' and 'soundscape'; both are based on perception by people [29]. The European Landscape Convention Agreements defined landscape as "an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors" [5]. This definition is altered by substituting "area" by "acoustic environment" because of the high spatial variability of the acoustic environment over any of the types of indoor and outdoor areas in which we are likely to be interested [20]. The resulting analogous definition of soundscape, as defined by the ISO 12913-1 standard, is: "the acoustic environment as perceived or experienced and/or understood by a person or people, in context" [29].

Natural soundscapes, defined as "the acoustic environment that would exist in the absence of human-related activity" [12], have a positive effect on people's mood and experience with the environment. But also soundscapes containing sounds of human-related acts can be useful for creating a certain atmosphere, announcing an upcoming event, or reminding people of certain things. In our study, both types of sounds, human-related and natural sounds, are combined in soundscapes. Besides this, the novelty aspects of this paper are the application of soundscapes for people suffering from dementia, the automatic adaptation of the soundscapes based on feedback, and the evaluation of the effect of soundscapes in a real nursing home environment.

In this research, we will answer the following research questions (RQ):

- RQ1: When is the soundscape system typically used and adjusted by providing feedback?
- RQ2: What proportion of sounds is selected by the recommender vs by the human expert? And what is the influence of the amount of provided feedback?
- RQ3: What is the influence of the soundscape system on the people suffering from dementia?

The remainder of this paper is structured as follows. Section 2 discusses related work in the context of soundscapes and the potential benefits for people exposed to these soundscapes. Section 3 provides technical details about the experiment setup with an overview of the hardware, the architecture, and the user tests with demographic data about the persons who participated. Section 4 describes the method to create personalized soundscapes by combining a set of sounds suitable for a specific activity. This section also specifies the working of the algorithm used to adapt and personalize the soundscape in accordance with the provided feedback. Results of the experiment and the impact it has on people are discussed in Section 5. Finally, Section 6 draws conclusions and points to future work.

2 Related Work

2.1 Augmented Soundscapes

The complexity as well as the potentials of soundscape research and practice have been demonstrated over the last decade. As a result, soundscape planning or acoustic design, becomes an important research topic [4]. In early research, the focus was purely on reducing noise levels, whereas in more recent studies a tendency to overall soundscape design can be witnessed [19]. The user's perception of the acoustic environment can be improved by simulating natural or human-related sounds [14]. The process of adding sounds to a real physical location, results in so called "augmented soundscapes" [17]. In our study, augmented soundscapes can be composed and are altered based on feedback from the caregivers in response to the behavior of the person with dementia.

2.2 Soundscapes in the Healthcare sector

The positive effect of a soundscape is getting increased attention for use in practice. Sounds that draw attention can trigger associations, create meaning, or change mood and emotion [10]. Noise induces stress and impedes the recovery process of patients in the clinical environment [16]. In contrast, sonic scenarios with music can reduce experiences of stress and danger [25]. Pleasant natural sound interventions which includes singing birds, gentle wind and ocean waves, have shown to bring benefits that contribute to perceived restoration of attention and stress recovery for patients and staff [16]. The researchers of that study also stated that clinicians should consider pleasant natural sounds perception as a low-risk non-pharmacological and unobtrusive intervention for speedier recovery of patients undergoing medical procedures. Moreover, studies have also shown that music and sound intervention in health care can have a positive effect on patient's emotions and even the recuperating processes [15]. However, details on how soundscapes impact patients and staff behaviour require further studies [16]. Our study builds on these insights and investigates the effect of soundscapes with natural sounds and pleasant human-related sounds on patients suffering from dementia. It expands previous work in the frame of the AcustiCare project, a study in nursing homes in Flanders, focusing on different acoustical aspects: the monitoring of sound levels and soundscape quality [1], the acoustic comfort [30] and the use of added sounds as soundscape augmentation [9]. In view of designing soundscapes, sounds should be evaluated based on its informative or orientational element [16]. Previous work addressed the design of a supportive sonic environment for persons with dementia in nursing homes [10]. That research showed that acoustic stimuli can be used for influencing mood, stimulating the feeling of safety, and triggering a response in a person. The goal of these stimuli, which are obtained by the playback of sounds, is to improve the well-being of the residents. Managing challenging behavior of persons with dementia is a priority in nursing home care because it comprises the well being of the resident; and a supportive soundscape can assist with that [21]. Indeed, it has been shown that an augmented soundscape can serve as a supportive sonic environment for persons with dementia in nursing homes [10].

Related to the use of soundscapes is music therapy [32]. Music therapy uses music as a means to achieve the goal (rest, activation, ...). This requires guidance from a therapist and it is a form of therapy. Our work in the context of the AcustiCare project is rather an 'environmental adaptation'. There are also tools that use sounds; but these are more focused on 1 activity. A well-known example is the sleep robot Somnox [26]. Also during "snoezelen therapy" [3], sounds are often used, typically relaxation music or sounds (e.g., whale sounds). Here the same addition as with music therapy: this is part of therapy and there must therefore also be guidance. These are not 'environmental adaptations' as in our study.

2.3 Personalizing Soundscapes

Currently designed soundscapes and frameworks for the composition of a sonic environment [10] are static and not personalized to a person's behavior and responses to sounds. This means that all persons in the nursing home hear the same soundscape, which is not changing over time. However, different persons will typically have a different preference for a specific sound and respond in a different manner to that specific sound. Moreover if many different sounds are available, the process of selecting the most appropriate sounds to compose a soundscape in a manual manner takes a lot of time and is often associated with a high cognitive burden of the selection process.

These problems can be solved by deploying a recommender system to compose the soundscape. Recommender systems assist users in making selections of content items [24]. They provide a personalized list of items to choose from, or they personalize the content of a service in order to obtain an improved experience [7]. Recommender systems are especially useful in domains where user interaction with the content is limited and users cannot consider all possible items for selection, such as streaming audio. In our research, a recommender algorithm is used to personalize the soundscape by selecting the most appropriate sounds for playback for each individual user that is exposed to the soundscape. According to our knowledge, our study is the first approach that personalizes soundscapes in the context of a nursing home.

