Get Ready for Activity – Ambient Day Scheduling with Dementia

Medical, psychological, and technological framework

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Authors:	Isabella Hämmerle, Walter Ritter, Guido Kempter, Josef Marksteiner, Elena Vanzo, Lisa-Marie Neier, Patrick Jost
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Project Coordinator:	University of Applied Sciences Vorarlberg (FHV), Austria
Project Partners:	Bartenbach GmbH Fachhochschule St. Gallen Apollis – Institut für Sozialforschung und Demoskopie O.H.G. Intefox GmbH Altersheim Stiftung Griesfeld EMT – energy management team AG CURAVIVA Schweiz Tirol Kliniken GmbH – Hall

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Preface

This document forms part of the Research Project "Get Ready for Activity – Ambient Day Scheduling with Dementia (GREAT)" funded by the AAL 2016 "Living well with dementia" funding program as project number AAL-2016-023. The GREAT project will produce the following Deliverables:

D1.1 Medical, psychological and technological framework

D2.1 Applicable hardware components

D2.2 Applicable software components

D2.3 Field tested hardware components

D2.4 Field tested software components

D3.1 Implementation report

D3.2 Field test report

D4.1 Communication strategy

D4.2 Stakeholder management report

D5.1 Report on market analysis

D5.2 Dissemination plan

D5.3 Intermediate business plan

D5.4 Exploitation plan

D5.5 Final business plan

D6.1 Consortium agreement

D6.2 Calendar year report 2018

D6.3 Calendar year report 2019

D6.4 Mid-term review questionnaire

D6.5 Final report

The GREAT project and its objectives are documented at the project website http://uct-web.labs.fhv.at. More information on GREAT and its results can also be obtained from the project consortium:

Prof. Dr. Guido Kempter (project manager), University of Applied Sciences Vorarlberg (FHV), Phone: + 43 5572 792 7300, Email: guido.kempter@fhv.at

Hermann Atz, Institute for Social Research and Opinion Polling OHG (APOLLIS), Phone: +39 0471 970115, Email: hermann.atz@apollis.it

Mag. Wilfried Pohl, Bartenbach GmbH, Phone: +43-512-3338-66, Email: wilfried.pohl@bartenbach.com

Quirino Nardin, Intefox GmbH, Phone: +43 699 1900 8889, Email: info@intefox.com

Dr. Marksteiner Josef, Tirol Kliniken Hall, Phone: +43 (0)50504 33000, Email: josef.marksteiner@tirol-kliniken.at

Mag. Tom Ulmer, University of Applied Sciences St. Gallen (FHS), Phone: +41 71 226 17 41, Email: tom.ulmer@fhsg.ch

Beat Sauter, energy management team ag (emt), Phone: +41 71 660 02 86, Email: beat.sauter@emt.ch

Anna Jörger, CURAVIVA Schweiz, Phone: +43 (0)31 385 33 45, Email: a.joerger@curaviva.ch

Cornelia Ebner, Stiftung Griesfeld, ÖBPB – APSP, Phone: +39 (0) 471 82 63 43, Email: cornelia.ebner@griesfeld.it

Content

1. Introduction

The main aim of this document is to provide an overview of the medical, psychological and technological framework of GREAT. The Deliverable D1.1 is the outcome of work package (WP) 1, focusing on the consolidation and integration of

- research findings regarding the course of dementia and typical symptoms as well as the effects of light, aroma and music interventions,
- interviews with formal and informal carers and care home managers of three caring institutions to gather information about the daily activities and routines of caring homes, learn more about people with dementia and their behaviour, challenges and problem solving in dealing with dementia patients and experiences with light, aroma and music treatment,
- Workshop with heads and managers of caring and nursing institutions and organisations
- technological developments and standards

The design of the GREAT system depends both on user needs and technical possibilities. Therefore, this document presents research and interview findings about psychological and behavioural symptoms and needs of people with dementia (PwD), the effects of light, scent and sound on PwD and also includes information about technological developments and standards. The collected information has been discussed and refined within the project consortium. The results will determine the design of the prototype and the use cases of field trials planned for the next project phase.

This document is structured as followed: After presenting basic statistical facts and models about demographic developments and dementia, chapter 2 presents typical dementia-related symptoms and difficulties for their carers in order to understand their needs and challenges better. After, the possibilities of light, sound and scent interventions to face behavioural and psychological symptoms of PwD are described on the basis of an extensive literature review and interviews with experts and informal carers. Possible pitfalls and rejections of the PwD and their carers towards AAL technology in general and the GREAT system will be considered.

The next section (chapter 3) deals with the requirements for the GREAT System. It lists concepts of the lighting industry, application of sounds and and deals with audible sound and ultrasonic and addresses the requirements in people´s homes as well as nursing homes.

It is followed by the technological framework, which gives an overview of current technological developments of software and sensor components that can be employed for our modular GREAT system (chapter 4).

Based on the cited literature, interviews, workshop results and experiences from previous projects (e.g. Guiding Light, West AAL), chapter 5 describes the basic aim of the GREAT System and concludes with specifications of the system.

2. The lifes of PwD and their carers

The project GREAT aims to develop, implement and validate a modular, persuasive ambient system to create appropriate indoor environment and prepare PwD for new or changing activities during the day and to prepare the system for market launch. The modular system will be composed of the three elements light, sound and scent. Market success and a high usability of the GREAT System will be achieved by taking into account the needs and behavioural and psychological symptoms (BPSD) of PwD as well as special challenges for carers and potential objections of the target users in this early project phase already. Therefore, an extensive literature review, interviews and workshops with target users and caring experts have been conducted by the consortium to gather information about the course and typical symptoms of dementia, the daily lives of PwD and their carers at home and nursing homes. Possible effects of light, scent and sound on PwD are also described in this chapter. This information forms the basis for the specification of the GREAT System.

2.1 Statistics about dementia and effects on the health systems

Europe becomes older - this is the main trend described by the most recent Demography Report from 2017 by the European Commission and Eurostat. Figure 1 reflects the population pyramids from 2001 and 2016: The proportion of people in the working age is shrinking while the relative number of those retired is expanding. A greater proportion of the "baby-boomers" are reaching retirement, which will increase significantly the share of older persons in the total population in the coming decades. The population age structure by major age groups from 2016 until 2080 is demonstrated in Figure 2.

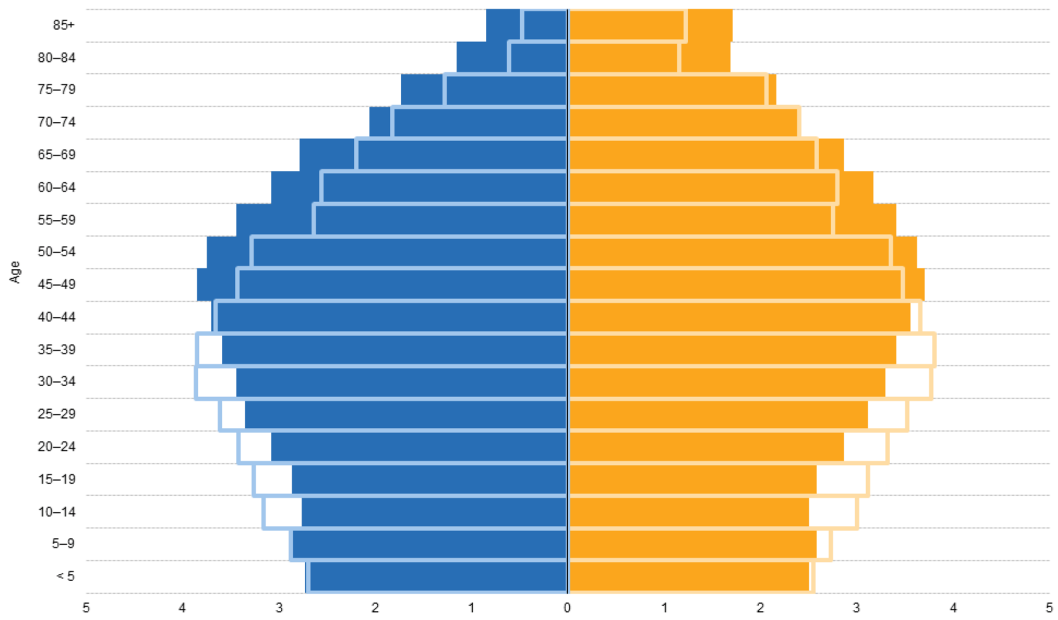


Figure 1: The graph shows the population in Europe-28 2001 (bordered) and 2016 (solid) for men (blue) and women (yellow) (Eurostat, 2017).

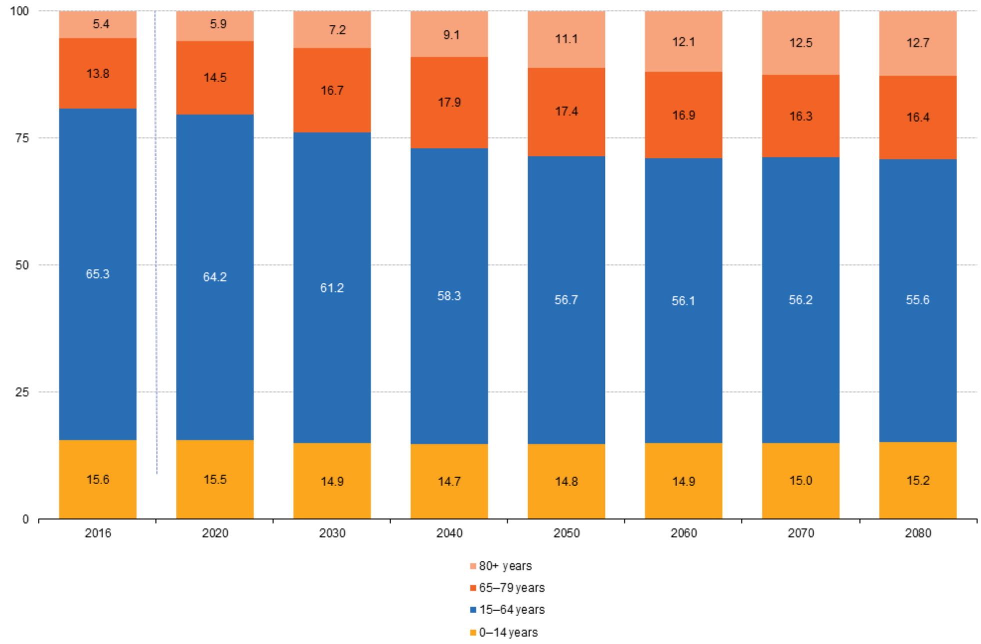


Figure 2: Average EU-28 age structured by major age groups from 2016 till 2080 (Eurostat, 2017).

This means a higher need for financial transfer from the younger taxpayers to the retired. If the baby boomers grow older in the 2040´s, our society will face a severe cost increase in caring for this ageing population, especially because the probability of developing diseases increases with age.

The incidence of dementia rises with age making it a common phenomenon in our aging population. The estimated annual incidence (rate of developing disease in one year) of the most common type of dementia – the Alzheimer type (AD) - appears to increase dramatically with age. From approximately 53 new cases per 1.000 people between 65 to 74 years, to 170 new cases per 1.000 people aged 75 to 84, to 231 new cases per 1.000 people aged 85 and above (Alzheimer´s Association, 2013). In Europe the amount of PwD is likely to double in the next generations and estimations for the worldwide development are 131.5 million PwD in 2050 (Prince et al., 2015). In Austria about 100.000 people have dementia (Österreichische Alzheimer Vereinigung, 2017) and extrapolations for 2050 assume about 260.000 PwD (Höfler et al., 2015). According to Alzheimer Schweiz (2017) 144.000 people in Switzerland suffered 2016 from dementia with estimations of 300.000 in 2040. For Germany those rates are about 1.5 million (2014) with assumed 3 million in 2050 (Bickel, 2016). The prevalence rate (estimated proportion of individuals in a given population that have a particular condition – in this case dementia – at a specific time) of dementia in EU-28 is about 1.55% of the population (Austria: 1.73%, Germany: 1.92%; Switzerland: 1.73%) (Alzheimer Europe, 2013).

This high increase in dementia is a severe threat for the financial feasibility of the caring system, since the estimated direct and indirect costs of dementia in Germany are about 25-30 billion euro per annum (Jahn, 2010). Prince et al. (2015) report a global societal economic cost of dementia of US$ 818 billion and assume that the costs will rise up to around US$ 2 trillion in 2030 (taking into account annual inflation).

About two thirds of residents in Austrian, German and residential care units suffer from dementia (Bartelt, 2012; Wancata et al., 2001; Weyerer & Bickel, 2007). This means the healthcare systems have to face even greater challenges in the future, since caring for PwD means greater efforts especially because of related behavioural and psychological symptoms (BPSD) than caring for elderly without dementia. Many informal caregivers like family members suffer from health problems (Vitaliano, Zhang & Scanlan, 2003) due to the burden of caring, and the behavioural changes in those they care for e.g. aggression, wandering or apathy often decrease social interaction (Thomas et al., 2006). This can cause a breakdown in the relationship or burnout of the caregiver and BPSD are therefore one of the reasons for transition to residential care (Cunningham, McGuinness, Herron & Passmore, 2015). This in turn generates high costs for the PwD, their families and society as a whole.

