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Soundscape Awareness Intervention Reduced Neuropsychiatric Symptoms in Nursing Home Residents With Dementia: A Cluster-Randomized Trial With MoSART+

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ABSTRACT

Objectives: Auditory environments as perceived by an individual, also called soundscapes, are often suboptimal for nursing home residents. Poor soundscapes have been associated with neuropsychiatric symptoms (NPS). We evaluated the effect of the Mobile Soundscape Appraisal and Recording Technology sound awareness intervention (MoSART+) on NPS in nursing home residents with dementia.
Design: A 15-month, stepped-wedge, cluster-randomized trial. Every 3 months, a nursing home switched from care as usual to the use of the intervention.
Intervention: The 3-month MoSART+ intervention involved ambassador training, staff performing sound measurements with the MoSART application, meetings, and implementation of microinterventions. The goal was to raise awareness about soundscapes and their influence on residents.
Setting and participants: We included 110 residents with dementia in 5 Dutch nursing homes. Exclusion criteria were palliative sedation and deafness.
Methods: The primary outcome was NPS severity measured with the Neuropsychiatric Inventory −Nursing Home version (NPI-NH) by the resident's primary nurse. Secondary outcomes were quality of life (QUALIDEM), psychotropic drug use (ATC), staff workload (workload questionnaire), and staff job satisfaction (Maastricht Questionnaire of Job Satisfaction).
Results: The mean age of the residents ($n = 97$) at enrollment was 86.5 ± 6.7 years, and 76 were female (76.8%). The mean NPI-NH score was 17.5 ± 17.3. One nursing home did not implement the intervention because of staff shortages. Intention-to-treat analysis showed a clinically relevant reduction in NPS between the study groups (−8.0, 95% CI −11.7, −2.6). There was no clear effect on quality of life [odds ratio (OR) 2.8, 95% CI −0.7, 6.3], psychotropic drug use (1.2, 95% CI 0.9, 1.7), staff workload (−0.3, 95% CI −0.3, 0.8), or staff job satisfaction (−0.2, 95% CI −1.2, 0.7).
Conclusions and Implications: MoSART+ empowered staff to adapt the local soundscape, and the intervention effectively reduced staff-reported levels of NPS in nursing home residents with dementia. Nursing homes should consider implementing interventions to improve the soundscape.

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The soundscape, or the sonic environment as it is perceived and understood by a person,[1] is often suboptimal for nursing home residents. Staff, household appliances, and other residents produce unexpected, repetitive, loud, or droning noises.[2,3] These intrusions can lead to severe sound annoyance.[4] At the same time, pleasant sounds are typically offered infrequently (eg, music that residents like).[5] Taken together, staff may unintentionally contribute to a soundscape that adversely affects the mood and quality of life of residents.[6] Moreover, people living in nursing homes frequently lack the cognitive and/or functional capacity to adjust the soundscape to their needs.[7] Those with dementia may also have difficulty understanding noises if they are unrelated to their own activities.[2] Poor processing of sounds due to diminished physical and cognitive functions makes them highly sensitive to detrimental soundscapes.[4,8]

The detrimental effects of poor soundscapes on the well-being of nursing home residents and staff have been shown in previous studies. Among residents with dementia, poor soundscapes have been associated with sleeping disorders and behavioral problems such as agitation, apathy, and wandering.[2] Such neuropsychiatric symptoms (NPS), which are present in around 80% of nursing home residents, are associated with a poor quality of life.[9] It has also been reported that nursing staff experience more irritability, anxiousness, difficulties concentrating, and errors because of environmental noise.[2] Despite the negative effects on residents and staff in nursing homes, no interventional studies focused on the impact of noise reduction in this setting.[2]

Recent soundscape research in residential facilities for people with profound intellectual disabilities led to the development of an app called Mobile Soundscape Appraisal and Recording Technology (MoSART; Soundappraisal). Asking nurse assistants to record actual and perceived soundscapes, which improved awareness of sounds, was associated with decreased negative mood and problem behavior among residents.[10] The intervention was piloted in 2 nursing homes to assess its usefulness among people with dementia, which has resulted in its expansion to include ambassadors, who are specially trained staff to promote sound awareness. This intervention was named MoSART+.

We hypothesized that the MoSART+ intervention could affect NPS in nursing home residents with dementia positively. The aim of the study was to observe the effect of the intervention on NPS.

Methods

Design

A 15-month, stepped-wedge, cluster-randomized controlled trial was conducted from August 21, 2018, to December 24, 2019. We included the staff and residents of 5 long-term care institutions (nursing homes) affiliated with our institution. Residents were eligible if they had a history of dementia and were excluded if they were completely deaf or received palliative sedation.

Every 3 months, one of the 5 participating nursing homes switched from the control condition to receiving the intervention.[11] Thus, there were 5 periods (steps), with the allocation sequence being randomly computer-generated and concealed from the nursing homes until we began preparing for the intervention in each home (eg, ambassador selection). Nursing homes received the intervention in succession, because it results in more power than a parallel group design.

The Medical Ethics Review Committee of the UMCG approved the study protocol. Informed consent was obtained from each resident when possible. Otherwise, the legal representative, typically the primary informal caregiver, gave consent. The trial was registered online at the International Clinical Trials Registry Platform (https://trialsearch.who.int/Trial2.aspx?TrialID=NTR7068) before enrollment of participants started.