Personalized soundscapes have proven their usefulness in improving user experience in different other contexts, such as in a public park environment [31]. In this study, the participants could compose their own soundscape using a smartphone app and listen to the results by means of a speaker in the park. The study showed that in the context of leisure activities in a park, users enjoyed the personalized soundscapes and consider them as an improvement of the park experience, especially because these soundscapes can mask disturbing noises such as traffic [8]. In this park environment, the composition of the soundscape was a manual process. In contrast, our study in the nursing home environment has a more automatic approach for the soundscape composition and update based on feedback by pushing a button.

A similar study investigated the creation of soundscapes to augment the acoustic information in a physical location [17]. Soundscapes could be composed by means of authoring tools that make use of user-contributed content, more specifically an online repository of sounds. The focus was on the authoring tools and they concluded that this collaborative authoring can simplify the sound asset management. The participants used a mobile client that can communicate its position to the soundscape generation engine and receive a personalized MP3 audio stream according to its position. Our study goes further by automating the soundscape creation and update process and by enabling the user to provide feedback. Moreover, the personalization in our study is on the level of each individual, and more fine-grained than on the level of the location of the client device.

The effect of music playlists and personalized soundscapes on the human focus has been investigated for young adults [13]. Participants were asked to perform tasks on a tablet, while wearing headphones. Three conditions were tested: no background sound (silence), popular music playlists for increasing focus (pre-recorded songs), and personalized soundscapes (audio composed in real-time to increase a specific individual's focus). The study has found that while participants were working, personalized soundscapes increased their focus significantly above silence, while music playlists did not have a significant effect [13]. The researchers also showed that focus levels can be predicted from physical properties of sound. The study emphasizes the impact of personalized soundscapes on the mental aspect of the listeners. However the goal and the context of this study (i.e. increasing focus while working on a tablet) is totally different than ours (which is improving the well-being of the residents in a nursing home).

In the context of an assisted living facility, an interview and observation-based study have been performed to evaluate soundscapes [18]. The aim of that study was to bring the benefits of outdoors to the indoor environments through augmented spatial natural soundscapes. The focus was on restorative, social, and experiential benefits. But unlike our research, that study does not include any form of personalization.

According to our knowledge, our study is the first to evaluate the configuration and usage of augmented soundscapes in nursing homes for residents suffering from dementia. The novelty of our paper consists of deploying augmented soundscapes as a tool to assist the residents in their orientation in time and place. The goals is to make the residents feel safe and reduce their behavioral and psychological symptoms of dementia.

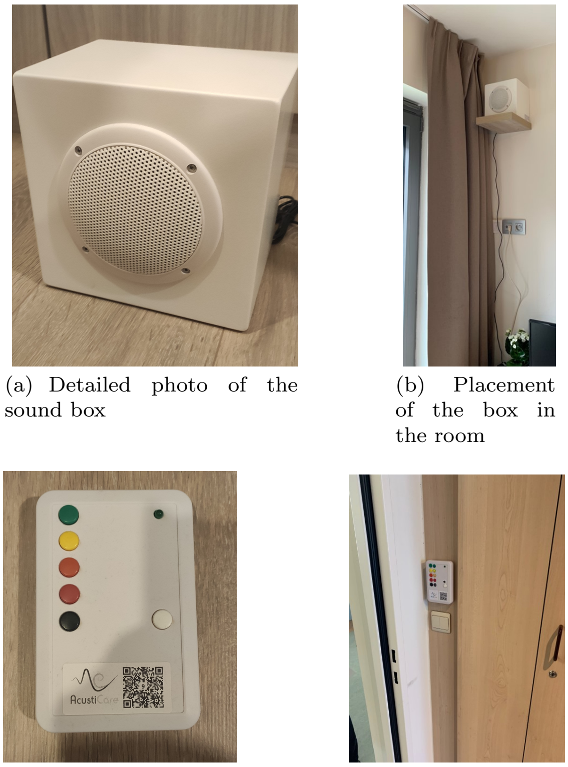
3 Experiment Setup

3.1 Hardware and Architecture

The soundscape system that we tested consists of two parts at the local site (in the nursing home). A soundbox that contains the hardware for playback of the personalized soundscape and a panel with colored buttons that allows the caregivers to give feedback. Figure 1 shows a photo of the soundbox (Figure 1(a)) and a typical placement in the room of the resident with dementia (Figure 1(b)). The box is a wooden casing, extending a dedicated audio player [9], based on a Raspberry Pi with high quality audio amplifier and loudspeaker. The box contains an SD card for local storage and a real-time clock module for time synchronization. An LTE USB dongle is used to enable wireless 4G communication to an Internet server.

Besides the sound box, also a panel is provided that allows to give feedback. Figure 1 shows a photo of the feedback panel (Figure 1(c)) and a typical placement in the room of the resident with dementia (Figure 1(d)). The panel allows the caregiver to give feedback based on the behavior of the resident in the room. This allows to measure if the soundscape has an influence on the behavior of people. During a briefing with the caregivers, we explained that this panel is a feedback tool for the caregivers, and not for the residents suffering from dementia or visitors. The panel is typically placed next to the door of the room, which is convenient for caregivers to provide feedback when leaving the room. The panel consists of a plastic casing containing the following battery powered hardware: 6 colored buttons (5 to give feedback, and 1 to mute the sound), a LED indicating whether the feedback has been processed correctly and a Bluetooth module to send the feedback to the Raspberry Pi in the soundbox.