If we manage to equip private households (and caring institutions) with technology that contributes to an indoor environment that suits the needs of PwD and therefore decrease BPSD, it would help their caregivers to look after them at home for a longer time and ease the burden of caring in institutions. This can spare costs and contribute to manage the challenges of the demographic change much better.

2.2 Dementia: Course of disease, related symptoms and challenges for caregivers

2.2.1 Course of dementia and typical symptoms

Dementia is in most cases a progressive, chronic disease. It is distinguished between different types of dementia, because the clinical symptoms can be due to a variety of underlying pathophysiological processes (e.g. neurodegenerative changes, vascular processes, internistic disorders, malnutrition, substance abuse). Alzheimer´s dementia (AD) (neurodegenerative) is the most common type (50-75%) followed by vascular dementia (20%), dementia with Lewy bodies (5%) and frontotemporal lobar dementia (5%). Other causes for dementia are Huntingdon´s disease, HIV/AIDS, Parkinson disease or Creutzfeld-Jakob disease (Cunningham, McGuinness, Herron & Passmore, 2015; Kopf & Roesler, 2013).

Primary dementias are types which can be affiliated to organic brain changes (e.g. AD, Lewy bodies) not directly related to any other organic illness. About 85% of dementia diseases are primary dementias and usually irreversible and incurable. The so called secondary dementias are those caused by other diseases, like HIV, chronic alcohol abuse or head injury (Jahn, 2010).

Dementia can be categorised according to the aetiology and the severity of the disease. The severity usually is distinguished in three stages: early stage, middle stage and late stage (Förstl, 2005). Beforehand, often a mild cognitive impairment (MCI) is diagnosed, which is likely to be a precursor to dementia (Lyketsos et al., 2002). The course of the disease is characterized by a progressive lost of cognitive functions, gradually deterioration of autonomy, upcoming psychopathological symptoms like apathy, aggression, hallucination etc. ending in need for care and neurological complications (Förstl, 2005). The average duration for the Alzheimer type is about 6 years, but depends on the age of the patient. In many cases the patients spend the last stage in caring institutions. Not only due to the loss of the autonomy caused by cognitive symptoms but also because of the behavioural changes, which can be very challenging for caregivers (Jahn & Werheid, 2015).

Because of the different aetiologies, other diseases with similar symptoms and age-related deterioration of cognitive functions, the diagnosis of dementia has to be done carefully. ICD-10, the international classification of diseases and DSM-V, the diagnostic and statistical manual of mental disorders, include guidelines for the diagnosis of dementia. For the Alzheimer´s disease, deterioration in memory is a typical symptom, manifesting for example in repetitive questioning because of problems to learn new information. Impairments in at least one other cognitive domain, e.g. language, judgment, abstract thinking, and executive functioning is required for a diagnosis. The duration of the symptoms and progressive course, effects on activities of daily life and changes in emotional and social behaviours are also important indicators for the diagnosis (Falkai et al., 2015; Dilling, Mombour & Schmidt, 2015).

Besides the widely known memory loss most PwD develop behavioural and psychological problems (BPSD) in the course of the disease. BPSD include signs and symptoms of disturbed perception, thought, mood or behaviour. According to the study of Lyketsos et al. (2002) the most common BPSD in PwD are apathy (36%), depression (32%) and agitation/aggression (30%), whereby the prevalence estimates were similar in AD and non-AD. Other studies found also apathy and depression to be the most frequently occurring BPSD, but anxiety was more frequent than agitation/aggression (Robert et al.; 2005; Steinberg et al., 2008). Overall clinically significant BPSD occur in about a third of persons with MCI and in about two thirds of PwD with more severe impairments (Lyketsos et al., 2000; Lyketsos et al., 2002). With the progress of the disease BPSD usually are more likely to occur.

BPSD not only contribute significantly to caregiver burden (Thomas et al., 2006), but also decreased quality of life (Thomas et al., 2006) and institutionalisation (Cunningham, McGuinness, Herron & Passmore, 2015).

Table 1 shows a list of typical symptoms of AD at different stages of dementia. It combines several literature sources, interviews with caregivers and personal experiences of members of the project team working with PwD.

		MCI	Mild dementia	Moderate dementia	Severe dementia
Cognitive Symptoms	memory	semantic memory: capitals, vocabulary, names (problems finding words), wordlist recall and discrimination, losing things, slight impairment of episodic new memory: events (confabulations)	semantic memory: capitals, vocabulary, names (problems finding words), wordlist recall and discrimination, losing things, impairment of episodic new memory: events (confabulations)	semantic memory: capitals, vocabulary, names (problems finding words), wordlist recall and discrimination, losing things, moderate impairment of episodic new memory: events (confabulations)	semantic memory: capitals, vocabulary, names (problems finding words), wordlist recall and discrimination, losing things, severe impairment of episodic new memory: events (confabulations)
	language	problems findings words	Degredation of speech contents (short sentences, gramar fails), language understanding impaired, difficulties in expression	Degredation of speech contents (short sentences, gramar fails), language understanding impaired, repetition commonly unimpaired	mutism with intermittant short expressions
	temporal orientation	slight impairment possible	Slightly impairment	Moderate to severe impairment	total temporal disorientation
	spatial orientation	slight geographical disorientation possible	slight spatial disorientation	Getting lost in non familiar spaces, spatial orientation often impaired	getting lost in familiar spaces, no independent operations in space possibe, total spatial disorientation
	situative orientation	not impaired	not impaired	not impaired	impaired
	personal self orientation	not impaired	not impaired	not impaired	impaired
	apraxia	slight impairment in planing and problemsolving	Slight impairment in planing and problemsolving of complex tasks e.g. financials	Moderate to severe impairment of planing (ideatoric apraxia) and problemsolving, ideomotoric apraxia	no independent operations possible
	alexia (reading, writing)	slight impairment possible	slight impairment	severe impairment	very severe impairment
	mental arithmetic	slight impairment possible	slight impairment	moderate impairment	very severe impairment
	concentration/alertness	Slight impairment of concentration	moderate impairment of concentration	moderate impairment of concentration	severe impaired concentration

		MCI	Mild dementia	Moderate dementia	Severe dementia
NonCognitive Symptoms	sleep/circadian rhythm	common, less SWS, longer sleep latency, higher arousability/awakenings, less sleep effenciency, daytime sleepiness, early bedtimes and early awakening, tendency towards decreased REM	common, less SWS, longer sleep latency, higher arousability/awakenings, less sleep effenciency, daytime sleepiness, early bedtimes and early awakening, tendency towards decreased REM	impaired sleep/wake cycle, fragmented sleep, less SWS, longer sleep latency, higher arousability/awakenings, less sleep effenciency, daytime sleepiness, early bedtimes and early awakening, tendency towards decreased REM	impaired sleep/wake cycle, fragmented sleep, less SWS, longer sleep latency, higher arousability/awakenings, less sleep effenciency, daytime sleepiness, early bedtimes and early awakening, tendency towards decreased REM
	mood	anxiety, depression, gloominess	anxiety, depression, gloominess	anxiety, depression, gloominess	anxiety, depression, gloominess
	agitation (verbal und physical aggression, "wandering", "hoarding"	none	common	common	common
	apathy	none	common	common	common
	personality	social withdrawal	social withdrawal	moderate personality changes, suspicion common	very severe personality changes, suspicion common
	incontinence	none	none	possible	present

Table 1: Source: own illustration according to (Cerejeira, Lagarto & Mukaetova-Ladinska, 2012; Jahn, 2010; Kopf & Rösler, 2013; Mace & Rabins, 2017; Seidl et al., 2007; Wächtler, 2003; Expertinterviews).

Environmental influence on BPSD

The physical environment seems to play an important role for PwD since they have an increased sensitivity to their surroundings because their ability to understand the implications of sensory experiences is reduced. Therefore, it´s likely that BPSD can be triggered by environmental stimuli (Cohen-Mansfield, 2001; Lawton & Nahemow, 1973; Sloane et al., 1998). Environmental determinants have for example been linked to agitation (Onega et al., 2016; Sloane et al., 1998), orientation (Namazi, Rosner & Rechlin, 1991; Nolan, Mathews & Harrison, 2001), sleep patterns (Gasio et al., 2003; McCurry et al., 2011) and aggression (Opie et al., 1999) among demented persons.

Different authors highlight the importance of the physical environment of care settings for demented people (Topo & Östlund, 2009; van Hoof & Kort, 2009) and that the modification of the environment can be a useful strategy to reduce dementia related symptoms (Cohen-Mansfield, 2001; Tilly & Reed, 2008; Weitzel et al., 2011; van Hoof et al., 2010). Current guidelines also recommend that dementia symptoms should first be treated with non-pharmacological interventions followed by the least harmful medication (Gauthier et al., 2010; Azermai et al., 2011).

According to O´Neil et al. (2011) non-pharmacological interventions can be classified as follows: 1) cognitive/emotion-oriented interventions (reminiscence therapy, simulated presence therapy, validation therapy), 2) sensory stimulation interventions (e.g. aromatherapy, light therapy, massage/touch, music therapy, Snoezelen multisensory stimulation), 3) behaviour management techniques and 4) other psychosocial interventions.

Within GREAT we aim to develop a modular system that contributes to a more appropriate environment for PwD and sensory stimulation with light, scent and sound.

2.2.2 Challenges for caregivers

Formal and informal carers play an important role in dealing with dementia. In a survey conducted for formulating the Swiss Strategy for Dementia (Bundesamt für Gesundheit, 2013), it has been shown that about 50% of people who suffer from dementia are living at home and are cared for by their family members (2/3 by spouse or children) and friends or neighbours. The amount of care required depends on the progress of the disease and varies from selective interventions at the beginning (43%) to continuous round-the-clock care in 10% of cases when the disease is more advanced.

Caring for someone usually is associated with different types of burdens like impacts on physical and mental health and lack of time for other things. Looking after someone with dementia affects the live of a carer even greater than other types of caring - more hours of caring per week are necessary, employment complications occur more often, impacts on mental and physical health are larger and conflicts with family members are more likely (Ory et al., 1999). Even the mortality in carers looking after someone with dementia is increased (Schulz & Beach, 1999).

Many negative effects of caregiving for PwD are associated with BPSD which affect about two thirds of PwD (Lyketsos et al., 2000; Lyketsos et al., 2002). BPSD are for example associated with decreased quality of life (Banerjee et al., 2005; Thomas et al., 2006), caregiver burnout (Ballard, Day, Sharp, Wing, & Sorensen, 2008) and health problems (Vitaliano, Zhang & Scanlan, 2003). According to Banerjee et al. (2005) BPSD are associated with quality of life three times as strongly as cognition.

Over 70% of informal carers would like or rather – are in need of - more assistance, especially when it comes to organising everyday activities (Bundesamt für Gesundheit, 2013). With our solution we respond to this need and thus help delay the relocation to a nursing home or hospital as long as possible.

We also aim to support the caregivers by making use of the concept of emotional contagion. This concept implies that the behavior of a person who represents a certain mood evokes a similar mood in other people, whereupon this mechanism works unconscious (Lorenz & Leyhausen, 1968; de Gelder, 2006; Osvath & Sima, 2014). Emotional contagion occurs when people start feeling similar emotions caused merely by the association with other people. You start feeling agitated, because other people around you are agitated or you start feeling depressed because you are in a crowd of people feeling depressed. Emotional contagion however does not require that one is aware of the fact that one experiences the emotions because other people experience them, rather one experiences them primarily as one's own emotion. Neuroscientists found that the so called “mirror neurons” play an important role in social contagion (Gallese, 2001; Keysers, 2011). With the help of the term “mirror neuron” scientists refer to the fact that there is significant overlap between neural areas of excitation that underlie our observation of another person's action and areas that are stimulated when we execute the very same action. A similar overlap between neural areas of excitation has also been established for our recognition of another person's emotion. This mirror neuron based behaviour is especially effective on PwD (Moretti et al., 2014; Lee et al., 2013). Since we create room ambiences, not just the PwD but also the caregivers benefit of certain room atmosphere and may feel more relaxed and convey their own mood and behavior on the PwD. The principal of the concept is illustrated in Figure 3.

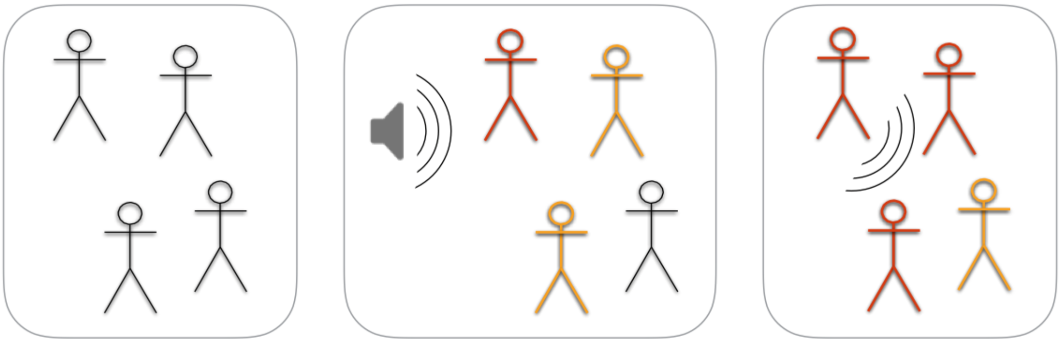


Figure 3: Illustration of our concept of emotional contagion

2.2.3 Daily routines in nursing homes

Part of the conducted interviews with carers and care home managers was to gather insights of the daily routines in a care home due to better understand how and when interventions of the GREAT system should be applied and designed.