Intervention

The MoSART+ intervention consisted of training sessions for ambassadors, soundscape measurement with the application, discussion meetings with the nursing staff, and microinterventions (Figure 1). First, we provided 3 training sessions for 3 to 4 ambassadors per organization. Ambassadors were professionals with acknowledged authority, had prior knowledge about or experience with sound (eg, education or work related experience), and were familiar with nursing team dynamics. The theoretical underpinnings of soundscapes and their relationship to psychological well-being,[12,13] implementation of MoSART+, and use of the application were discussed during the training sessions. The role of an ambassador was to raise questions about the soundscape in the nursing home and to facilitate implementation of the MoSART+ intervention.

Next, we provided nursing staff a general introduction about sounds and how to use the MoSART app, which was downloaded onto a smartphone. The app is based on theory of soundscape quality and auditory environment assessment (Supplementary Figure 1).[10] Staff received 3 or 4 cues at random during a shift to record 30 seconds of audio and to complete a short questionnaire about the auditory environment.[10] To ensure the privacy of residents and staff, audio records were anonymized.[14]

Finally, after staff had used the app for 2 weeks, ambassadors and staff members met to discuss the results and possible microinterventions to improve the soundscape of communal spaces. Examples were the use of a tablecloth before setting a table, unpacking the dishwasher at set times, and fixing a squeaky door. Afterwards, the MoSART application was used for 2 weeks. The results of the first and second measurement periods were discussed with the staff during a final meeting led by the ambassadors.

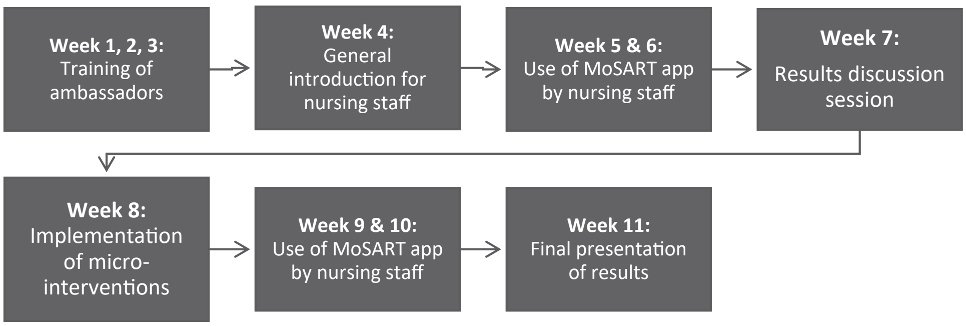

Fig. 1. Chronological overview of the MoSART+ intervention by week.

Outcomes and Other Variables

Six visits were planned—1 at baseline and 1 after each of the 5 intervention periods. The primary outcome was NPS severity. Secondary outcomes were residents' quality of life (QoL) and psychotropic drug use, as well as staff's workload and job satisfaction.

Resident Outcomes

The nurse assistant with primary responsibility for the care of a given participant assessed the NPS with the validated Dutch version of the Neuropsychiatric Inventory—Nursing Home version (NPI-NH).[7,15] It measures frequency (Likert scale from 1 to 4), severity (1-3), and staff-related distress (0-5) of 12 neuropsychiatric symptoms.[9] If a symptom is not present, the frequency, severity, and caregiver distress are scored zero, giving an overall range of 0 to 144. All raters were trained and certified before the start of the trial.

The residents' QoL was assessed by the nursing staff with the QUALIDEM.[16] This is a 40-item questionnaire (total range, 0-111) that spans 9 domains: care relationship, positive affect, negative affect, restless tense behavior, positive self-image, social relations, social isolation, feeling at home, and engagement in meaningful activities.

Psychotropic drugs were classified according to the Anatomical Therapeutic Chemical (ATC) classification system. Research staff extracted details from electronic patient records using a preformatted datasheet.

Age and gender were recorded at baseline from residents' files. Trained research staff rated the severity of dementia using the Dutch version of the Clinical Dementia Rating scale,[17] cognitive dysfunction using the Severe Impairment Battery—26,[11,18] and auditory (dys) function using the Severe Dual Sensory Loss Screening tool.[19]

Nursing Staff Outcomes

Staff workload was measured with the 8-question Workload Questionnaire,[20] covering intensity of work, amount of work, work pace, mental strain, and work complexity. Items are scored on a 5-point Likert scale ranging from 1, never, to 5, always (total range, 8-35). Job satisfaction was measured with the 21-question Maastricht Questionnaire of Job Satisfaction (MAS-GZ),[21] assessing satisfaction with the head of department, promotion chances, quality of care, personal growth, contact with colleagues, resident contact, and clarity about tasks. Item are scored on a 5-point Likert scale from 1, very dissatisfied, to 5, very satisfied (total range, 21-105).