Figure 2 shows the architecture of the complete system. The feedback panel and the sound box, which communicate with each other through Bluetooth, are localized in the nursing home. Remote, we have a server running the recommender algorithm for personalizing the soundscapes, as described in Section 4.2. This server also hosts the web interface to create activities, associate soundscapes to these activities, and select specific sounds for these soundscapes (cfr. Section 4.1.2).



(a) Detailed photo of the sound box

(b) Placement of the box in the room

(c) The colored feedback buttons

(d) Placement of the panel in the room

Fig. 1 The sound box used to play soundscapes and the feedback panel.

3.2 User Tests

For recruiting the participants of our experiment, we have contacted multiple nursing homes with the question to collaborate in our study. From each nursing home that provided a positive answer, 3 persons with dementia were selected. (Except for 1 nursing home, 4 persons were selected). The persons were selected to obtain a good mix of people suffering from a mild degree of dementia, and people suffering from a severe degree. As a result of this recruiting process, the soundscape system was evaluated in 6 nursing homes by 19 persons suffering from dementia. The study was approved by the Ethics Committee of Ghent University with B.U.N.(Belgian unique number): B6702020000597 and date: 21/8/2020. All participants or their representatives signed an informed consent.

Table 1 provides the demographic details of the test population. The impact of the soundscape playback system is evaluated by gathering feedback of the users in three subsequent phases.

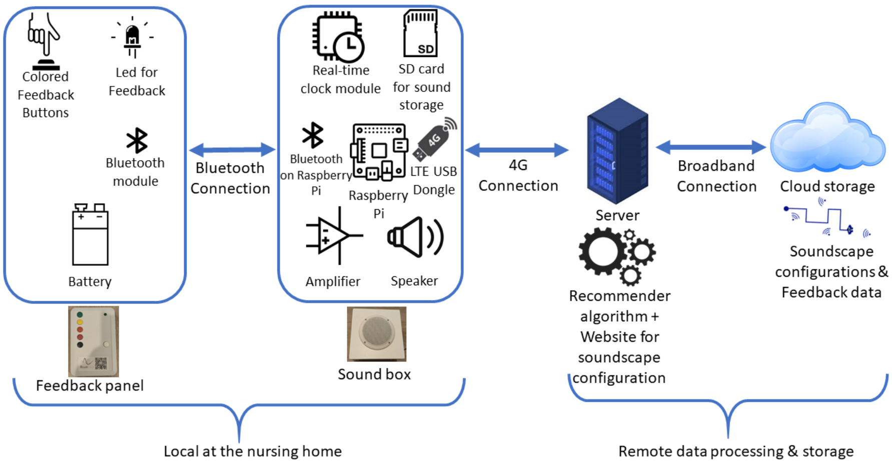


Fig. 2 The architecture of the soundscape system.

Table 1 Demographic information of the participants of the study

	Male	Female	
Gender	7	12	
	Mean	**Min-Max**	**St. Dev.**
Age (years)	85	72-99	6.43
Duration of stay (years)	2	0-9	2.12

1. Pre-Soundscape phase (2 weeks). This phase serves as a baseline situation to assess the BPSD and behavior of the resident without influence of the soundscape system. In this phase, no sounds are played but the resident's behavior is evaluated multiple times a day.
2. Soundscape phase (4 weeks). In this phase the soundscape system is operational and sounds are played during the day. The influence of the soundscape system on the BPSD and behavior of the resident is evaluated. The hypothesis is that a carefully composed soundscape might have a positive effect on the resident.
3. Post-Soundscape phase (2 weeks). In this phase no sounds are played. During this period, the influence on the resident's BPSD and behavior after experiencing the soundscape system is measured.

4 The Soundscape

4.1 The Soundscape Configuration

A soundscape is created as a composition of multiple sounds scheduled for playback on a specific time. The catalog of sounds that was used to create the soundscapes contains a great variety of sounds such as a tower clock, which indicates the hour, music fragments, which can be used as background sound, and nature sounds, such as birds, waves and wind, which can be used to relax [31]. For every activity in the nursing home (e.g., sleeping, waking up, having breakfast, etc.) a separate soundscape is created.

4.1.1 Suitable Sounds

Not all sounds are suitable at any hour of the day. Therefore, a group of experts in the domain of sounds marked the sounds as suitable or not for a specific activity in the nursing home [10]. There are 3 score levels. These levels are the initial scores of the sounds for a specific activity. These levels are also used for configuring the soundscape in the user interface (as visible in Figure 4) as well as for personalizing the soundscape by the recommender. The levels are defined as follows:

Level 2: This sound is very suitable for the activity. It is initially associated with this activity in the user interface during the configuration of the soundscape (Figure 4).

Level 1: This sound is more or less suitable for the activity. It is not initially associated with this activity, but it can be selected in the user interface during the configuration of the soundscape. It can also be selected by the recommender to be part of the soundscape, in case one or more level 2 sounds receive feedback, indicating that changes are wanted.

Level 0: This sound is not suitable for the activity (as defined by experts). The sound will never be part of the soundscape for this activity. It is not possible to select this sound in the user interface. The recommender will not include this sound in the soundscape of this activity. However, this sound might be suitable for another activity.

4.1.2 Initial Soundscape

Before soundscapes are played in the room of the resident of the nursing home, a caregiver can configure the activities and the associated soundscapes according to the weekly schedule of the nursing home. Figure 3 shows a screenshot of the user interface, where the caregiver can specify the weekly schedule with activities and their start and end time. Since the user tests are performed in Flanders, the Dutch speaking part of Belgium, the user interface was offered in Dutch for the convenience of the caregivers who had to use it. Figure 3 shows the English version of the user interface. The different lines in the schedule represent the days of the week (Monday until Sunday). For each day, activities are specified. For an average day, the following activities are typically specified: having breakfast, washing and dressing, drinking coffee, having lunch, having a visitor in the room or another social activity, resting, having supper, and sleeping at night. Each of these activities is associated with a soundscape, consisting of sounds that are suitable for the specific activity, e.g. bird sounds might be suitable for activities in the morning, such as breakfast.