All care homes follow more or less the same routine:

- Breakfast together starts around 7:00 – 7:30 am
- After body hygiene and different therapies, but this is very individual
- Lunch together starts around 11:00 – 12:00
- After lunch resting until 13:30 – 14:00
- Start of afternoon coffee varies from 13:30 – 15:00
- Therapies and activities till 16:00
- Dinner together starts around 17:00 – 18:00
- Going to bed around 20:00

In Figure 4 a typical therapy plan for one week is illustrated.

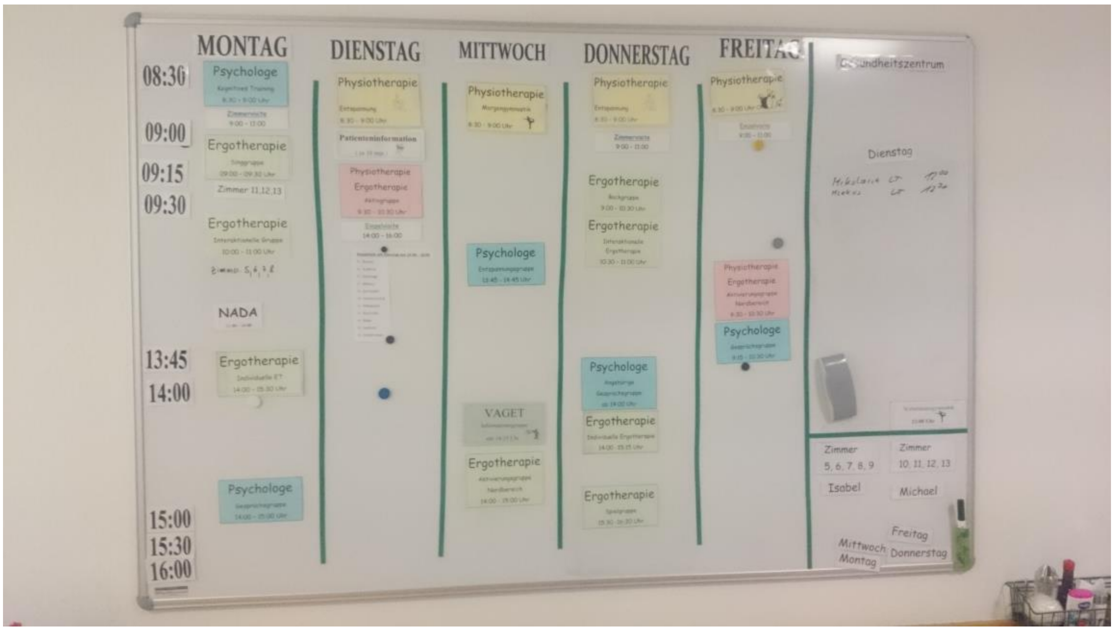


Figure 4: Therapy plan for one week in the "Tirol Kliniken Hall"

2.3 Effects of light, sound and scent on PwD and experiences in caring institutionalizations

In this chapter we describe age-related changes in seeing, hearing and smelling and how light, sound and scent are used as non-pharmacological interventions and their effects on PwD.

We conducted a literature review concerning the effect of light on PwD and one review which included only systematic reviews concerning the effect of light, sound and scent interventions in PwD. Description of detailed results and methodological approaches can be found in the appendix. Further literature reviews were done for the effect of sound and scent interventions on PwD. This results are displayed in an excel matrix which is also part of the appendix. The findings of the literature reviews are supplemented by the results of the interviews with caregivers and experts.

2.3.1 Light

The illumination standards DIN 5035-3 and DIN EN 12464-1 formulate the minimal requirements for hospitals concerning lighting, e.g. 100 lux for general illumination and for sleeping rooms. In these standards only the necessary light quantity for visual reception is considered but any recommendations concerning the light colour are not included. Like the national standards, international illumination standards also don´t consider age-based requirements for illumination, although it is known that with age the visual sense deteriorates. Usually the need for light is increased, glare sensibility is higher and an increased brightness homogeneity is required. And even more, illumination does not only support visual perception, but also safe mobility and the circadian rhythm and is the most important "Zeitgeber".

The importance and interest of the effect of light for elderly people can be seen in the enormous amount of studies that already focus on light treatments in elderly to improve health, mood, behaviour and cognition. But research in persons with dementia is still sparse.

There are different kinds of light treatments that can be distinguished. The most commonly used approach is light with high illuminance reaching the eye of an observer (bright light approach). Intensities can vary but usually bright light therapy uses vertical illuminance (at the eye level) of 2,500 Lux applied for 2 hours or 10,000 Lux applied for 30 minutes. Other approaches focus on variations of colour temperature, expecting different results if high or low colour temperatures are applied during the day. Usually colour temperatures below 3000 Kelvin (K) are classified as “low” while colour temperatures higher than 3000 K are classified as “high”. Additionally, there is an approach focusing on variations of light illuminance in the morning and evening, simulating natural light conditions provided during dawn and dusk. Dawn-dusk-simulations start to intensify light levels in the early morning from a very low level to awake a sleeping person and end the day in the evening with a reduction in light levels to prepare a person for going to bed.

In the following studies examining the effect of different light interventions on PwD are described as well as a short summary of interviews conduct with informal and formal caregivers.

Since PwD show a disturbed sleep-wake rhythm, restlessness and wandering, which are a high burden for caregivers, improvement of this symptoms would be a big relief for PwD and caregivers. It seems like bright light has a positive impact on sleep and the circadian rhythm of PwD (Ancoli-Israel et al., 2002; Ancoli-Isreael et al., 2003; Dowling et al., 2005; McCurry et al., 2011; Sloane et al. 2007; van Hoof et al., 2008; van Someren, 1997; Yamadera et al., 2000) when exposed to at least 1800 Lux at the eyelevel for 2 hours. Morning bright light (~9-11 am) and all-day bright light (~10-11 hours) applications seem to be most effective, while exposure to evening bright light showed inconsistent findings. Bright light interventions not only influence the circadian rhythm but can also affect behaviour and cognitive functioning. However, findings are somewhat inconsistent. Some studies showed a decrease in agitation (Figueiro et al., 2014; Onega et al., 2016; van Hoof et al., 2008) or delay of agitation acrophase by 1.63 hours (Ancoli-Israel et al., 2003), reduced depression scores (Onega et al., 2016) and positive effects on cognitive functioning (Graf et al., 2001; Nowak et al., 2011; Riemersma-van der Lek, 2008; Yamadera et al., 2000) whereas Dowling et al. (2007) van Hoof et al. (2009) and Barrick et al. (2010) found that bright light interventions had negative effects on the behaviour of PwD (increased agitation, anxiety and depression). Gender may play a role in the effectiveness of bright light treatment, since Hickman et al. (2007) found negative effects of morning and all-day bright light on men`s mood and a not significant positive trend of morning bright light on women's mood. Even though many studies found positive effects of bright light interventions on cognitive functioning, Forbes et al. (2014) couldn´t proof those findings in their review.

But near-infrared could be another approach to improve cognitive functioning, since Saltmarche et al. (2007) found near-infrared light to have positive effects on cognition in mildly to moderately demented people. Consistent bright light sources may also help to eliminate frightening shadows, avoid distraction and lessen hallucinations (Turner, 1991) and support certain activities like reading (Cluff, 1990). Brush et al. (2002) showed that higher light levels in a caring institutionalisation for PwD resulted in higher caloric intake and more conversations during meals.

Besides bright light treatment another intervention approach is the variation of the colour temperature, but so far findings are inconsistent. Figueiro et al. (2014) found positive effects on circadian rhythm and decreased depression scores with a high colour temperature (colour temperature CCT = 9.325 K) and van Hoof et al. (2008) and Figueiro et al. (2014) reported improvements in agitation, whereas van Hoof et al. (2009) didn´t find any positive effects of variable colour temperature (CCT ~2700 vs. ~4500 K) on circadian rhythm and found increased agitation and other negative effects. Similar are the results of Barrick et al. (2010) who reported increased agitation in PwD with a CCT ~6,500 K. Sloane et al. (2015) didn´t find any effects of high colour temperature (CCT = 13.000 K) on patients but on the subjective perception of caregivers.

According to the results of Gasio et al. (2003) Dawn-dusk-simulation could be an effective treatment to enhance the sleep quality of PwD. But further research is necessary to confirm this results.

Additional to this literature overview interviews with informal carers, professional carers and care home managers of health care institutions - the dementia and psychiatric stations of the "Tirol Kliniken Hall", the care home "Stiftung Griesfeld", which has a extra unit for demented persons and the care home "Helios Goldach"- were conducted. The results indicated that light plays an important role, not only for PwD, but also for caring tasks and some wished for brighter light, especially in the common areas. One station of the Tirol Kliniken Hall is taking part in a light study at the moment and the interview partners reported subjective perceived positive effects of the installed light. One formal carer stated that he has the feeling, the PwD are going to well lit places and one informal carer also reported, that light is very important for her demented mother and she always likes her rooms well lit. In the care home Helios Goldach they are also already using light interventions. The light in the common areas is operated automatically but can also be operated manually. The manual overriding for example is used if the patients are very restless – then a relaxing light is activated. The subjective impression of the care home manager regarding the light is that the patients and the caring staff benefit a lot, particularly patients with more severe dementia.

Summary

In the course of light interventions most promising seems to be bright light intervention to improve sleep, circadiane rhythm and cognitive functioning of PwD. Results on the effectiveness of light interventions on mood/depression, aberrant behaviour and agitation are very inconsistent as well as the impact of colour temperature on PwD. It also has to be taken into account, that most described studies had limitations like small sample sizes, only subjective ratings, no specific diagnosis of dementia or ratings of disease severity were not assessed. Nevertheless, there are many hints in the literature that with optimized light situations and light treatments the life of PwD and their carers can be enhanced. Furthermore, the responses of the interviewed carers support those results.

2.3.2 Sound

Humans only can notice acoustical events in a certain frequency spectrum and at certain sound pressure levels (from 20 hertz (hz) to 20 kilohertz (kHz)). The sound above the audible level is called ultrasonic (Hagendorfer et al., 2011). All audible natural sounds also include non-audible ultrasonic. The physiological and psychological effect of this non-audible sounds on humans are called „hypersonic effect“ (Oohashi et al., 2000). Figure 5 shows the frequency spectrum of a water drop which reaches from about 100 hz to 500 kHz.

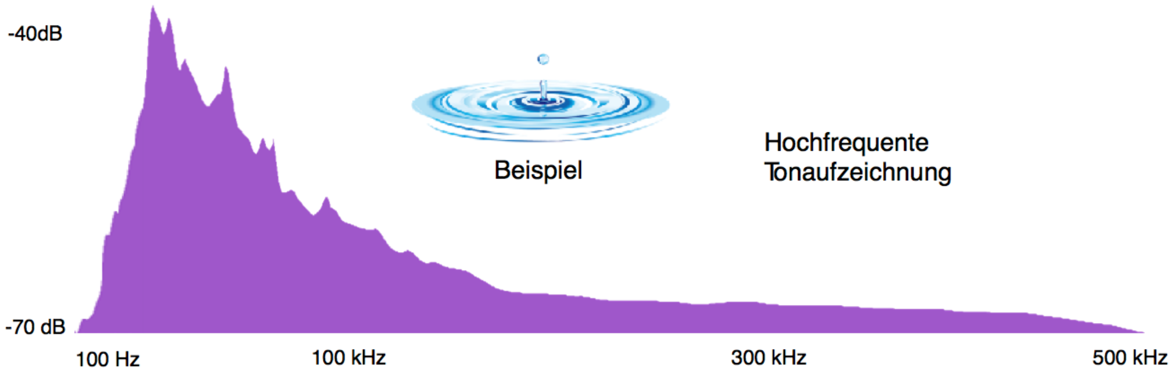


Figure 5: Frequency spectrum of a water drop; the area between spotted lines indicates the audible frequency spectrum of humans

With age the threshold of audibility decreases, usually from about 20 kHz to 12 kHz (Hagendorfer et al., 2011). This loss is mostly compensated by a combination of increased attention, lip reading and extrapolation of the things understood, which is pretty hard for PwD (Hyde, 1989). Therefore, extra attention needs to be paid to the acoustical environment of PwD.

Music has been used for centuries in different cultures as a medium of therapy and has developed as a clinically applied treatment – music therapy – over the last fifty years and is now accepted as a science and profession in some countries (Bonde &

Wigram, 2002). Music therapy can be applied in a variety of ways (e.g. playing, singing, creating, listening) and uses music and it´s elements (e.g. sound, rhythm, melody and harmony) to improve physical, social, communicative and emotional health and wellbeing (World Federation of Music Therapy, 2017). Regarding dementia music seems to play an important role, since the musical memory may is not affected in some forms of dementia (Cuddy & Duffin, 2004). O´Neil et al. (2011) conducted a review on the effectiveness of non-pharmacological interventions for PwD and found that individuals with dementia may retain the ability to sing old songs and musical abilities appear to be preserved in some individuals despite aphasia and memory loss.