Soundscape Outcomes

The effects of the intervention on the soundscape are described in detail in another article.[14]

Sample Size Calculation

Sample size was calculated with the method of Hussey and Hughes.[22] We calculated that 11 dementia care units (clusters) within 5 organizations needed to be enrolled. We planned to continue participant enrollment throughout the trial to replace participants who dropped out. The targeted sample size was 88 residents at baseline and 78 during the study (newcomers), giving a total sample of 166. We expected the recruited dementia care units to employ approximately 250 nursing staff.[23] The Supplementary Material shows the full calculation.

Data Analysis

Baseline participant characteristics were compared by organization using means or proportions, as appropriate. Participants who completed the study were also compared with those who dropped out because of death, relocation, or withdrawal. We were required to perform both intention-to-treat (ITT) and per protocol analyses because one of the homes did not implement the intervention, treating this nursing home as if it had adopted the intervention for the ITT analyses and as not having adopted it for the per protocol analyses.

Originally, we planned to perform a linear mixed model analysis of the effect of MoSART+ on NPS, but we discovered that around 15% of residents had scored zero on the NPI-NH during at least 1 visit. A mixed Tobit analysis was performed to account for this floor effect.[24] We used a random slope with a random intercept at an individual level, and an unstructured covariance. We imputed a score of zero when up to 2 individual NPI-NH items were missing, but otherwise assumed that scores were missing at random. Linear mixed models were used to analyze the intervention effect on QoL, assuming that data were missing completely at random and did not require imputation. Logistic generalized estimation equation analysis was used for the impact on psychotropic drug use, again assuming that data were missing completely at random and did not require imputation. Only continuous use was considered active drug use and was for that reason included in the analysis.

Three mixed models were fitted for each patient outcome (Supplementary Table 1). We selected the simplest acceptable regression model with the likelihood ratio test. Sensitivity analyses were run for each model, removing newcomers from the analyses, to assess the impact of attrition (drop-out) and participant replacement after baseline.

Generalized linear mixed models were used to study the intervention effect on staff workload and work satisfaction. Model 1 was corrected at the nursing home, cluster, and individual levels as fixed effects and using time as a categorical variable. Model 2 was expanded with correction for gender as a mixed effect.

Two researchers analyzed the data independently using Stata 16.0.[25] They discussed and checked their analyses until there were no discrepancies in the results. The 3 researchers (T.C. Andringa, R.A.J. van Elburg, S. Warmelink) employed by the company that developed MoSART+ had no role in the above-mentioned data collection or analysis during the trial.

Post Hoc Analysis

At the request of the editor, a post hoc proprietary time-frequency analysis of the recorded sounds with the MoSART app was done. The researcher T.C. Andringa employed by Soundappraisal that developed MoSART+ performed this analysis. The results and method are described in the Supplementary Material 2.

Results

Recruitment and Sample

Five nursing homes with 20 units participated in the trial. Figure 2 gives a summary of the participant flow. Families did not provide consent for 56 of 152 eligible residents (37%), resulting in 91 residents undergoing baseline assessments; of those included, 82 had at least 1 follow-up assessment. After baseline, 7 new residents were included, of which 4 had a follow-up assessment. Thus, we included 98 residents in the baseline analysis. During the trial, 37 residents (38%) were lost to follow-up: 36 (97%) of these died and 1 (3%) moved to another nursing home.

Table 1 and Supplementary Table 2 shows the baseline characteristics of participants enrolled at baseline and newcomers by nursing home. The mean age of residents was 86.5 ± 6.7 years and 76 (76.8%) were female. The mean NPI-NH score at baseline was 17.5 ± 17.3 (median, 12.0). There were some important differences between