Figure 4 shows how such a soundscape for a specific activity can be configured. On the left hand side, the caregiver can specify the name of the activity, the day on which the activity takes place, the start and end time, and a description of the activity. Moreover, there is an option to specify whether the resident is hearing impaired. This option can be adjusted for each activity since the resident might wear a hearing aid only during specific activities. The volume of the soundscape is adjusted accordingly. On the right hand side, the caregiver can listen to and select the sounds. The sounds are visualized into three groups. Group 1) A selection of level 2 and level 1 sounds that are currently part of the soundscape. These sounds are visualized in the group at the top of Figure 4 (specified as "Current settings"). When the caregiver starts using the application, the initial soundscape is visible here. For each activity, a group of sound experts has created this initial soundscape by selecting a set of well-suited sounds. Group 2) All sounds that are very suitable for the specific activity, i.e. the level 2 sounds, and sounds that are proposed by the recommender to include in the soundscape. The caregiver can make a selection of these sounds to personalize the soundscape. These sounds are visualized in the group at the middle of Figure 4, and indicated as "suggested sounds". Sounds marked in green are selected to be part of the soundscape, sounds in red are excluded from the soundscape. Group 3) All sounds that are more or less suitable for the activity, i.e. the level 1 sounds. These sound are by default not part of the soundscape, but can be selected to become part of the soundscape. These sounds are visualized in the group at the bottom of Figure 4 (specified as "reserve sounds")

Level 0 sounds are not visible in the interface, since these are not suitable for the specific activity and can therefore not be selected. After this initial configuration, the soundscape is adapted automatically based on the feedback received through the panel, as described in Section 4.2.

4.2 Personalization Algorithm for Soundscapes

Figure 5 shows a graphical overview of the personalization algorithm for soundscapes. The different components will be discussed in this section.

4.2.1 Scope of the Feedback

Feedback is provided by pushing the colored buttons (Figure 1(c)). This feedback is used in the recommender to make changes to the soundscapes based on the feedback value. To enable this, the obtained feedback gets associated with:

- the currently playing sound
- in case there is no sound currently playing, the last played sound in an X minutes time window. (In the test we set X = 10 minutes.)

The suitability of a sound is depending on the activity. For example, kitchen sounds are suitable during lunch hour, but not during the night. Therefore,

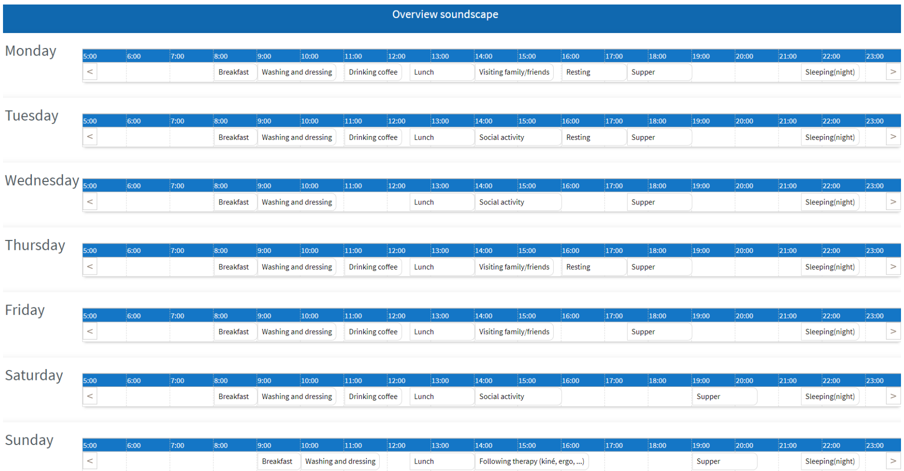


Fig. 3 The user interface that shows how activities and their associated soundscapes can be defined in the weekly schedule

the influence of the feedback is limited to the specific sound of the soundscape that is coupled to the current activity. As a result, the feedback is used for adjusting the soundscape of the activity (e.g., lunch) that is performed during the feedback event (i.e., the push on the color button).

Soundscapes associated to other activities are not affected by the feedback, even if they contain the same sound. For example if sound S, played during activity A, receives negative feedback, it can be removed from the soundscape associated with activity A. However, sound S might be very suited for activity B, and therefore it can remain a part of the soundscape associated with activity B.

Repeated pushing of the buttons in a Y minutes time window (we set Y = 1 minute) is considered as a single feedback by taking the first score. This prevents too abrupt changes to the soundscape in a short period of time.

4.2.2 Sound Score Update Strategy

Each sound has a score, indicating if it can be part of the soundscape of the specific activity or not. The initial values are the levels determined by the experts. The scores are updated as follows:

$$NewSoundScore = OldSoundScore * (1 - LearningRate) + FeedbackScore * LearningRate \quad (1)$$

This score function was based on incremental update mechanisms that are often used in recommender system design. Old Sound Score stands for the score that a sound has for a specific activity before feedback is given. Feedback score stands for the score given using the color buttons. New score stands for the score that a sound has after feedback is given. For our experiment, we set the