Physiological reactions of music strongly depend on the individual disposition of a subject, nevertheless the reactions can be roughly categorised as follows (Evers, 1991): polyphonic music in major with dissonance and staccato sound, with great envelope, accented rhythm and dramatic character evokes a „sympathetic tone“ with increasing blood pressure, muscle tension, respiratory and heartbeat frequency and decreasing peripheral blood circulation and digestion activity as well as dilated pupils. Homophonic, consonant music in minor with legato sound, small envelope, melodic rhythm and lyrical character evokes a „parasympathetic tone“ with sloping blood pressure and skin resistance, decreasing muscle tension, respiratory and heartbeat frequency and increasing gland and digestive activity as well as small pupils.

There is a great body of research dealing with the effect of music treatment in general, but also on PwD. Many of them are measuring the effect of music therapy on behaviour (e.g. agitation, apathy and aggression) mood (e.g. depression and anxiety) or cognitive functioning. Contrary to the amount of literature in the field of audible music, studies measuring the effect of ultrasonic are rare and none were found including PwD.

The literature review showed that many studies and reviews examining music treatment were concentrating on the modulation of agitation and most of them showed positive effects (Abraha et al., 2017; Blackburn & Bradshaw, 2014; Millan-Calenti et al., 2016; Lin et al., 2011; Livingstone et al., 2014; Raglio et al., 2008; Raglio et al., 2010; Sung et al., 2012; Ueda et al., 2013) but Cooke et al. (2010) didn´t find any effect and the review of Brasure et al. (2016) reported insufficient evidence to draw conclusions on the effectiveness of music therapy (and other non-pharmacological therapies). Music therapy also seems to have positive impacts on apathy (Raglio et al., 2008; Raglio et al., 2010; Brodaty & Burns, 2012), aggression (Abraha et al., 2017; Blackburn & Bradshaw, 2014; Sung et al., 2012), anxiety (Abraha et al., 2017; Raglio et al., 2008; Raglio et al., 2010; Ueda et al., 2013; Zhang et al., 2017), depression (Blackburn & Bradshaw, 2014; Chu et al., 2014; Raglio et al., 2010, Zhang et al., 2017), nocturnal disruptions (Raglio et al., 2008) and disruptive behavior in general (Zhang et al., 2017). Blackburn & Bradshaw (2014) and Chu et al. (2014) even reported that music therapy can improve cognitive functioning and Zhang et al. (2017) found in their review positive trends supporting the use of music therapy for the treatment of cognitive function and enhancement of quality of life. But like for agitation there are also hints that music therapy may isn´t an effective treatment for aggression (Brasure et al., 2016), depression (Raglio et al., 2010), nocturnal disruptions (Raglio et al., 2010) and wandering (Robinson et al., 2007).

Since our project is dealing with passive sound interventions the effect of ambient music and nature sound is described more detailed in the following. With ambient music and nature sound a stimulating, secure environment should be created that supports to meet social and emotional needs and reduce challenging behavior of PwD (Cohen-Mansfield, 2001). Padilla (2011) concluded in his systematic review on the effect of ambient music on agitation, examining six systematic reviews and one nonrandomized controlled study, that ambient music may indeed helps decrease agitation and can indirectly contribute to improved attention, but the effect is modest. Burgio et al. (1996) were examining the effect of listening to environmental white noise (mountain stream, ocean waves) and found a reduction of 23% in verbal agitation in severe demented nursing home residents. A review of Opie et al. (1999), analysing studies using music in residential institutions, found that listening to preferred music during various activities had positive impacts on aggressive behavior (e.g. abusive language, verbal and physical resistance). The power of preferred music is also reported by Garland et al. (2007). They compared the effect of three different audiotapes (favourite music, scripts prepared by a family member, non-emotive reading from a gardening book) the participants were listening to. All three interventions reduced verbal and physical agitation, but favourite music had the strongest effect on levels of physical agitation. Background rhythmic music can also enhance the participation in social and other activities (Groene, 2001; Mathews, Clair & Kosloski, 2001). The results of an observational qualitative study indicate that background music increase positive social interactions (smiling, talking, eye contact) and decrease negative behaviors (aggression, agitation) (Ziv et al., 2007).

Besides this mostly positive reports of music and sound interventions on PwD it has to be taken into account, that the effects of ambient music or sound seem to be strongest during or immediately after a session, but evidence for long-term effect is lacking (Livingstone et al., 2005; Opie et al., 1999; O´Neil et al., 2011).

The results of the interviews conducted with caring staff showed that experiences with professional music therapy are lacking but activities including active or passive use of music, like playing and singing together or simply listening to music, are common. One interview partner reported very positive reactions of the PwD during musical activities, e.g. they come to life and smile while singing old songs they know.

Although it is generally accepted that humans cannot perceive sounds in the frequency range above 20 kHz, there are evidences that "inaudible" low-frequency ultrasound may affect people. Oohashi et al. (2000) showed, that noninvasive physiological measurements of brain responses indicate significant effects in the brain activity of listeners of sounds containing high-frequency components above the audible range. Additionally, psychological evaluation indicated that the subjects felt the sound containing high-frequency components to be more pleasant than the same sound lacking these components.

When they compared the natural sound environment of uninhabitated forests against an artificial urban environment, we will find, that urban noises (indoor and outdoor) are mostly concentrated in the audible range, and natural environments are rich in inaudible low-frequency ultrasounds. The parts of the human brain which are activated by natural noises play an important role in various modern-day neurodegenerative disorders such as with PwD.

Several authors have investigated whether ultrasound changes our audible impressions when we listen to music. Higuchi et al. (2009) and Nishiguchia et al. (2009) showed when sounds played back with and without ultrasound that we can distinguish between the two of those sounds by subjective estimations, whereas Kamada & Toraichi (1989) showed that ultrasonic components influenced psychological attributes like distinctness, brightness, and loudness of tones (see also Unger, 1999). Following this approach, Honda (2015) has accumulated evidence through basic research as well as clinical researches with the aim of developing a treatment for PwD.

Humans can also detect ultrasound up to at least 100 kHz when the ultrasonic source has direct contact with the body. Lenhardt et al. (1991), for example, transmitted sound within ultrasonic range at 28kHz and 40kHz through transducers which were attached to the skull. The results suggested that words were perceived as speech. Ultrasound sets the brain into forced vibration, and it is the brain oscillation that is detected on the base of the cochlea in normally hearing individuals. In this situation, it could be that the body is acting as a demodulator of the ultrasonic vibrations.

Similarily, the apparatus called „neurophone“ works by stimulating parts of the brain through the administration of ultrasonic waves with 20-100 kHz directly onto the skin. Research has shown increases in speech reception as a result of this transdermal stimulation (Hughes et al., 1974). Puharich & Lawrence (1969) conclude that the high frequency in the ultrasonic content has the effect of increasing blood flow of the brain. Following this approach, promising preclinical studies have demonstrated that focused ultrasound can reduce the number of plaques and improve cognition in PwD (Meng et al., 2017).

Summary

Although there are many studies concluding that music therapy has positive effects on challenging behavior like agitation, apathy and aggression and also seems effective to reduce anxiety and depression it has to be taken into account, that many of those studies had methodological limitations like sample size, measurement issues and length and quantity of the music therapy sessions were differing a lot. Also the way music therapy was conducted differs a lot, from group settings to individual treatment, from singing and playing instruments to simply listening to music or nature sounds. A generalization of the results therefore is very difficult. It also has to be mentioned, that most studies only showed short-term effects, but no long-term changes. Nevertheless, there are many hints that active music interventions and listening to background music or nature sound have positive impacts on PwD and therefore we include music, respectively sound, in our GREAT system and test it´s effect on PwD.

Furthermore, from the presented findings we believe that air vibration components exceeding the upper limit of the human audible range, which are abundant in the natural environmental sounds but which are markedly absent from the artificial environment of modern rooms, might help to optimize the deep brain activity and contribute to the prophylaxis and treatment of PwD.

2.3.3 Scent

The human olfactory sense usually decreases with a certain age and some people loos this sense completely within the process of aging. The odour detection threshold differs individually, but can be decreased by training. To recognize a certain scent a much higher concentration is needed than for the detection. The ability to recognize a scent decreases after the first 30 seconds but is constant afterwards for a long time. Scents have a high resistance to extinction, usually humans remember them very well and for a long time. With the exposition duration the perceived intensity of a scent decreases. This is due to the fact that the olfactory sense mainly detects changes. This adaption process differs from person to person but takes about 20 minutes. After this time a scent molecule isn´t recognized any more although it still reaches the mucous membrane (Hagendorfer et al., 2011).

Memories evoked by scents are called "autobiographical odor memory" by Willander and Larsson (2006). Those memories are mostly emotional due to the fact, that the limbic system ("centre for emotions") is next to the system where scent stimuli are processed in the brain (Hagendorfer et al., 2011; Willander & Larsson, 2007). The strongest reactions to scent stimuli are emotional appraisals in terms of positive or negative reactions (Hagendorfer et al., 2011). The individual construction and appraisal of scents include inhere as well as learned preferences and aversions (Pudel, 2005; Chambers & Bernstein, 2003, cited by Heckel, Rester & Seeberger, 2012). In the course of life scents get individual emotional and autobiographical meanings (Heckel, Rester & Seeberger, 2012). Therefore, reactions to certain scents are highly individual and have to be taken into account when using aromas in a therapeutic way.

Certain scents are described to have specific effects. They can be relaxing (e.g. anise, geranium, chamomile, lavender, rose, ...) or stimulating (e.g. citronella, melissa, peppermint, tangerine, ...) and can trigger physiological reactions like muscle relaxation (Gobel et al., 1994), changes in heart and respiratory frequency and blood pressure (Hongratanaworakit et al., 2006), beta-activity of the brain (Diego et al., 1998) and the plasma-hormone-concentration (Kawakami et al., 1997).

In care the effects of odours are systematically used to enhance the wellbeing of patients. Professional aromatherapy is the practice of inhalation or bodily application of fragrant essential plant oils for a therapeutic purpose. Among non-pharmacological treatments aromatherapy is reported to be one of the most widely used treatments for PwD (Cohen-Mansfield, 2001). The interviews we conducted in the care institutions showed that the use of aromas is popular among most institutions and different ways of applications are used, e.g. vaporisers, diffusers, body massages, baths and sniffing. When dealing with PwD the type of application has to be considered carefully since they can be a source of danger (Warner, 2000).

Studies testing the impact of aromatherapy as a non-pharmacological intervention to deal with symptoms of dementia are similarly diverse and face likewise methodological issues (small simple size, different types of interventions, lack of control of intervening variables, ...) as light and music therapy.

As for music therapy agitation was addressed in many studies and showed mostly positive effects (Ballard 2002; Holmes et al., 2002; Kaymaz & Ozdemir, 2017; Lin et al., 2007; Moorman et al., 2017; Smallwood et al., 2001; Yang et al., 2015) but some studies also didn´t find any enhancement of agitation after the application of aromatherapy (Burns et al., 2011; Fu, Moyle & Cooke, 2013). Besides agitation other BPSD improved in the studies of Ballard et al. (2002) and Kaymaz and Ozdemir (2017) after aromatherapy. Johannessen (2013) found improved insomnia and decreased anxiety using lavender diffusion during the night and Yang, Wang and Wang (2016) reported decreased depression scores after aromatherapy massage. Jimbo et al. (2009) used rosemary and lemon essential oils in the morning and lavender and orange in the evening as an intervention for PwD. The results showed significant improvement in personal orientation of patients suffering from different forms of dementia. Kaymaz and Ozdemir (2017) also found decreased caregiver burden and distress after the use of essential oils applied by inhalation or hand massage. Although several studies found positive effects on typical symptoms of dementia there are also studies that don´t support this results. Fu, Moyle and Cooke (2013), Moorman et al. (2017) and Burns et al. (2011) reported no impact of aromatherapy on BPSD like wandering/restlessness, anger and aggression and anxiety. Burns et al. (2011) also measured the effect of aromatherapy on activities of daily life and quality of life but didn´t report any significant changes.

Three systematic reviews also come to different conclusions: Padilla (2011) reported in a systematic literature review, which included seven systematic reviews, that aromatherapy may help to reduce agitation and other BPSD and enhance relaxation in PwD whereas O´neil (2011) concluded in a systematic review insufficient evidence that aromatherapy is effective in reducing BPSD in PwD. Forrester et al. (2014) analysed seven studies and concluded that the benefits of aromatherapy for PwD are equivocal. They stress the importance of more well designed studies before clear conclusions on the effectiveness of aromatherapy can be drawn.

It also has to be noted, that there are also studies reporting negative effects of aromatherapy, such as skin rash and anxiety (Padilla, 2011) and several studies combined the use of essential oils with a massage.