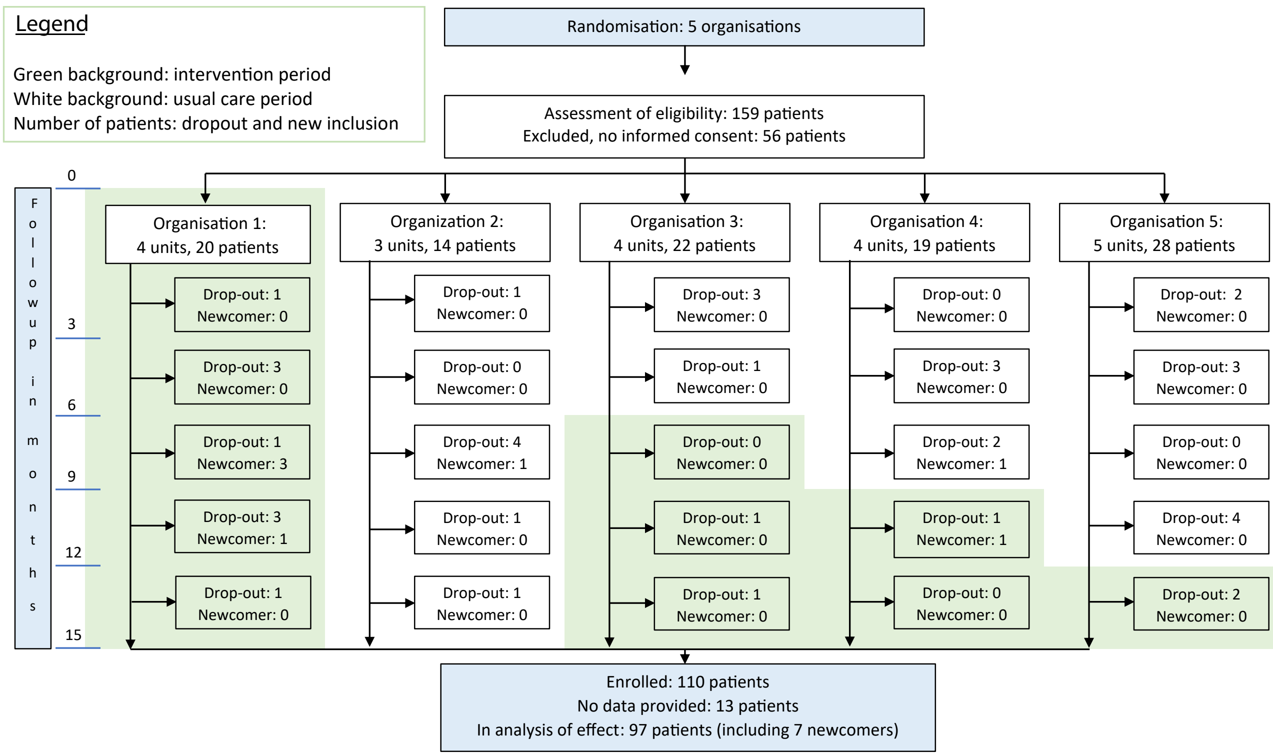

Fig. 2. Flowchart of patients.

individual nursing homes at baseline. Residents in one home had more severe NPS and lower QoL; in another, a higher proportion used psychotropic drugs; and in 2 nursing homes, residents had longer durations of stay. In addition, duration of stay was notably longer for residents enrolled at baseline than for those included after the trial had started. Workload was highest and job satisfaction was lowest among the nursing staff in the nursing home that did not implement the intervention.

Effects of the MoSART+ Intervention

Table 2 shows the effect of MoSART+ on NPS severity, QoL, and psychotropic drug use among residents. The ITT analyses showed a clinically relevant effect on NPS (ie, >3 on the NPI-NH) in all 3 fitted models. Model 1 showed that MoSART+ reduced NPS by −7.1 (95% 95% CI −11.7, −2.6) between the study groups. In model 2, the effect was −8.0 (95% CI −12.6, −3.5) after correction for probable

Table 1
Characteristics of Residents and Nursing Staff at Baseline

Characteristic	Nursing Home					
Residents	1 (n = 22)	2 (n = 12)	3 (n = 20)	4 (n = 16)	5 (n = 27)	Total n (N = 97)
Age, y, mean (SD)	87.3 (6.1)	85.4 (5.3)	86.6 (7.7)	87.3 (6.2)	85.9 (7.6)	86.5 (6.7)
Women, n (%)	18 (82)	8 (67)	14 (70)	12 (75)	24 (89)	76 (78)
Duration of stay, median (IQR)	15.0 (1.5-51.8)	20.0 (8.8-37.3)	8.5 (4.0-31.3)	11.5 (1.0-34.8)	38.0 (20.0-61.0)	20.0 (5.5-44.0)
Dementia severity*, n (%)						
0.0	0 (0)	3 (25)	0 (0)	0 (0)	0 (0)	3 (3)
0.5	1 (5)	1 (8)	2 (10)	2 (13)	7 (26)	13 (13)
1.0	4 (18)	0 (0)	2 (10)	2 (13)	6 (22)	14 (14)
2.0	4 (18)	2 (17)	6 (30)	7 (44)	7 (26)	26 (27)
3.0	12 (55)	6 (50)	10 (50)	4 (25)	7 (26)	39 (40)
Cognitive function†, median (IQR)	26.0 (6.0-33.0)	25.0 (17.0-30.0)	24.0 (14.8-30.5)	27.5 (18.3-32.3)	24.0 (16.0-31.0)	17.0 (2.05-31.0)
Hearing loss‡, median (IQR)	2.0 (0.3-5.0)	1.04 (0.0-2.0)	1.5 (0.5-3.0)	2.0 (1.0-3.0)	1.0 (0.0-2.0)	1.0 (0.0-3.0)
Neuropsychiatric symptoms§, median (IQR)	15.0 (9.0-30.5)	18.5 (8.0-28.5)	6.0 (0.0-23.8)	14.0 (9.0-22.8)	9.0 (4.5-22.0)	12.0 (6.0-26.0)
Quality of life‖, mean (SD)	73.1 (15.4)	69.8 (14.6)	79.5 (13.1)	77.5 (15.6)	79.6 (10.3)	76.6 (13.7)
Psychotropic drug use, n (%)	6 (27)	0 (0)	9 (45)	9 (56)	19 (70)	43 (44)
Nursing staff, n	17	21	19	22	49	128
Job satisfaction**, mean (SD)	24.8 (2.3)	22.7 (2.2)	22.9 (2.5)	24.9 (2.2)	27.3 (2.9)	25.3 (3.2)
Workload††, mean (SD)	25.6 (3.3)	31.2 (3.1)	28.6 (4.6)	27.8 (5.4)	24.0 (4.2)	26.5 (4.9)

*Measurement instrument: Clinical Dementia Rating scale (range 0-3; higher is worse).
†Measurement instrument: Severe Impairment Battery–26 (range 0-100; higher is better).
‡Measurement instrument: Severe Dual Sensory Loss Screening tool (range 0-6; higher is worse).
§Measurement instrument: NPI-NH (range 0-144; higher is worse).
‖Measurement instrument: QUALIDEM (range 0-111; higher is better).
**Measurement instrument: Maastricht Questionnaire of Job Satisfaction (range 21-105; higher is better).
††Measurement instrument: Work satisfaction (range 8-35; higher is worse).