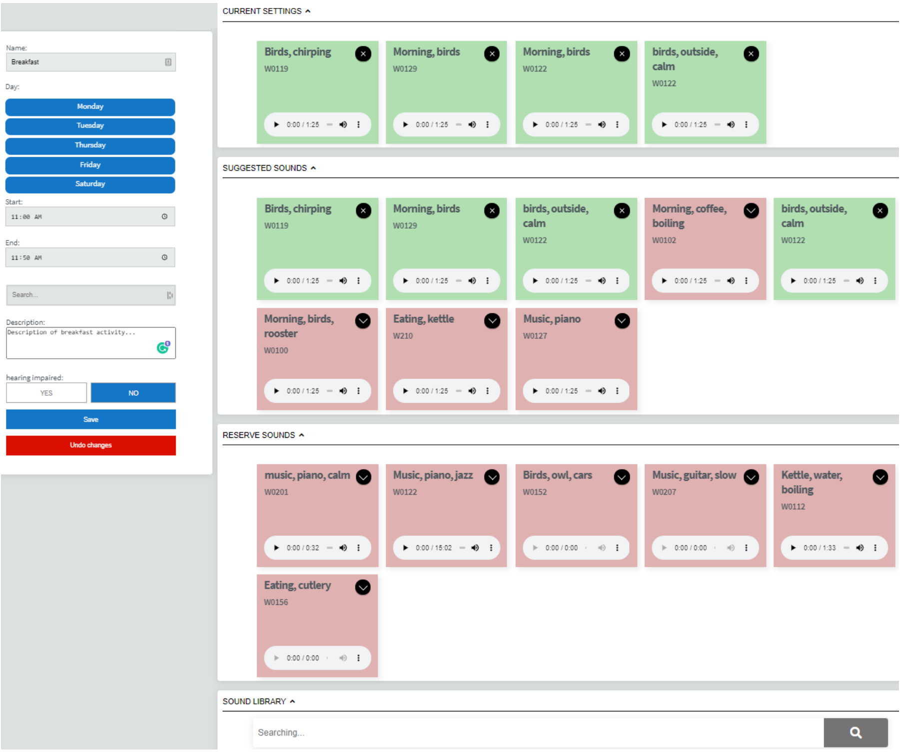


Fig. 4 The user interface that shows how sounds can be selected for the soundscape associated to a specific activity

learning rate = 0.25, which was experimentally determined. The learning rate parameter can be changed depending on how fast soundscapes should change when receiving feedback. Therefore, the impact of Old Sound Score decreases as more feedback is provided. This update strategy allows for an immediate effect on the score of a sound without the need for large amounts of data to learn from.

As an alternative, we considered a time decay of the score based on the elapsed time. But for this an additional parameter is needed (i.e., the time that specifies how fast a score decays). Because the amount of feedback was highly variable over the different nursing homes (see also Section 5.1), a time decay was not a good solution. Therefore, we opted for updating the score every time that feedback is provided as in equation 1. This way, the update rate is according to the intensity of usage of the feedback system.

4.2.3 Coloured Buttons Feedback

This section explains the meaning of the buttons of the feedback panel.

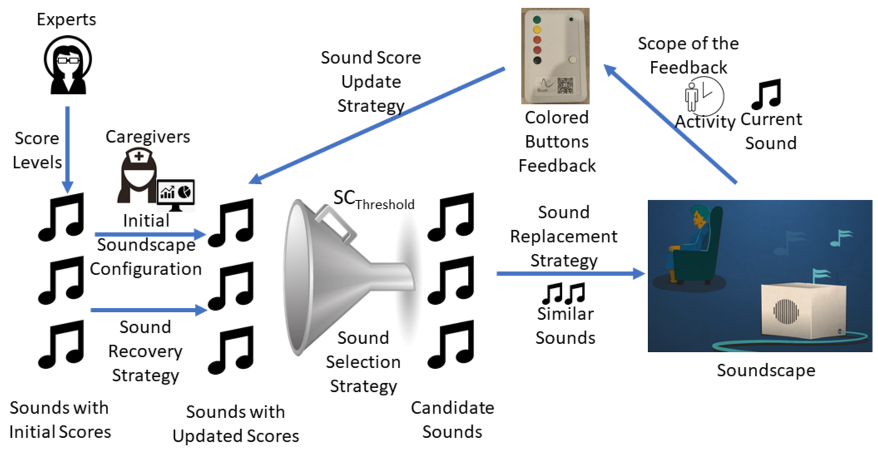


Fig. 5 Graphical overview of the personalization algorithm for soundscapes

White button for snooze functionality. When pressing this button, the soundscape is muted for this activity. But this button has no influence on the configuration of the soundscape or the scores of the sounds of this soundscape. The purpose of this button is to temporally switch off the soundscape system if this is desired.

Green, yellow, orange, red and black button for feedback. These coloured buttons are used to indicate the current BPSD and behavior of the resident. The feedback options range from green, which denotes an excellent BPSD and behavior, to black, which is used for a bad BPSD and behavior. Every coloured button is associated with a $FeedbackScore$ with values in descending order according to equation 2 .

$$Score_{black} < Score_{red} < Score_{orange} < Score_{yellow} < Score_{green} \quad (2)$$

The values of the $FeedbackScore$ are chosen relative to the SoundScape Threshold, $SC_{Threshold}$, and the Reserve set Threshold, $RES_{Threshold}$ value. $SC_{Threshold}$ stands for the minimum $SoundScore$ that is needed for including a sound in the soundscape. $RES_{Threshold}$ is the minimum $SoundScore$ for assigning a sound to the set of reserve sounds. The set of reserve sounds are not part of the soundscape but are good candidates for replacing one of the current sounds of the soundscape. In other words, this sound is suitable for the activity but not part of the current soundscape.

The green button stands for the most positive feedback, and $Score_{green}$ is assigned a value greater than $SC_{Threshold}$. As a result, feedback with the green button increases the $SoundScore$ and keeps the sound in the soundscape. $Score_{yellow}$ and $Score_{orange}$ are chosen between $SC_{Threshold}$ and $RES_{Threshold}$ indicating that these sounds can be replaced in the current soundscape, but in case of replacement still deserve a spot in the set of reserve sounds. $Score_{red}$

and $Score_{black}$ are less than $RES_{Threshold}$. These colors represent negative feedback and the sounds are therefore banned from the soundscape and the set of reserve sounds. This results in the following equation:

$$Score_{black} < Score_{red} < RES_{Threshold} < Score_{orange} < Score_{yellow} < SC_{Threshold} < Score_{green} \quad (3)$$