Having a closer look at the type of oils used for the therapy, lavender (Fu et al., 2013; Holmes et al., 2002; Johannessen, 2013; Lin et al., 2007; Moorman et al., 2017; Smallwood et al., 2001; Yang et al., 2015; Yang, Wang & Wang; 2016) was the most common one, but melissa (Ballard et al., 2002; Burns et al., 2011; Jimbo et al., 2009), rosemary (Jimbo et al., 2009), orange (Jimbo et al., 2009) and lemon oils (Jimbo et al., 2009) were used as well.

As already mentioned above the interviews with caring staff showed that most of them already use different essential oils to treat the PwD, but no studies on the benefits were done so far. The reported subjective impression on the impact of aromas was positive and aroma interventions are very popular among the patients. Aromas are also used to get rid of unpleasant smells like urine. One carer said it would be great if the aroma diffuser would work automatically. Another one pointed out the importance of smells for the orientation of the PwD: "I have the impression that the smell of coffee in the afternoon rises the awareness that it is afternoon now."

Summary

Aromatherapy is widely used even though the benefit of this kind of treatment is still somewhat unclear. On the one side there are several studies giving hints on the effectiveness of the use of essential oils, especially agitation seems to decrease after aromatherapy, on the other side there are also studies and literature reviews indicating no special effects. This probably is due to the methodological issues most studies are facing: non-randomized trials, small sample sizes, lack of control of intervening variables etc. Nevertheless, there are promising studies and also the subjective impressions reported by caring personal are positive.

2.4 Attitude towards and acceptance of AAL technology in general and the GREAT System in particular

Ambient assisted living (AAL) systems support handicapped and elderly people to stay independently in their homes, at work, or „on the road" for longer. There are a variety of AAL products to support PwD like the GREAT System will. Developing AAL technology is a corner stone of EU and national funding in order to cope with the demographic changes. However, market success of such systems highly depends on the attitude of the users towards AAL systems and should thus be taken into account.

Generally speaking, attitudes towards AAL or technology in general depend on beliefs and values that older people have achieved during their lifetime (Pancer et al., 1992; Gardner et al., 1993). It is often assumed that seniors are rather reluctant to use modern technology – but this is only half the truth. Although elderly users accept new technology less than their younger counterparts (Hertzog & Bleckley, 2001), they are motivated to use it once they are sure that the benefits clearly outweigh the effort of learning or accepting something new (Melenhorst et al., 2006). Span et al. (2015) even report that PwD were enthusiastic about taking part in the design and development process of an assistive technology.

The GREAT System will be used "on" PwD, which means it doesn´t require any input from the PwD themself, but their carers have to handle the system. Since literature has shown that primary care professionals often lack of enthusiasm and awareness about assistive technologies or knowledge regarding its evidence base (Sanders et al., 2012; van Den Heuvel et al., 2012; Woolham, Gibson, & Clarke, 2006) we already conducted a workshop with this user group at an early stage of the project to involve them in the development of the product as early as possible.

The first workshop with heads and managers of nursing organisations and institutions took place in September at the University of Applied Sciences Vorarlberg, Austria. The participants have leading roles in institutions in the Vorarlberg region as well as practical nursing experience with elderly in general and some with PwD. After a short introduction of the GREAT project and discussion about their experience with light, sound and scent as a treatment and nursing support the eight persons had to take part in short tests with a demo setup. The setup included light, scent and sound modules that were connected to a control unit triggering the modules in a specific way and order.

As the GREAT light module wasn't finalized yet a RGB Philips Hue light bulb was used to simulate different light temperatures between 2500 and approximately 5000 Kelvin. To improve the effect the blinds were closed that only parts of the sun light could enter the room. The scent module was equipped with volatile oil spray dispensers triggered by motors. The sound modules consisted of a stereo speaker pair and an mp3 player playing audible sound files.

In one room the modules were set up to relax with lavender volatile oil, wave sounds and light changing from neutral white to warm white. The other room got equipped with activating components consisting of citric volatile oil, bird and church bell sounds as well as light changing from neutral white to cold white. The test participants took place in a comfortable chair in a corner of the room where the GREAT modules were placed. They had the possibility to read some newspapers although all just sat there doing nothing. Each test lasted for three minutes. In both settings were two male and two female participants each. The average age was also almost the same in both settings (mean 51.2 in the activating setting, mean 50.5 in the relaxing setting)

After that they filled out a questionnaire including a 7-scale semantic differential with the following items:

The system was perceived as (un)comfortable, useful/useless, activating/relaxing, silent/loud, (un)predictable, (un)practicable, (in)effective, innovative/conventional

Additionally, they answered the following questions:

- How will the system affect PwD?
- How will the system affect nursing staff?
- Will the mood and/or behaviour of the staff transfer to the PwD?
- Will affected people use the system at home?
- Will nursing and care institutions use the system?

The questionnaire results are as follows (blue line = activating setting, brown line = relaxing setting):

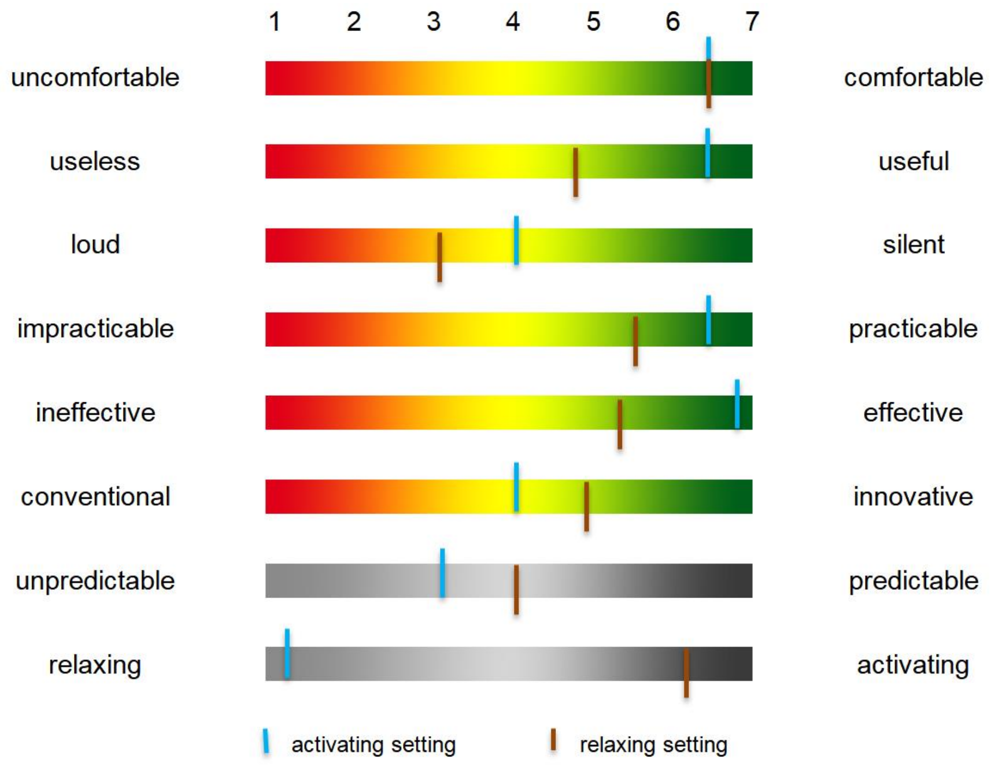


Figure 6: questionnaire results

As the number of participants was low (n=4 per setting) the results have to be dealt with caution, but nevertheless they give some interesting insights. The most obvious insight is that the persons in the activating room perceived the situation as relaxing whereas the supposedly relaxed participants felt activated. Further the persons who got supported in relaxing assessed the system as more useful than the other group.

Almost all participants believed that the system might have a high impact on PwD (Table 2) (mean rating 4,3 of 5) as well as on nursing staff (mean rating 4,2 of 5). They also attested a high relevance of mood transfer from caregivers to PwD (mean rating 3,9 of 4). This also affects the prediction who might use the system. While the likelihood the system gets used was rated quite high for nursing homes (mean rating 3,4 of 4) the participants were more sceptical concerning usage in private homes (mean rating 2,5 of 4).

	Mean value	**standard deviation**	**max value (higher = better)**
positive effect on PwD	4,3	1,6	5
positive effect on caregivers	4,1	1,1	5
likelihood of mood transfer to PwD	3,9	0,4	4
likelihood of usage in nursery homes	3,4	0,7	4
likelihood of usage in private homes	2,5	0,9	4

Table 2: Impact of the GREAT system

The contradicting assessment concerning activating and relaxing light, scent and sound makes it obvious that all modules have to be re-evaluated in the future. The planning for the next much larger test run has already started.

After testing and rating the system the workshop participants discussed the experience in plenum. They were quite pleased with the 3-minute experience. One of them even would buy such a system if the price was within a three-figure range, although others were more sceptical. The following table tries to sum up the impressions of the participants.

General impression	Comfortable and relaxing experience. Works well in a separate setting as with a chair in a room corner but most likely not during normal studies or work. All three modules should relate to the daily structure, i.e. smell of coffee and cakes in the afternoon, etc. Using the system in common rooms could lead to problems as all modules are invasive and perceived differently depending on personalities, perception and memories.
Scent module	The noise of the motors for the spray was very annoying for at least half the people. The activating citrus scent was perceived as activating by half the people but it wasn't enough to feel activated. Scent was too intense for some and triggers memories. Might be different memories for each single person.
Sound module	Church bells have to be used very carefully as they might provoke very different and potentially negative feelings. Silence was very uncomfortable for several persons, after turning off the sound it got missed a lot.

	Birds singing was more relaxing than activating.
Light module	The light was quite dark so it didn't get much attention. Can be used more easily for groups as light doesn't trigger individual memories and less a question of taste like i.e. smell.

Table 3: Impressions regarding the GREAT system

During the whole project, possible objections or fears of all user groups will be treated with great care during the development process. In addition, the usability of the system as well as the light, sound and scent modules will be developed in close cooperation with test users and important stakeholders.

3. Requirements for the GREAT System

3.1 Lighting requirements

3.1.1 Lighting in private homes and nursing homes

Whether seniors continue living in their own homes, or move to an apartment or retirement community, lighting is going to become an ever more important part of everyday life. It will add to comfort and enjoyment and it will help keep seniors safe and more mobile.

Currently private homes of elderly people

- are mainly lit by daylight during the day with unevenly distributed light levels indoors (e.g. high light levels near the windows and low light levels in the back).
- are illuminated with artificial lighting systems in areas and rooms with a lack of daylight or for task lighting which often are not used during day and night or provide an illumination which doesn't fulfill basic physiological lighting requirement of elderly people (e.g. glare-free higher illuminance levels).

Several studies (e.g. Aarts & Westerlaken, 2005; Higgins et al., 2010; Sinoo et al., 2011) could reveal that illuminance levels within working areas in private homes (e.g. bathroom, bedroom and kitchen) are far below 500 lux, which is recommended for younger persons at work places. In the course of the EU-funded project "Aladin - ambient lighting assistance for an ageing population" mean horizontal illuminance levels of 113 lux in the working areas were measured (Becker, 2007). These light levels are representative for private homes in general.

In addition, Aarts and Westerlaken (2005) assessed light conditions in Dutch care homes and homes for older people. They found that conditions are too poor for proper vision. Similar results have been found and reported in the literature, for instance, in the United States by Hegde and Rhodes (2010) and Bakker et al. (2004), and in Belgium by De Lepeleire et al. (2007).

The dominant lamp colour temperature in private homes is warm white with a colour temperature between 2700 Kelvin and 3000 Kelvin. Measurement of the lighting condition during the day revealed a colour temperature between 3300K and 4500K in seven Dutch nursing homes (Sinoo et al. 2011). These recorded colour temperatures are a mixture of the prevailing daylight and artificial light and were measured at eye level in areas with different distances to the windows.

Finally, field studies clearly demonstrate that exposure to bright light is limited although bright light is needed to synchronize circadian wake-sleep rhythms, improve mood, cognition and sleep quality in the aged. Aarts and Westerlaken (2005) reported 19 minutes of light exposure of 1000 lux or more at eye level within a Dutch elderly population living in their private homes (Figure 7).

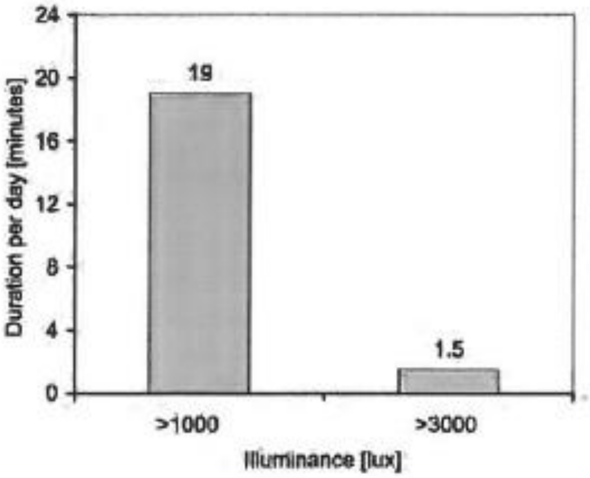


Figure 7: Average daily duration of light exposure of 1000 lux or more (Aarts & Westerlaken, 2005)

Field studies in the sunniest part of America reported similar bright light exposure durations. Espiritu et al. (1994) and Savides et al. (1986) measured 59 minutes and 29 minutes of daily light exposure duration over 2000 lux of elderly people between 55 to 81 years and of people with Alzheimer´s dementia living in old people´s home.