Table 2
Effects of MoSART+ on Residents

	Neuropsychiatric Symptoms*, B (CI)	Quality of Life†, B (CI)	Use of Psychotropic Drugs‡, OR (CI)
Model 1, basic model			
With ITT	−7.1 (−11.7, −2.6)	2.1 (−1.3, 5.4)	1.2 (0.9, 1.5)
Per protocol	−3.9 (−8.7, 0.8)	−0.4 (−3.1, 3.9)	0.9 (0.7, 1.3)
Model 2, with probable confounders			
With ITT	−8.0 (−12.6, −3.5)	2.8 (−0.7, 6.3)	1.2 (0.9, 1.7)
Per protocol	−4.4 (−9.1, 0.4)	−0.8 (−2.9, 4.5)	1.0 (0.7, 1.3)
Model 3, with probable and possible confounders			
With ITT	−8.4 (−13.0, −3.7)	2.6 (−1.0, 6.2)	1.2 (0.8, 1.8)
Per protocol	−4.3 (−9.3, 0.6)	0.7 (−3.1, 4.6)	0.9 (0.6, 1.3)

*Mixed Tobit model.
†linear mixed model.
‡Logistic generalized estimation equation model.

confounders. Correction for additional confounders in model 3 further improved the effect to −8.4 (95% CI −13.0, −3.7). Although per protocol analyses showed smaller effects in models 1, 2, and 3, these were still clinically relevant at −3.9 (95% CI −8.7, 0.8), −4.4 (95% CI −9.1, 0.4), and −4.3 (95% CI −9.3, 0.6), respectively (Table 2).

The intervention had no clear effect on QoL across the 3 ITT models. It showed a difference of 2.1 (95% CI −1.3, 5.4) in model 1, of 2.8 (95% CI −0.7, 6.3) in model 2, and of 2.6 (95% CI −1.0, 6.2) in model 3. Per protocol analyses showed even smaller differences (Table 2).

Similarly, we found no clear effect of the intervention on psychotropic drug use. Model 1 showed an odds ratio (OR) of 1.2 (95% CI 0.9, 1.5); model 2, of 1.2 (95% CI 0.9, 1.7); and model 3, of 1.2 (95% CI 0.8, 1.7). The per protocol analyses showed even smaller or reversed effects (Table 2).

Finally, the intervention also had no clear effect on staff workload or job satisfaction (Table 3). On workload, model 1 showed an effect of −0.2 (95% CI −0.3, 0.8), and model 2 showed an effect of −0.3 (95% CI −0.3, 0.8). Job satisfaction was reduced by 0.2 (95% CI −1.2, 0.7) in both models.

Sensitivity Analyses

The ITT analyses without newcomers showed no meaningfully different effects on NPS. For models 1, 2, and 3, the results were −7.4 (95% CI −11.8, −3.0), −8.2 (95% CI −12.7, −3.7), and −8.2 (95% CI −12.9, −3.5), respectively.

Discussion

In this stepped-wedge cluster-randomized trial, the MoSART+ sound awareness intervention substantially reduced NPS in nursing home residents with dementia. However, it did not show any relevant effects on secondary outcome measures, including the QoL and psychotropic drug use of participants, or the workload and job satisfaction of nursing staff.

We found a clinically relevant effect of MoSART+ on NPS in the ITT analysis. It was −8.0 (95% CI −12.6, −3.5) when corrected for probable confounders. The lower limit of the CI indicates that we can have confidence in this effect. In addition, 15% of the residents had no NPS at 1 or more visit and they could only have contributed to the effect if MoSART+ also prevented NPS. Although the per protocol analysis showed a smaller effect of MoSART+ on NPS (−4.4, 95% CI −9.1, 0.4), it is still clinically relevant.[26] The participants in the nursing home that failed to implement the intervention had the highest mean NPS score at baseline and the lowest mean score at the end of the trial. This possibly created an overestimation of the effect in the ITT analyses and an underestimation in the per protocol analyses. Hence, the true effect of MoSART+ on NPS, as measured by the NPI-NH, probably lies between −8.0 and −4.4, which still indicates a clinically relevant improvement.[26]

Despite showing improvements in NPS, only slight increases in the QoL of residents were reported after implementing MoSART+. This was unexpected given the association between NPS and QoL,[27] but it may reflect the fact that QoL is difficult to measure in people with dementia.[27] Further, we identified no clear effect on psychotropic drug use, which although remarkable, is not uncommon for trials testing psychosocial interventions.[28] Indeed, for this to happen, the prescribing physician must observe a reduction in NPS, not attribute it to the medication being used, and decide to discontinue or reduce that medication.[28] Even when this process occurs, there will be a time lag until that decision is made.