4.2.4 Sound Selection Strategy

For each activity, each sound has a *SoundScore*. The initial value is the suitability value as provided by the experts ($Score_{level0}$, $Score_{level1}$ and $Score_{level2}$) with values according to equation 4.

$$Score_{level0} < RES_{Threshold} < Score_{level1} < SC_{Threshold} < Score_{level2} \quad (4)$$

The feedback with color buttons can change these scores according to equation 2. The meaning of the value of the *SoundScore* is as follows:

$$\begin{aligned} SC_{Threshold} \leq SoundScore &\Rightarrow \text{This sound is used for the soundscape.} \\ RES_{Threshold} \leq SoundScore < SC_{Threshold} &\Rightarrow \text{This is a reserve sound.} \\ SoundScore < RES_{Threshold} &\Rightarrow \text{This sound is unsuitable for the soundscape.} \end{aligned} \quad (5)$$

During an activity, the sounds of a soundscape are played during the activity time window. The sounds are shuffled in a random order.

4.2.5 Sound Replacement Strategy

If a sound that is part of the soundscape receives negative feedback, it can be removed from the soundscape. This sound of the soundscape becomes a reserve sound or an unsuitable sound (according to the threshold values specified in equation 5). If one sound is removed from the soundscape, one reserve sound is added to the soundscape as a replacement. The selection of this reserve sound is done as follows:

- All reserve sounds are candidates.
- Calculate the soundscape similarity S_r between the reserve sound r and the sounds $i = 1..N$ that belong to the soundscape. The sound that has to be removed, index j, is excluded from the sum:

$$S_r = \sum_{i=1, i \neq j}^{N} W_i * Sim(r, i) \quad (6)$$

  where $Sim(r, i)$ represents the similarity measure between 2 sounds and W_i is a weight to be calculated from the *SoundScore* of the sound i .

$$W_i = \frac{SoundScore_i}{\sum_{i=1, i \neq j}^{N} SoundScore_i} \quad (7)$$

– The reserve sound with the highest value of S_r is added to the soundscape.

4.2.6 Sound Similarity

One of the most important aspects in the selection of sounds is the similarity function. This has two components

1. The acoustic similarity, calculated based on acoustic properties (AP), with the frequency as dominant factor
2. The metadata similarity, calculated based on metadata (M) (tags, category and classification taxonomy)

The similarity measure $Sim(r, i)$ between two sounds r and i is calculated as follows:

$$Sim(r, i) = W_{AP} * Sim_{AP}(r, i) + W_M * Sim_M(r, i) \quad (8)$$

The weight for the AP component, W_{AP}, was experimentally determined as the dominant contribution in equation 8.

4.2.7 Sound Recovery Strategy

If too many sounds receive negative feedback and are banned to the set of unsuitable sounds, it is possible that the set of reserve sounds is empty. In that case, the unsuitable sounds that were originally marked as level 2 or level 1 by the experts, can be recovered from the set of unsuitable sounds, and put again into the set of reserve sounds.

5 Results

5.1 Usage of the system

In this section, we explain how and when the soundscape system was used. Feedback on the soundscapes was provided by caregivers by pushing the color buttons. Figure 6 shows the percentage of these feedback events for the various activities in the 6 nursing homes. Most feedback (52%) is provided during sleeping time: falling asleep (13%) and sleeping during the night (19%) as well as sleeping during the day (20%). Also during morning activities, such as waking up (8%) and breakfast (13%), a lot of feedback was obtained. During other day activities such as drinking coffee (1%) or a person-centered activity (7%) less feedback was provided. One of the reasons is that these activities were not always performed in the personal room of the resident but sometimes in a common room together with other residents of the nursing home. Another reason is that the caregivers were not always in close proximity or available to push the feedback buttons. In total, 3624 feedback events have been registered for the 6 nursing homes. These numbers answer RQ1: “When is the soundscape system typically used and adjusted by providing feedback?”

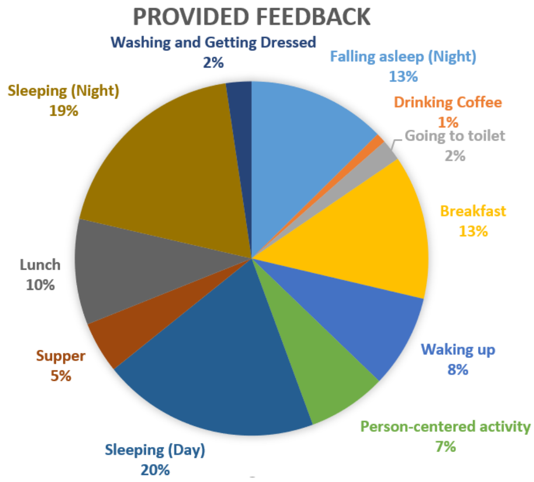


Fig. 6 Pie chart showing the activities during which feedback was provided

Figure 7 shows the number of played sounds, with the number of sounds that were selected by the recommender versus sounds selected by the experts. The initial soundscape contains all sounds selected by experts, but based on negative feedback these sounds can be replaced by the recommender. We witnessed a significant difference in the usage of the soundscape system over the different nursing homes. The caregivers in nursing home 1 were very active with the soundscape system. Over the test period of 8 weeks, they provided 1089 times feedback. This feedback is valuable information for the recommender that will adjust the soundscape accordingly. As a result, the majority (76.4%) of the sounds is selected by the recommender in nursing home 1. In contrast, much less feedback was obtained in nursing home 2; more specifically 301 feedback events were registered. This is reflected in the selection process of sounds for the soundscape. In nursing home 2, only 11.9% of the played sounds were chosen by the recommender. In this case, limited feedback was available, and as a result the soundscape was only slightly changed. This reasoning was also valid for the other nursing homes. We obtained a positive correlation of 0.76 between the number feedback events in the nursing home and the percentage of sounds that were selected by the recommender. In other words, more feedback means more personalization in the soundscape by the recommender algorithm. This gives an answer to RQ2: "What proportion of sounds is selected by the recommender vs by the human expert? And what is the influence of the amount of provided feedback?"