Higgins et al. (2010) reported very low levels of light in the home environment of elderly (with light exposure smaller than 20 lux nearly all over the day) considerably less than reported in a study of Martin et al. (2008) with daytime bright light exposure (>1000 lux at eye level) of 48 minutes and 30 minutes, respectively. Finally Mishima et al. (2001) found out that in ten nursing homes, residents received an average of daily 15 minutes of bright light under standard lighting conditions. These low light levels are not able to induce non-visual light impacts.

Summarizing the current lighting condition in private homes of elderly people and care units, it can be said that in general the lighting levels measured are not adjusted to the reduced retinal levels of elderly people. Although the daylight conditions are acceptable near the window, it is not enough once entered further into the room. The artificial light necessary to perform visual tasks is not adjusted to the older eye, either.

3.1.2 Lighting standards

Since the 1990 efforts have been carried out to accomplish a joint European illumination standard for functional lighting at work places. With the first release of the DIN EN 12464-1 "Light and Lighting – Lighting of work places" a framework for illumination engineers and light planners was given on an European level but depending on the special application and nationality also different national standards have to be taken into account.

Generally spoken, depending on indoor areas, tasks and activities (e.g. general areas inside buildings, industrial activities, educational or health care premises) minimum lighting requirements are given within this lighting standard in the following form:

- minimum level of the average illuminance within the work place
- minimum level of brightness uniformity (given by the value g which is the ratio between minimum to average illuminance levels within working areas)
- maximum level of discomfort glare (specified with the unified glare rating method) and
- minimum level of colour rendering (specified with the colour rendering index).

Additionally, other lighting aspects like maintenance factor or a minimum indoor daylight level are described for all work places.

Another lighting standard which is relevant since 2015 is DIN SPEC 5031-100 "Optical radiation physics and illuminating engineering - Part 100: Melanopic effects of ocular light on human beings – Quantities, symbols and action spectra. Within this standard so-called melanopic (non-visual, biological or circadian) light effects are described and a calculation procedure of these effects is introduced for the first time.

The ANSI/IES RP-28-16 "Lighting and the visual environment for seniors and the low vision population" is intended to increase the designers understanding of age-related vision loss and the importance of their design decisions that could impact the safety and independence of elderly people. This new edition focuses not only at housing and senior care facilities (like the 2007 edition) but covers also offices, hospitality, healthcare, commercial and places of assembly. This standard gained broad acceptance and is now the recommended lighting design practice for older adults.

The available illumination guidelines for older people generally do not distinguish between horizontal and vertical illuminance due to visual and biological light effects. Nor do they care about maximal luminance levels within the field of view to avoid discomfort and disability glare. A Dutch research team (Sinoo et al., 2011) recommend that the colour temperature of the light sources should be between 2700K and 3000K in accordance with personal preferences and characterize horizontal illuminance levels (see Table 4).

Location	Eh [lux]	Comments
Living Room	200-300 (ambient lighting) 1000-2500 (task lighting)	Van Hoof et al. (2010)
Dining Room	500-1000 (task lighting)	Van Hoof et al. (2010) and De Lepeleire et al. (2007)
Hobby Space	500-1000 (task lighting)	Van Hoof et al. (2010) and De Lepeleire et al. (2007)
Corridors	200-300 (day) 50-80 (night)	De Lepeleire et al. (2007)

Table 4: Recommended lux per type of room

3.1.3 Lighting recommendations for elderly people

Several lighting concepts and principles of different research groups (e.g. Lighting Research Center at Rensselaer Polytechnic Institute) and the leading lighting industry exist (e.g. Zumtobel, Bartenbach, DerungsLicht AG). Summarizing these recommendations, it can be said that a good illumination for supporting visual perception of the elderly are in general:

- **Ambient lighting that is uniform** within a room and from one room to another because older eyes take longer to adjust to changes in light levels.
- **Higher levels** of light because normal age-related changes within the eye restrict the light coming in and absorb the light. Thus more light is needed to compensate this process.
- **Glare-free light** because light scatters within the eye causing an increased sensitivity to glare and the loss of the ability to see subtle details at lower light levels.

For supporting non-visual lighting effects the following general recommendations can be made:

- Varying light colours and intensities during the day constitute a clear visual signal of the time of the day.
- Higher vertical illuminance at eye level, especially in the early morning or early evening hours according to the subjective biological needs (e.g. to phase advance or phase delay circadian rhythms, to enhance mood, to shorten sleep latency, to increase sleep duration, etc.).
- Maximal outdoor daylight exposure facilitates exposure to UV-radiation and significantly increases the daily light dose.

Bartenbach established on the basis of different research projects the following specifications in lighting concepts for elderly people:

- Light intensity at task area: $0.3 < E_{zylindric}/E_{horizontal} < 0.6$ at eye level and at height of desk
- Maximum luminance in range of vision: 1000 cd/m² (avoids glare in elderly with higher sensitivity to glare)
- Horizontal luminance in task areas for elderly should provide 1000 Lux during the day and 300 Lux during the night
- Spectral quality should provide a colour rendering index of at least 80
- Avoid multiple shadows
- PWM-dimming frequency >400 Hz

3.2 Sound requirements

3.2.1 Acoustic atmospheres in nursing and private homes

Naturally, the acoustic level of noise is varying in nursing homes and private homes. In this regard importance of noise level is undoubted. In nursing home settings, noise has been associated with poor sleep, reduced ability to perform tasks and distraction from completing a task. Importantly, agitation and fear are associations found caused by acoustic influences (Van Hoof et al., 2010). A qualitative study by Hyde (1989) points out that unnecessary noise/sounds can couse a wiede range of (negative) side effects.

However, noise is also accepted as part of the routine of people with dementia. In care facilities people with dementia (PwD) are generally exposed to disturbing aural stimulation, including telephone ringing and alarms. As indicated by van Hoof (2010), several studies on nursing home acoustics call for reduction of excessive noise. More importantly, Hayen and Gafford (2008) note that tempered talking, radio and television as well as background music can calm residents. Several studies on nursing home acoustics also emphasize that sounds can confuse/irritate PwD. For example, whirlpool noises from exhaust fans, whirlpools and outside noise of traffic or people. During preparation of meals and dinner, sounds from radio/television are a source of negative distraction (Petersen, 2002). Fear, agitation or even panic due to misinterpretation are possible while soft/ambient music presents a possibility for calmation (Van Hoof et al., 2010). All these acoustic-environment aspects are, in fact, to regard in nursing home as well as in private home scenarios.

An important aspect, however, when considering music is semantics and particularly individual meaning and feelings/emotions coupled with melodies. Individual music intervention has proven positive effects on PwDs communication behavior, situational well-being, and their expression of positive emotions (Schall et al., 2014).

Requirements/acceptance interviews with dementia-care personnel from our End-User partners in WP 1 showed a broad acceptance of background music particularly for calming PwD without individual segregation. The Geropsychiatry Ward A4 at the County Hospital Hall, Austria is currently applying music as non-medical intervention for calming agitative behaviour specifically at weekends. However, individual differences of melodies and acoustic semantics on mood have to be regarded closely as the nursing experts in the requirements workshop (Connexia WS I) have emphasized. Marksteiner et al. (2013) are in this context pointing out that PwD seem to have explicit (semantic) memory for music. As the GREAT sound module is planned as portable and light-weight it should also integrate an adjustable volume for each sound module/speaker pair to allow for individualisation of acoustic interventions (e.g. directed at the persons personal bed in the room.

In private-home settings, on the other hand, the advantage of individual songs can be brought to full potential (Park, 2008). Biographically researched music can, for example, be integrated in a playlist that would even allow for personal sorting and other comfort. Importantly, the personal mood reactions – soothing or activating effect – should be determined by the relatives/nurses but can also be learned by the system.

While melodies have the mentioned semantic qualities, two other approaches were determined during requirements analysis. First, audiotapes of nature can result in reduction of agitation but also potentially involve semantic differences for PwD as elaborated in the Connexia WS I. Second, environmental white noise can be a valid approach for calming PwD as confirmed by Burgio et al. (1996). This is a particularly interesting option since it could be administered unobtrusively in the background even when other acoustic sources such as TV or radio are active. A frequent scenario in the common rooms with our End-User partners according to interviewed nursing staff and as witnessed by our own on-location visits.

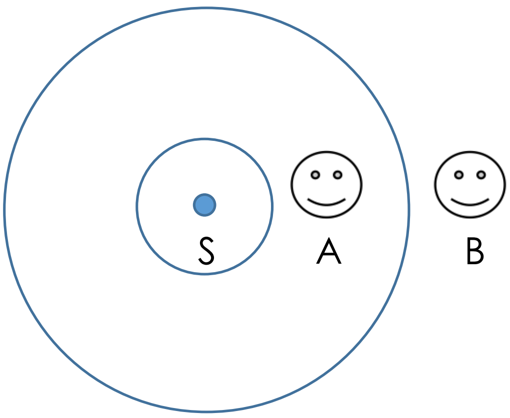
When generally observing the natural auditory ambience in nursing homes during our interviews and on-location research, the importance unobtrusiveness became obvious. Possibilities to integrate such sounds into intelligent atmospheres are presented by inaudible sounds in the ultrasonic spectrum.

3.2.2 Properties for ultrasonic approaches

Ultrasound presents the possibility to integrate sound atmospheres unobtrusively in the background in any scenario – private home or nursing facility. However, the basic specifics of ultrasound create special requirements for application. As ultrasounds we understand inaudible soundwaves with over 20 kHz. As figure 5 demonstrated, nature (e.g. water dropping) already produces ultrasounds humans cannot perceive. Thereby the ultrasonic soundwaves follow the same principles as all sound waves which have to be regarded when applied e.g.:

- Snell's Law
- Destrucive and constructive interference
- Acoustic attenuation
- Acoustic absorption
- Spreading losses

Specifically of interest is the fast attenuation of high frequency sounds. Consequently, the modular speakers for the GREAT system must be able to produce sound-waves in the sufficient range and intensity and placement of the module has to be adequate. For an ultrasound contribution to the room atmosphere speakers have to be in range of PwD.



	Without attenuation	With attenuation, room temperature 20° C, humidity 80%
S	100 dB	~100 dB
A	60 dB	~55.9 dB
B	50,5 dB	~38.2 dB

Figure 8: Attenuation of ultrasound waves – example

Sound waves spread spherically and room temperature as well as humidity are to be considered for attenuation as the example in figure 8 illustrates. A point source of 85 kHz sound 1 meter away from observer A and 3 meters away from the observer B. The sound intensity level 1cm away from speaker, S, is 100 dB. A few possibilities for creating adequate ultrasounds are listed in figure 9. The possibilities present a substantial price range. However, certain speaker models available on the market should also be able to transmit ultrasounds. The range and efficiency/intensity will be tested in the FHV laboratory the next months during HW pilot creation. Implementation suggestions in the daily routine of PwD based on requirements-feedback of nursing staff are illustrated in figure 10.

Avisoft BL Light,
1 kHz – 125 kHz
~ 1900€

ZHIPU,
25 kHz – 60 kHz
~1€

Research Prototype,
25 kHz – 300 kHz
Unknown

Figure 9: Hardware possibilities to create adequate ultrasound waves for GREAT

Seat-integrated speakers

Sound cushion

Parametric speakers

PC speakers

Headphones

Figure 10: Available sound hardware for integration in daily routine

It should be noted, that many modern electronic devices are emitting ultrasounds as byproduct. This is to regard when configuring the sound module at a nursing home or a private home to avoid interferences. Moreover, analysis of sound spread in our laboratory has shown a rather focused/pointed spread of ultrasonic waves.

When considering effects of ultrasound not many consistent research results are available. Aside from mentioned results from Oohashi et al. (2000) and Fukushima et al. (2014) proving that ultrasounds affect brain activity not many researchers have published reliable insights. However, our own research (FHV – UCT) over the course of the last 4 years has proven effects off ultrasound on skin conductance response and HR standard deviation. Audible sinnusoial noise and the same noise blended with ultrasonic elements thereby produced different responses. Therefore, the GREAT sound module is required to have the ability to emit ultrasound in sufficient intensity/range but also must be able to blend audible and inaudible ultrasound. Table 5 summarises some further research and possible effects of sound atmosphere creation on PwD.

Suggested effects on	Acoustic intervention	Sources
Somatosensoric sensitivity	Air transmitted ultrasound relaxing at 30 – 50 kHz, activating at 80 – 100 kHz	Oohashi et al. (2000); Burgdorf et al. (2011); Herbertz & Grunter (1981)
Alpha-activity of the brain	Air transmitted ultrasound relaxing at 30 – 50 kHz, activating at 80 – 100 kHz	Oohashi et al. (2000)
Muscle relaxation	Hearable sound at 16 Hz – 20 kHz relaxing with slow, steady rhythm, activating with fast, versatile rhythm	Möckl et al. (1994); Gembris (2009); Jeon et al. (2009)
Heart rate	Hearable sound at 16 Hz – 20 kHz relaxing with slow, steady rhythm, activating with fast, versatile rhythm	Gembris (2009)
Skin conductance	Hearable sound at 16 Hz – 20 kHz relaxing with slow, steady rhythm, activating with fast, versatile rhythm	Gembris (2009)
Plasma hormone concentration	Hearable sound at 16 Hz – 20 kHz relaxing with slow, steady rhythm, activating with fast, versatile rhythm	Möckl et al. (1994)

Table 5: Research / suggested effects of acoustic interventions (low acoustic power < 100 mW/cm²)

3.2.3 Requirements/suggestions for sound intervention at End-User facilities

Based on our requirements research/interviews, table 6 outlines recommendations on adequate integration in the daily routine of private and home care for PwD.