MoSART+ did not affect staff outcomes in this trial. This was unexpected because NPS are associated with an increased workload for nursing staff, and disturbing sounds negatively influence their workload and work satisfaction. Possibly, implementing MoSART+ and performing the trial measurements temporarily increased staff workload and, in turn, reduced job satisfaction. Alternatively, again, a time lag between incorporating the intervention and an improvement in the work environment may have occurred.

A recent review about sounds in nursing homes identified 4 randomized trials that had investigated whether noise reduction affected NPS.[2] Two showed that reducing nighttime noise led to improved nighttime sleep, less agitation, and less daytime sleep.[29,30] The other 2 trials found a greater reduction in agitation when presenting live social noises instead of simulated social noises or music.[31,32] Our results confirm the positive results of these previous trials, supporting the argument that soundscape improvement is an attainable goal in nursing homes and can positively affect NPS in residents with dementia.[33]

In our study, a number of changes to the soundscape occurred during the intervention: (1) The nurses became more sensitive to the quality of the soundscape, and how it influences the residents. (2) They implemented small changes to the environment to improve the soundscape. Examples of such microinterventions are pads on kitchen doors and fixing squeaky chairs. (3) The soundscapes in the participating nursing homes were less often chaotic and more often calm after the intervention.[14]

Table 3
Effects of MoSART+ on Nursing Staff

	Workload	Job Satisfaction
Model 1: Outcome with intervention and time*	−0.2 (−0.3, 0.8)	−0.2 (−1.2, 0.7)
Model 2: model 1 + gender	−0.3 (−0.3, 0.8)	−0.2 (−1.2, 0.7)

*As fixed variables.

Strengths and Weaknesses

A strength of our study was the active participation of nursing staff in the intervention. Given that staff proposed the microinterventions, these were likely to fit in with specific local needs.[14] The active participation of professionals with different backgrounds and perspectives also improved the discussions about soundscapes. In addition, the intervention led to more interaction between employees and stakeholders from different hierarchical levels. For example, the management had to be involved in executing some microinterventions, such as agreeing on rules of conduct for staff and visitors, fixing a squeaky door, or the purchase of new material.

Another strength of the study was the use of a stepped-wedge design to increase its power. This design also ensured that all participating nursing homes received the intervention.

A limitation of the stepped-wedge design is that a nursing home randomized to a certain intervention period (step) cannot be replaced at random when it decides not to implement an intervention.[34]

Additionally, in an unblinded trial, some information bias is hard to avoid.[35] Staff who measured the behavioral outcomes were also the interventionists, raising concerns that the differences noted could have resulted from detection bias from nonblinded data collectors.

Conclusions and Implications

Our findings must now be corroborated by future research. MoSART+ focuses on increasing awareness among nursing staff to improve soundscapes in communal spaces by reducing annoying sounds. We recommend exploring ways to improve the soundscapes of private and communal spaces by introducing pleasant sounds in future studies. The AcustiCare project employs soundboxes in the residents' rooms that play sounds adjusted to the personal likings and daily rhythm of the residents to either stimulate or help relax them.[14,36,37] Further in future studies, actively communicating with physicians and encouraging them to perform medication reviews after implementing the intervention will also be key to clinical success.

With respect to future stepped-wedge trials, we advise that researchers anticipate drop-out of a cluster by including more clusters at inception. This approach requires a longer follow-up period, and more visits will be needed. However, benefits are greater power and acquiring additional knowledge about the implementation process. An alternative for future studies would be to include only those nursing homes that are considered organizationally stable.

In a stepped-wedge cluster-randomized trial, the MoSART+ soundscape improvement intervention substantially reduced NPS in nursing home residents with dementia. Nursing staff can be empowered to discuss and adapt soundscapes to improve the well-being of residents. Nursing homes should consider implementing interventions to improve the soundscape.

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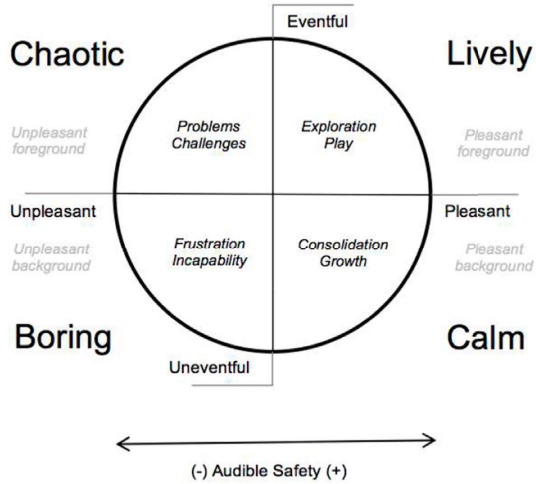
Supplementary Material 1

Box: Soundscape theory

The main dimensions of a soundscape are pleasantness and eventfulness, which yield four categories of soundscape quality: lively, calm, boring, and chaotic (4, 13). A calm environment allows us to consolidate and care for ourselves and our environment through ample indications of safety, whereas a lively environment is stimulating, safe, and allows us to play and learn. By contrast, a boring environment misses indications of safety and a chaotic environment may indicate unsafety and insecurity. Pleasant environments help to reassure people because they offer audible safety, whereas unpleasant environments will concern people due to the lack of audible indications of safety. Loudness is weakly correlated with the four categories, even though lively and chaotic environments tend to be louder than calm and boring environments.