5.2 Explicit Feedback

The soundscape system was evaluated with 19 persons suffering from dementia with demographics as indicated in Table 1. In this section, we discuss the effect

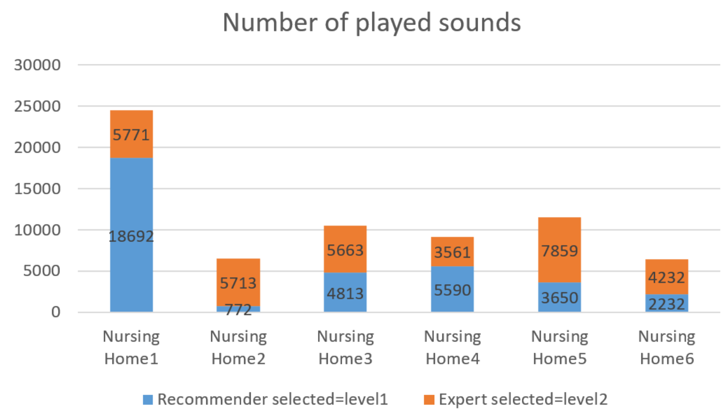


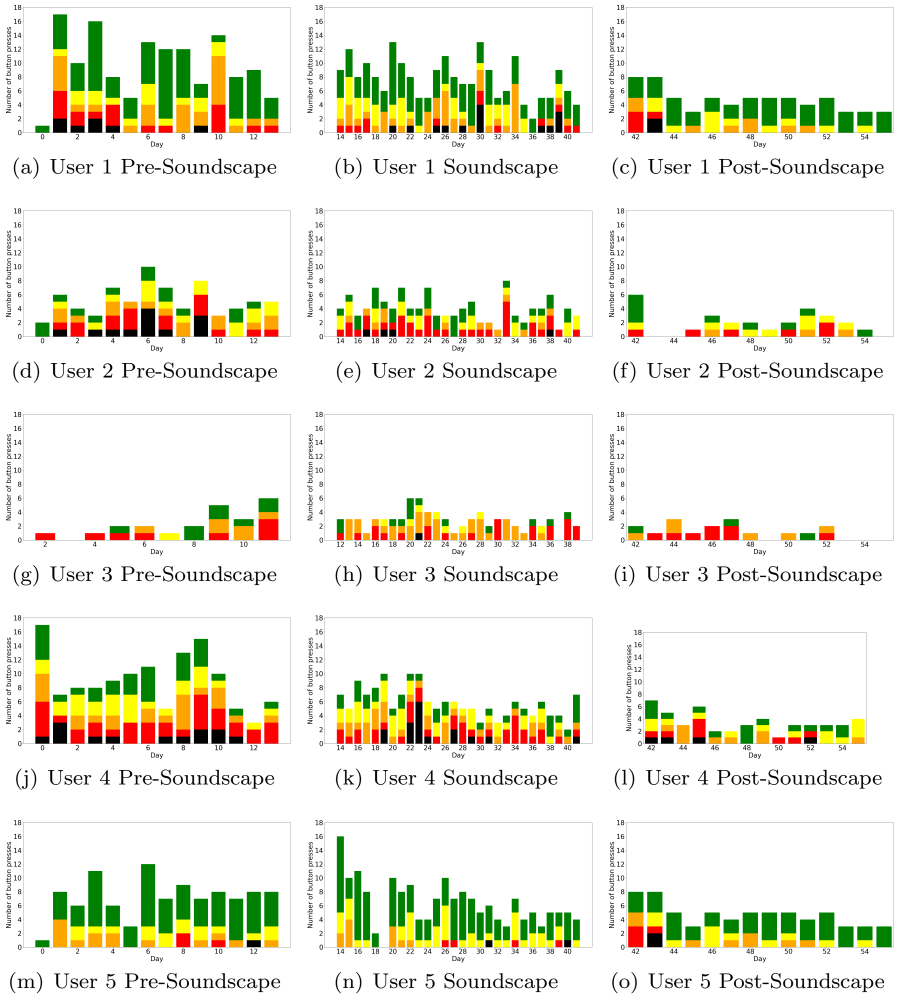
Fig. 7 For each nursing home, the number of played sounds that were selected by the recommender or selected by the experts

Table 2 Details of 5 typical users

User	Gender	Age	Type of dementia	MMSE score	Result experiment
User1	Female	87	Alzheimer	10/30	Significant improvement for all phases
User2	Female	90	Signs of dementia not confirmed	Not measured	Significant improvement for 1 phase, improvement but not significant for the other
User3	Female	83	Alzheimer	4/30	Deterioration but not significant
User4	Female	84	Schizoaffective disorder	21/30	Status quo
User5	Male	71	Alzheimer	0/30	Significant deterioration

of the soundscape system for 5 example users, which are residents of nursing homes. Table 2 provides details of the 5 users we discuss. For each user, the MMSE score (Mini Mental State Examination) is specified. The MMSE is a commonly used set of questions for screening cognitive function [6,11]. The maximum MMSE score is 30 points. Scores of $25-30$ out of 30 are considered normal; the National Institute for Health and Care Excellence (NICE) [23] classifies $21-24$ as mild, $10-20$ as moderate and < 10 as severe impairment. On average, the MMSE score of a person with Alzheimer's disease declines about two to four points each year [33].