Goal	Location	When	How	Requirements
Activate	Therapy room and private home rooms	On demand	Nature sounds, individual music optional with pulsating ultrasounds (80 – 100	Speakers or headphones that can create sound waves > 80 kHz;

			kHz); Combinations with lighting	individualised songlists
Relax	Common room, directed/integrated on seats; private rooms/home integration	Cyclic or on demand	Nature sounds, white noise; optional ultrasonic overlays (30 – 50 kHz, pulsating)	Small/mountable or seat-integrated speakers that can create sound waves up to 50 kHz;
Mitigate sundowning	Common room, private room	In the afternoon	Nature sounds, white noise (nursing home); favourite relaxing music (private home)	Speakers (nursing home, private home) or headphones (private home)

Table 6: Possible sound interventions and their requirements for private homes and nursing homes

3.3 Scent requirements

3.3.1 Aroma atmospheres in nursing and private homes

Aroma therapy is used widely in nursing homes. Research and interviews on requirements with our end-user partners have revealed several different general application methods of aromas:

- Aroma lamp/nebulizer
- Room spray/dermal spray
- Smelling bottle
- Aroma cloth
- Massages with aromatic oils
- Exactions with aromatic balms or ointments
- Aromatic lavation / baths / footbaths
- Aroma compresses and wet packs
- Punctual application of aroma drops

The GREAT scent module can support in systematic, automatized application of aromas in the room atmospheres. Requirements interviews in the Geropsychiatry Ward A4 in Hall and the dementia care unit in Egna, Italy have shown a desire of the nursing personell to simplify application of room sprays. Currently the application is done by hand, mainly to overlay smells of urine and other bad odours coming with the daily care routine. In the dementia nursing home in Italy aroma therapy is widely applied and daily activities like cooking in the kitchen are creating naturally structuring odours from preparing food. As pointed out in this regard by Cometto-Nuniz (2001) awareness of airborne chemials is perceived by olfaction and chemesthesis. While the first sense raises awareness for odours, the second gives rise to perception of pungent sensations. Particularly important when considering the requirements of odour application is the fact that olfaction is closely linked to the sense of taste (Ebersole et al. 2004). This has especially to be considered in a kitchen scenario.

Other requirements from care routine at home and in nursing facilities are originating from natural bad odours and also strong cleaning smells which have shown effects of overstimulation (Cohen, 1993). These scents should be neutralised or shielded from perception by adequate room atmosphere creation. The strong emotional effect of scents arises from the conncetion to the limbic system, which connects emotion and memory processing (Brawley, 1997). Simlilarly to the semantic properties of music this might require individual adaption to some PwD who could have aversions to specific aromas. A matter especially important in common room scenarios within dementia care units.

However, the behavioural influence of aromas on PwD is well documented. Improvements concerning agitation have been pointed out, for example, by Burns et al. (2009). Alleviation of stress has been found with PwD when applying baths with aromas (Bakker, 2003; Petersen, 2002). Additional stress relieve through reminiscing is observed due to aroma atmospheres created from natural plants but also artificial fragranes. Importantly, as the requirements interviews with our end-users have revealed and studies confirm (Bakker, 2003), regarding PwD it is imperative to create aromatic room atmospheres through equipment save from being confused, disassembled or even eaten (e.g. bowl of potpourri).

Moreover, on-location research (Hall) showed that ultrasonic nebulizers were in-place but not actively used. Whereas aroma sprays were used frequently in the morning to compensate bad odours (e.g. urine) according to the head nurse at the Geropsychiatric Ward, the nebulizers were not in regular use since during the eventful days the water runs out and is not refilled. An important requirement for the GREAT scent module is therefore to automate application of aromas to ease the burden for the nursing staff. The automisation is thereby also useful for private home scenarios as caring relatives might leave the flat of the PwD and return irregularly. Manual refilling of water or aromas should thus be reduced.

Regulations of the participating nursing facilities are posing further constraints on the options for applying room aromas. Safety protocol is omitting application through aroma lamps and all devices operating with fumes (incense sticks) or open flames. Devices creating heat/heating up are also not adviseable as PwD or nursing staff could touch them / operate them falsely and suffer burns.

3.3.2 Properties and possibilities for creating aroma atmospheres

Genral available devices for room aroma creation are displayed in figure 11. However, as stated requirements analysis restricts usage of several concepts. As pointed out by the interviewed nursing staff and the experts in the Connexia Workshop I, room spray is one alternative that is used regularly and has proven acceptance. Nonetheless, the FHV – UCT laboratory is considering alternatives as well, since nebulizers for example have advantages in purity of aromas. Room sprays do include alcoholic admixutres which demands that they also are kept out of reach from PwD and also combustibility has to be regarded. Although, as open flames are generally prohibited in nursing homes this could pose a concern for private home application.

Vaporizer Humidifier Ultrasonic nebulizer Sprayer

Figure 11: Available devices for aroma application and integration in daily routine

Suggested effects of air-transmitted aromas on	Sources	Aroma interventions
Beta-activity of the brain	Diego et al. (1998)	<u>Relaxation:</u> - Anise - Geranium - Chamomile - Jasmine - Lavender - Palmarosa - Rose, Rosewood - Sandalwood
Muscle relaxation	Gobel et al. (1994)	
Pulse frequency	Hongratanaworakit et al. (2006)	
Respiratory rate	Hongratanaworakit et al. (2006)	<u>Activation:</u> - Citronella - Eucalyptus - Pine needles - Tangerine - Balm - Orange - Peppermint - Rosemary - Petitgrain
Blood pressure	Hongratanaworakit et al. (2006)	
Plasma hormone concentration	Kawakami et al. (1997)	

Table 7: Research / suggested effects of aromas (low concentration <100 µ/m3 VOC = volatile organic compounds). Example: perception threshold orange oil 6 µ/m3 (Ohloff, 1990)

In order to assess the amount of aroma to apply, it is important for automatization to determine the amount of fragrance that has been dispersed. The GREAT aroma module will therefore also have to feature a sensor to assess volatile organic compounds in the air.

With respect to air-transmitted aromas several studies are presenting information on aroma effects and required application. Table 7 outlines fragrances applied for relaxation and activiation in several different studies that applied room oriented aromas. Requirements specifics for people with dementia and application duration as well as frequency can be compared to other studies involving room air aromas which are listed in table 8.

Suggested effects	Aroma intervention	Type and Duration	*N*	According to
Less agitation	Lavender; two times per week 10:00-12:00 and 14:00-16:00	Evaporator; four weeks	21	Smallwood et al. (2001)
Improvement of cognitive abilities	Lime & Rosemary; daily 9:00-11:00 Lavender & Orange; daily 19:30-21:00	Evaporator; 28 days	28	Jimbo et al. (2009)
Improved sleep quality	Lavender; every night at bed-time	Evaporator; three months	24	Johannessen (2013)
Less agitation	Lavender; 20 min. twice a day	Evaporator; two months	23	Moorman Li et al. (2017)
Less agitation	Lavender; two hours a day	Spray; five times in 10 days	15	Holmes et al. (2002)
Less agitation	Lavender; once every hour per night	Spray; three weeks	70	Lin et al. (2007)

Table 8: Exemplary studies – specific room-aroma effects concerning people with dementia

3.3.3 Requirements/suggestions for aroma intervention at End-User facilities

Based on our requirements research/interviews, table 9 outlines recommendations on adequate integration in the daily routine of private and home care for PwD.

Goal	Location	When	How / Aromas	Requirements
Relaxation – reduce agitation	Common room; private rooms	On demand; specifically at late afternoons and in the night	Spray or humidifier; activate in the morning with e.g. citronella or rosemary; relax in the evening with e.g. lavender or rosewood;	No continuous spraying and limit interference from e.g. kitchen odours
Activation – reduce apathy	Common room; private rooms	On demand	Spray or humidifier; activate with e.g. citronella, eucalyptus or orange	No continuous spraying and limit interference with kitchen odours
Reduce nervousness or remove bad odour	Common room; lunch area and corridors	On demand; after lunch	Spray or humidifier; activate with e.g. citronella, pine needles or peppermint	Automatisation important for reducing burden of nursing staff/carers
Reduce bacteria in air / improve air quality	Private rooms	On demand; before bed-time	Spray with anti-bacterial effect	Automatisation important for reducing burden of nursing staff/carers

Table 9: Possible room aroma interventions and their requirements for private homes and nursing homes

4. Technical framework

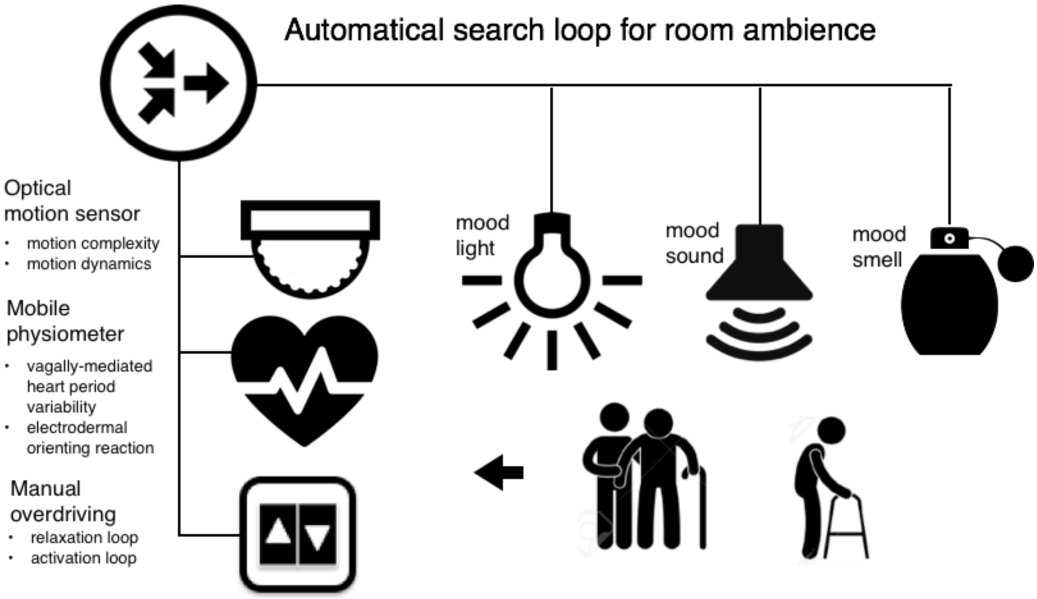


Figure 12: GREAT Components Overview, Source: GREAT consortium

To allow for the GREAT system to be used in widely varying environments a highly modular approach is envisioned. The components for light, sound, and scent can be used individually or in combination with one another. Also multiple modules of the same type should be supported.

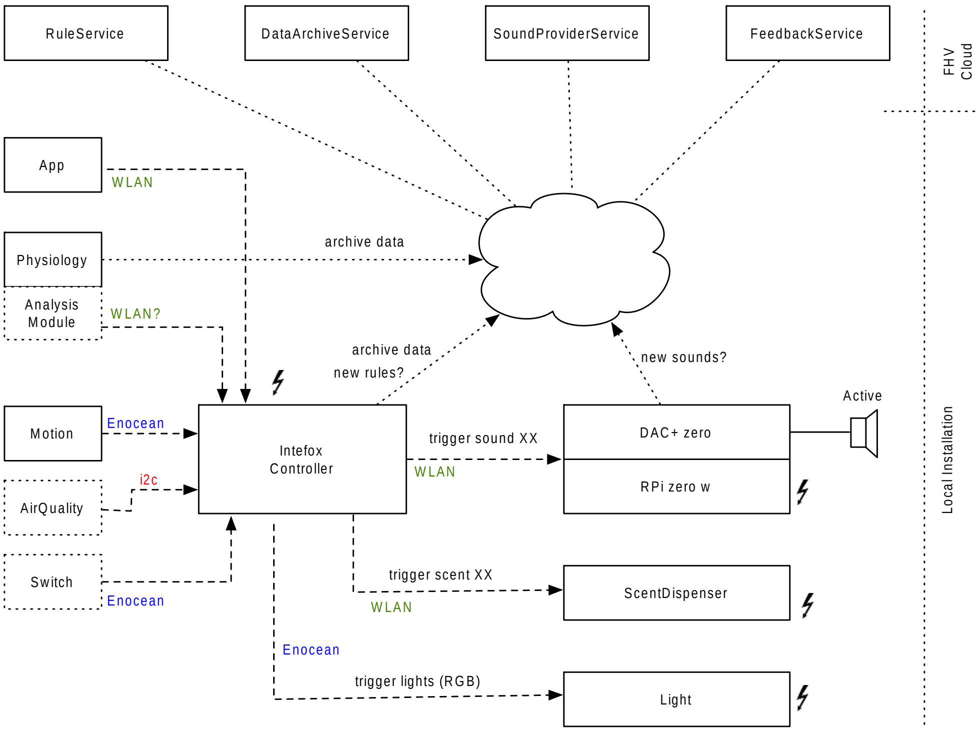


Figure 13: GREAT Distributed System Overview, Source: GREAT consortium

The GREAT system is comprised of a main controller, light-, scent-, and sound-modules, sensors for room-based motion activity and physiological data capturing for selected persons, as well as a cloud based storage and configuration layer.