The figure shows the four main categories of soundscape quality, the underlying dimensions, and the relations to behavior and audible safety (4). Permission was obtained to use this image.



Supplementary Fig. 1. Box Soundscape Theory.

Supplementary Table 1
The Models Used in the Analysis of the Patient Outcomes

Model Used	Tobit Model	Linear Mixed Model	Logistic Generalized Estimation Equation
Outcome assessed	Neuropsychiatric Inventory	Quality of life	Medication
Model 1, basic model	Outcome with intervention and time*	Outcome with intervention and time*	Outcome with intervention and time*
Model 2, with probable confounders	Model 1 + sex and severity of dementia*	Model 1 + severity of dementia and duration of stay*	Model 1 + sex and severity of dementia*
Model 3, with probable and possible confounders	Model 2 + age, baseline QoL, baseline medication, duration of stay, and subgroup*	Model 2 + age, sex, baseline NPI score, baseline medication, and subgroup*	Model 2 + age, baseline NPI score, duration of stay, and subgroup*

MoSART+, Mobile Soundscape Appraisal and Recording Technology with an ambassador; NPI, Neuropsychiatric Inventory; QoL, quality of life.
*as fixed variables.

Supplementary Table 2
Baseline Characteristics Newcomers and Participants Enrolled at Baseline Noted Apart

Characteristic	Enrolled at Baseline					Enrolled After Baseline*				
	Nursing Home					Nursing Home				
	1 (n = 19)	2 (n = 11)	3 (n = 20)	4 (n = 15)	5 (n = 27)	1 (n = 3)	2 (n = 1)	3 (n = 0)	4 (n = 1)	5 (n = 0)
Residents										
Age, y, mean (SD)	87.3 (6.1)	85.5 (5.5)	86.6 (7.7)	87.2 (6.4)	85.9 (7.6)	NA	83.8 (NA)	—	88.5 (NA)	—
Women, n (%)	15 (79)	8 (73)	14 (70)	12 (80)	24 (89)	2 (68)	1 (100)	—	0 (0)	—
Duration of stay, median (IQR)	22.0 (9.0-63.0)	23.0 (10.0-38.0)	8.5 (4.0-37.3)	15.0 (1.0-37.0)	38.0 (20.0-64.0)	3.0 (NA)	0 (NA)	—	1.0	—
Dementia severity†, n (%)										
0.5	1 (5)	3 (27)	2 (10)	2 (13)	7 (26)			—	—	—
1.0	3 (16)	1 (9)	2 (10)	2 (13)	6 (22)	1 (50)		—	—	—
2.0	3 (16)	1 (9)	6 (30)	7 (47)	7 (26)	1 (50)	1 (100)	—	—	—
3.0	12 (63)	6 (55)	10 (50)	4 (27)	7 (926)			—	—	—
Cognitive function‡, median (IQR)	25.0 (4.5-30.0)	25.0 (17.0-30.0)	24.0 (14.8-30.5)	27.5 (18.3-32.3)	24.0 (16.0-31.0)	48.0 (NA)	—	—	—	—
Hearing loss§, median (IQR)	2.0 (0.0-5.0)	1.0 (0.0-2.0)	1.5 (0.3-3.0)	2.0 (1.0-3.0)	1.0 (0.0-2.0)	4 (NA)	3 (NA)	—	NA	—
Neuropsychiatric symptoms‖, median (IQR)	15.0 (6.0-29.0)	19.0 (8.0-33.0)	6.0 (0.0-25.3)	14.0 (9.0-21.0)	9.0 (4.0-22.0)	54.0 (33.5-60.0)	0	—	44.0	—
Quality of life**, mean (SD)	74.4 (14.6)	67.7 (13.2)	79.5 (13.1)	77.5 (15.6)	79.6 (10.3)	48.0 (NA)	93.0 (NA)	—	NA	—
Psychotropic drug use, n (%)	5 (28)	0 (0)	9 (45)	8 (53)	19 (70)	1 (33)	0 (0)	—	1 (100)	—
Nursing staff, n	14	21	18	13	47	3	0	1	9	2
Job satisfaction††, mean (SD)	24.8 (2.5)	22.7 (2.2)	23.0 (2.6)	25.4 (1.9)	27.2 (2.8)	25.0 (1.9)	—	21.3 (NA)	22.0 (1.9)	31.0 (NA)
Workload‡‡, mean (SD)	25.9 (3.3)	31.2 (3.1)	28.4 (4.8)	27.6 (5.4)	24.0 (4.2)	24.3 (3.5)	—	31.0 (NA)	28.2 (5.8)	20.0 (NA)

*Number of newcomers is defiant from flowchart since not all newcomers delivered data for their first measurement.
†Measurement instrument: Clinical Dementia Rating scale (range 0-3; higher is worse).
‡Measurement instrument: Severe Impairment Battery–26 (range 0-100; higher is better).
§Measurement instrument: Severe Dual Sensory Loss Screening tool (range 0-6; higher is worse).
‖Measurement instrument: NPI-NH (range 0-144; higher is worse).
**Measurement instrument: QUALIDEM (range 0-111; higher is better).
††Measurement instrument: Maastricht Questionnaire of Job Satisfaction (range 21-105; higher is better).
‡‡Measurement instrument: Work satisfaction (range 8-35; higher is worse).