Figures 8(a),8(b),8(c) show the feedback provided by caregivers based on the behavior of user 1 (BPSD) and her reaction to the sound. This user has a MMSE of 10/30 (Table 2), which can be described as a moderate degree of dementia. To evaluate the obtained feedback, we mapped the color buttons green, yellow, orange, red, and black to respectively 5, 4, 3, 2 and 1. In the pre-soundscape phase, a mean score of 3.88 was given. When the soundscape was



(a) User 1 Pre-Soundscape (b) User 1 Soundscape (c) User 1 Post-Soundscape

(d) User 2 Pre-Soundscape (e) User 2 Soundscape (f) User 2 Post-Soundscape

(g) User 3 Pre-Soundscape (h) User 3 Soundscape (i) User 3 Post-Soundscape

(j) User 4 Pre-Soundscape (k) User 4 Soundscape (l) User 4 Post-Soundscape

(m) User 5 Pre-Soundscape (n) User 5 Soundscape (o) User 5 Post-Soundscape

Fig. 8 Comparison of the obtained feedback of 5 typical users over the three phases.

active, a slightly higher score of 3.96 was obtained. This improvement continues in the post-soundscape phase that has a score of 4.32. Indeed in the post-soundscape phase we see less red and black button feedback. This improvement showed to be significantly according to the Mann Withney U test (p=0.021 for the difference between post-soundscape and soundscape phase; p=0.022 for the difference between post-soundscape and pre-soundscape phase). Figure 8 also shows that for this user, more feedback was given than for the other users 2, 3, 4 and 5. Because this user spent a lot of time in her room, the caregivers could give more feedback for this user. Because of this extra feedback, the recommender was able to learn preferences and improve the soundscape composition based on the feedback obtained for user 1.

Figures 8(d),8(e),8(f) show the feedback obtained for user 2. This user has signs of dementia, but has not yet been diagnosed with dementia. In the pre-soundscape phase, the mean score was 3.05, which is rather low because of the black feedback. This user had some behavior problems. In the soundscape phase, the influence of the sounds improved the score to 3.44, and the amount of black button feedback is reduced. During the post-soundscape phase, the obtained score was 3.69, which is significantly higher than the pre-soundscape phase (Mann Withney U test: p=0.030). The difference between soundscape and post-soundscape phase was not significant. In comparison with user 1, less feedback was obtained for user 2. This explains why the last difference was not significant.

Figures 8(g),8(h),8(i) visualize the button feedback obtained for user 3. This user suffers from a severe impairment due to dementia with a low MMSE score of 4/30. The feedback obtained during the pre-soundscape phase has a mean value of 3.39. When the soundscape was active, a mean score of 3.13 was obtained. And during the post-soundscape phase, the mean score was 2.79. So we notice a decrease in the score that evaluates the behavior of user 3. However, this negative effect of the soundscape was not significant. This indicates that the soundscape does not have a positive effect for all users. Probably due to the severe degree of dementia, this user could not identify the sounds. Also for other users with a severe degree of dementia, we witnessed less good results with the soundscape (See Table 3).

Figures 8(j),8(k),8(l) show the feedback obtained for user 4. This users suffers from a mild degree of dementia with an MMSE of 21/30. This user has a score of 3.20 for the pre-soundscape phase, a score of 3.24 for the soundscape phase, and a score of 3.52 for the post-soundscape phase. Although we see an improvement of the score for the subsequent phases, these differences are not significant. Therefore, we consider the effect of the soundscape as 'status quo'. This is a user for whom additional feedback can make the differences significant.

Figures 8(m),8(n),8(o) show the feedback obtained for user 5. This user suffers from dementia in a severe degree (MMSE of 0/30). During the pre-soundscape phase, a mean score of 4.44 was obtained. During the soundscape phase, the mean score was 4.51. But this was not significantly different from the pre-soundscape phase. In the post-soundscape phase, the score decreased to 4.07 which is significantly lower than the pre-soundscape (Mann Withney U test: p=0.027) and soundscape phase (Mann Withney U test: p=0.005). Again we see here that for a person with a severe degree of dementia, a deterioration of the feedback can be witnessed.

Table 3 shows the effect of the soundscape for three different degrees of dementia according to the MMSE score. We clearly see a relation between the degree of dementia and the effect of the soundscape. For users with a mild degree of dementia, most user (80%) experienced a positive effect. Also for users with a moderate degree of dementia, the effect of the soundscape was in most cases (78%) positive. In contrast, for users suffering from a severe degree of dementia, a positive effect was obtained for only 40% of the users.

Table 3 The effect of the soundscape for different degrees of dementia

Degree of dementia	Mild	Moderate	Severe
Positive significant	3	3	0
Positive not significant	1	4	2
Status quo	1	1	1
Negative not significant	0	1	1
Negative significant	0	0	1

Summarizing, for 13 of the 19 users who used the soundscape system, we obtained an improvement in feedback score over the different phases. For 6 of these users, the improvement was also significant. We believe that if more feedback was provided, significant differences would be obtained for some additional users. This gives an answer to RQ3: "What is the influence of the soundscape system on the people suffering from dementia?"

6 Conclusion

In this paper, we investigated the impact of augmented soundscapes in a nursing home environment. The study showed that most residents suffering from dementia appreciate the augmented soundscape, and hearing these pleasant sounds has a positive effect on their behavior. The caregivers gave the most feedback during sleeping moments of the residents and during morning activities, such as waking up and breakfast. The amount of provided feedback showed to be an important factor in the selection of sounds. In case of limited feedback (around 300 feedback events or less), the soundscape remains mainly ($> 88\%$) the same as initially created by the caregivers. In contrast, if the caregivers give a lot of feedback (more than 1000 feedback events), more data for personalizing the soundscape are available, and most sounds are selected by the recommender ($> 76\%$). For 13 of the 19 residents who used the soundscape system, we obtained an improvement in behavior of the resident due to the augmented soundscape. We see different opportunities for future work. The soundscape system can be tested by a larger population and over a longer period of time. In addition, the recommender algorithm can be made more intelligent by including context aspects such as season, weather, or the exact location of the resident in the room.

Funding and Conflict of interest

This research was performed in the context of the Acusticare IOF project (https://www.acusticare.be/) and funded by Ghent University, Belgium. The authors declare that they have no conflict of interest.

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