Supplementary Material 2. Analysis of Sound Recordings

In response to a request from the editor, we performed a post hoc analysis of the actual sound recordings.

Methods

The sound recordings were made with Xiaomi Mi A1 mobile phones through the MoSART application (SoundAppraisal Inc.) while the nurses used the same app to assess the soundscape as part of the sound awareness intervention. The phones made 1882 recordings during the study. They lasted for 30 seconds to maximally 2 minutes (rare) and were made 1 to 6 times per day, totaling 2-3 minutes per day (1/500th of a day). Soundscapes were assessed from 0 to 100 on 4 attributes: pleasantness, eventfulness, complexity, and range of affordances. The nursing staff also graded the environment on a scale of 0 to 10.

We performed a proprietary time-frequency analysis of the 1882 waveform audio files with a sample frequency of 22,500 Hz, as described before.[1] We calculated the mean decibel level with a standard deviation (EdB_mean with EdB_std) as an approximation of the audible decibel level dB(A) over the whole file. In visual terms, this would be the average color or average exposure level of a photo.

We then computed Pearson correlation and associated 95% CIs between mean decibel level and the measurement period, the 4 attributes, and the overall grade. The correlations and CI were calculated with Python 3.9.[2]

Results

The table presents the correlations (see below). Overall, they were not strong. The correlation between the mean decibel level and the measurement period was effectively absent (coefficient 0.02, 95% CI 0.015, 0.018). Nevertheless, a complex (chaotic), eventful, and high affordances (lively) soundscape was associated with higher decibel levels. A pleasant soundscape and a higher grade were associated with lower decibel levels. Because of the high number of recordings (N = 1882), the CIs (95%) were very narrow.

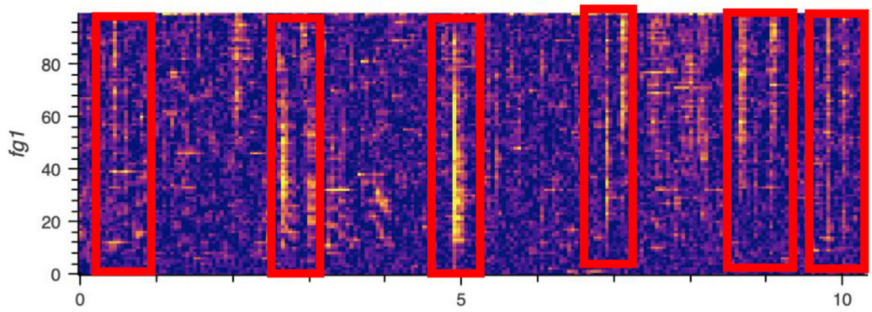
	Pearson *r* (95% CI)
Measurement period	0.02 (0.015, 0.018)
Pleasantness	−0.16 (−0.157, −0.154)
Eventfulness	0.45 (0.451, 0.453)
Complexity	0.39 (0.386, −0.389)
Range of affordances	0.35 (0.347, 0.349)
Overall mark	−0.23 (−0.230, −0.227)

Discussion

We did not analyze the sound recording before for several reasons. Microinterventions are intended to create a safe soundscape, that is, to reduce the number of stress-inducing sound-related events. As these events are usually of short duration, such a reduction is unlikely to affect the average loudness levels. Also, many microinterventions only affect how such an event is experienced, not the related decibel level, for example, announcing the use of a household appliance before switching it on. Only some interventions could be expected to measurably reduce the audible decibel level, for example, closing the door of the maintenance room when the washing machine is in use. Moreover, an increase in the number of pleasant sounds to make a soundscape less boring would counteract such a reduced loudness level. Even if, in contrast to our expectation, the changes in the soundscapes affected the average loudness levels, the probability that this effect was captured in these recordings is low (of the order of 1/500).

In addition, these effects are even harder to capture because of the questionable consistency of the audio recordings. The recordings were made with multiple smartphones that were not calibrated for loudness and were likely to use some sort of automatic gain-control (we noticed that the first 250 ms of each file were of lower loudness than the rest). Recording levels could therefore vary among the phones. Further, phones were sometimes put on the table during the recordings, whereas others were held in the hand. This influenced the recorded sound level and spectral tilt. Holding the phone also increased the risk of blocking the microphone.

Additionally, the recordings were contaminated by the nurses filling in the questionnaire simultaneously on the touchscreen. The typing on the touchscreen can be seen in the picture below, where every yellow line (outlined in red boxes) represents a sound of tapping the phone. These tapping sounds resulted in (partly) masking the background sounds that were actually audible in the environment. Also, the nurses sometimes moved the phone while touching the screen and this created relatively loud pulses that were (effectively) inaudible in the room but highly visible in the analysis. During the study, the same set of smartphones and the same processing procedures were used, so we can assume that the limitations were similar in all homes.



Close-up of a number of touch "sounds" in the first 10 seconds of a recording. [We used an auditory model (Gammachirp) with 100 channels and a log frequency axis between 30 and 11,000 Hz.[1] The picture is a filtered representation that enhances onsets and pulses.]

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