The main component of the GREAT system is the local controller, that acts as a coordinator among the different components. It runs an already available middleware solution for smart buildings control (provided by Intefox) with built-in support for a wide range of common protocols (e.g. DALI, EnOcean, KNX,…). The middleware system is also highly extensible to allow for integration of other components, either based on standard protocols or application specific ones.

Multiple GREAT systems can be used at the same time in multiple locations, each of them can be tailored to local requirements.

The controller and the modules are connected over wireless links (EnOcean, WLAN, optionally Bluetooth LE). The WLAN is provided by the GREAT controller itself. For internet connection, an Ethernet port with publicly accessible Internet is required. All communication from the controller to the Internet is encrypted. To allow for remote administration of the system individual controllers are connected into a virtual private network, thus not requiring an externally accessible IP-address.

4.1 Software

The basic functionality of the main controller is provided by an OSGi based software layer.

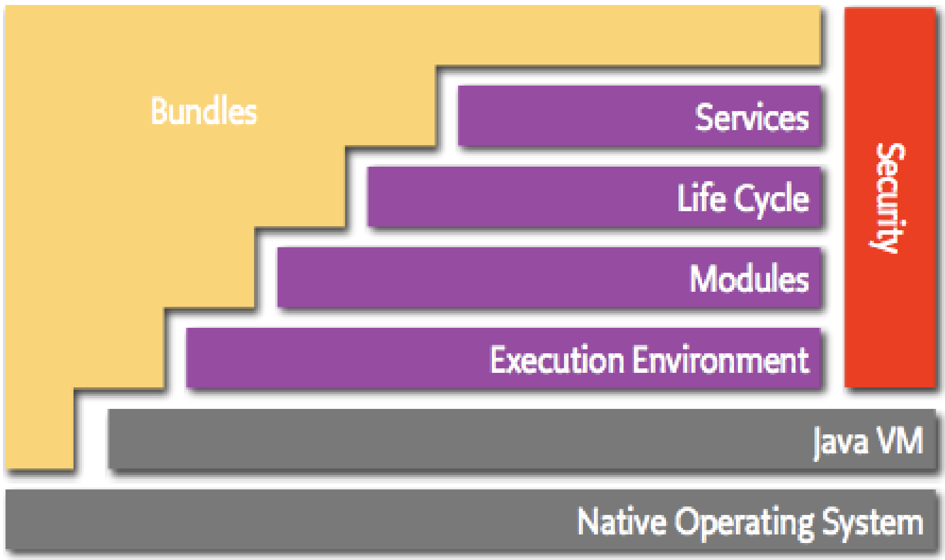


Figure 14: OSGi Architecture Diagram, Source: OSGi Alliance, https://www.osgi.org/developer/architecture

By using the OSGi dynamic component architecture, the functionality of the controller can be extended even at runtime. In the GREAT setup this middleware software runs on a Raspbian Linux operating system, but could be run on other Linux-/macOS- or Windows-based systems too.

The configuration of the controller is edited using a graphical configurator software based on the Eclipse rich client platform (RCP) that is available for multiple platforms (e.g. Linux, macOS, or Windows).

In addition to the middleware layer, the controller also takes on the role of a wireless access point, that provides a wireless network for the individual components (scent- and sound-module, as well as physiology sensor gateway).

For communication with the sound-/scent-modules and the physiology gateway plugins (aka bundles) are created for the controller, that support communication over an encrypted TCP/IP stream. Each module should support automatic reconnection in case a connection is dropped unexpectedly (e.g. power outage when relocating to another power outlet).

All communication between the modules and the controller, as well as from the controller to the cloud based storage layer is encrypted using a private key infrastructure based on TLS.

To allow for secure remote administration without the need of having an externally accessible IP address, the controller connects to a protected GREAT maintenance virtual private network, from where it can be reached for reconfiguration. Only clients with valid certificates in place can connect.

The software on the scent module is based on a Raspbian Linux system, running a server application that receives commands from the controller over the network and controls the corresponding I/O lines accordingly. Communication attempts are only permitted from the controller (identified by certificate). All communication is encrypted.

The application is built using Python due to out of the box availability, low resources consumption, and a range of available libraries for I2C communication and GPIO ports. In the prototyping phase, another advantage of the Python based approach are, that programs don't need to be recompiled before changes can be tested directly on the device.

The software on the sound module is based on a Raspbian Linux system, running a sound connector application that receives commands from the network interface and controls sound playback via the MPD (music player daemon) system. The connector application is also built using Python.

On the system level, sound is played via the Linux ALSA architecture.

Communication attempts to the sound connector application are only permitted from known hosts (identified by certificate). All communication is encrypted.

The light module software is directly built on top of the standardized EnOcean stack, implementing the EnOcean profile and is controlled by light representations inside the middleware on the controller. To implement various light curves as stimuli, a special light curve bundle is created, that offers the functionality of target values (light intensity/color) at certain times and certain intervention overlays.

4.2 Hardware

The main controller is based on a Raspberry PI 3 board-computer with integrated support for Bluetooth LE and WLAN. To integrate EnOcean components, a Raspberry Pi EnOcean module based on the TCM310 EnOcean transceiver module is used that is connected to the built in serial port.

The light module consists of LED modules and a driver board to control the LEDs with radio based on EnOcean standard. Each LED strand is controlled by single driver circuits. Detailed hardware specifics of the light module are documented in deliverable 2.1 – applicable hardware components.

The scent module is based on a Raspberry Pi Zero W module that provides WLAN connectivity. Each scent module contains two drives for two different pump sprays. The drive motors are controlled via a DVR8833 motor driver module with active current limitation. The motor current is measured by a shunt connected to a 12bit A/D converter (TI ADS1015) that is connected to the Raspberry PI Zero module via an I2C interface. Micro metal gearmotors from Pololu (PO-1093) are used for the pump drive mechanism.

The sound module is based on a Raspberry Pi Zero W module that provides WLAN connectivity. For audio output an IQaudIO Raspberry PiDACZero module is used, offering 192kHz/24bit playback (using a TI PCM5122 DAC offering 32-bit/384kHz). It features a112dB SNR and -93db THD. The DAC is connected via an I2S Interface to the Raspberry to transmit audio signals.

As sound output device, the commercially available Logitech Z150 active loudspeakers are used. They are small enough to integrate into a typical GREAT setting, while still allowing for acceptable ultrasonic capability in this price range (limiting the range to about 1m). They operate on the same 5V level as the Raspberry PI, therefore requiring only one common power supply.

The Raspberry PI control board is built into the casing of the Logitech Z150 speakers, resulting in a very compact sound setup.

Stimulus material can be downloaded automatically to the sound module in form of standard audio file formats (typically 192kHz 24bit wav files), thus allowing customization to a specific location.

Passive infrared (PIR) sensors are used to track activity inside the GREAT controlled room. The PIR sensors are connected via the standard EnOcean profile for motion detectors to the controller (figure 15/table 10).

For capturing physiological data, a sensor from Biovotion will be used that offers heart rate, blood oxygenation, skin temperature, skin blood perfusion and motion measurements. It connects over Bluetooth to a gateway device. The gateway device itself connects over WLAN to the main controller while delivering index-parameters for activation- and relaxation status of persons, as well as an activity measure.

4.3 Sensors for acquiring activation and relaxation status

The sensors used to detect changes in the activation and relaxation level of the group follow two approaches. Ambient PIR (passive infrared) sensors measure group activity based on frequency of motion detection. Body worn sensors are in use for caregivers to measure activity level and stress level. Wearables and smart textile for the patients are not in use due to the vulnerability of the target group and expected difficulties with acceptance and adherence.

4.3.1 PIR Sensor

The standard use case for PIR sensors is triggering lighting on basis of detected movement or presence. For GREAT the main aspect is monitoring of activity and detection of group activity levels.

For the activation of lighting the sensor is typically triggered once by motion or presence and switches the light. For a period of 60-90 seconds or more the light is activated and the sensor falls into a sleep mode to conserve energy. After that sleep period the sensor starts to detect activity again. If no activity is detected, the light is switched off otherwise the light stays on and another sleep period starts.

The requirement for GREAT is to continuously detecting activity. Therefore, the sleep period has to be as short as possible. To support convenient and modular installation the second requirement is wireless technology. Since there is a conflict between a wireless and energy-saving architecture and high frequency detection the chosen product has to be modified. The minimum sleep period was reduced to about 1 second. An additional modification is made due to the fact that the sensor is placed on top of the ceiling and not as concealed-installation. The sensor uses an optical shell combined with a magnetic cap to provide easy access in case of battery change without the necessity to completely removing the sensor.

Thermokon "EasySens" SR-MDS BAT

Vendor	Thermokon Sensortechnik GmbH (Germany)
Series	EasySense
Type	SR-MDS BAT
Retail price	250,00 EUR

Technical design	Wireless
Wireless technology	EnOcean ISO/IEC 14543-3-10
Radio frequency	868,3 MHz
Functions	Motion detection and brightness measurement
Motion detection	Passive infrared
Detection area	360°; 105° conical (ceiling installation)
Detection radius (2,5 m room height)	3,25 m
Power source	3 x Battery 3,6V 1/2 AA LS14250
Birghtness (Accuracy)	0-510 Lux (+/- 30 Lux)
Sleep time interval (modified)	1s – 1000s

Table 10: Technical specification for Thermokon SR-MDS BAT

Figure 15: Thermokon SR-MDS BAT and mounting accessories

4.3.2 Body worn sensor

Changes in activity and stress or relaxation level can be measured by body worn sensors, which measure corresponding physiological parameters like heart rate, skin conductance or motion patterns via accelerometers. The Everion sensor (figure 16/table 11) from the company Biovotion (Zurich, Switzerland) makes use of various different sensing techniques which can all be applied on the upper arm. There are several optical channels based on different colors to detect changes in subcutaneous tissue. Temperature and galvanic skin response is based on additional specific sensors. The advantage of the Everion in comparison to other sensors is the quality of data (e.g. compared to wrist worn sensors) and the higher level of acceptance (e.g. compared to chest straps or ECG-variants with electrodes attached to the chest). The sensor is lightweight and convenient to wear, can store data locally, transmit data in real-time or whenever in range of a gateway and can be recharged easily by placing the sensor onto a conductive charging cradle. The comfortable wearing is supported by an elastic textile band.

Figure 16: Biovotion Everion upper arm sensor

Vendor	Biovotion AG (Switzerland)
Type	Everion
Price (project)	550,00 EUR
Technical design	Wireless with rechargeable battery
Wireless technology	Bluetooth 4.0 + LE (IEEE 802.15.1)
Transmission range	<10 m
Radio frequency	2,4 GHz
Parameters	Heart rate
Blood oxygenation	
Skin temperature	
Skin blood perfusion	
Steps / Motion	
Experimental parameters (project)	Respiratory rate
Heart rate variability	
Energy expenditure	
Blood pulse wave	
Skin conductance	
Data modes	Vital sign parameters, raw data, mixed mode
Battery life	24 h
Power source	Embedded Li-Ion battery rechargeable

Table 11: Technical specification for Biovotion Everion

The sensor can transmit precalculated vital sign data or raw data from every parameter channel in real-time or buffer it to the internal memory. The memory can hold several days of vital sign data or 4 hours or raw data. The sampling rate of raw data at 53 Hz with 12 different channels causes a heavy data volume which leads to asynchronous data transmission over time (transmission is slower than recording of raw data).

In GREAT the vital sign mode is the prefered mode since the basic vital parameters are calculated in real-time for detection of changes in activation/relaxation and physical activity levels. For receiving data a gateway has to be installed. Different variations are currently evaluated and considered for use. The preferred gateway is a Raspberry Pi 3 board controller which is also in use as the main controller of the GREAT system. Alternatives can be smartphones with an Android operating system or a Raspberry Pi Zero, which is the cheapest of all variations.

The vendor currently only supports Windows and Android operating systems. Those variations rely on more expensive hardware like Stick-PCs based on Intel architecture, which is in conflict with a cheap end user price. To provide maximum compatibility and avoid problems with various different Bluetooth stacks of different hardware components the vendor developed his own BT-Dongle. This dongle is also expensive (120 CHF). Different alternatives including advantages and disadvantages as well as the price tag are listed below in table 12.

Variation	**Pro/Cons**	**Price (CHF)**
Intel Stick-PC with Windows 10 and BT-Stick  	**Pro:** Use of existing software **Cons:** Expensive Stability issues	250
Raspberry Pi 3 with Windows		

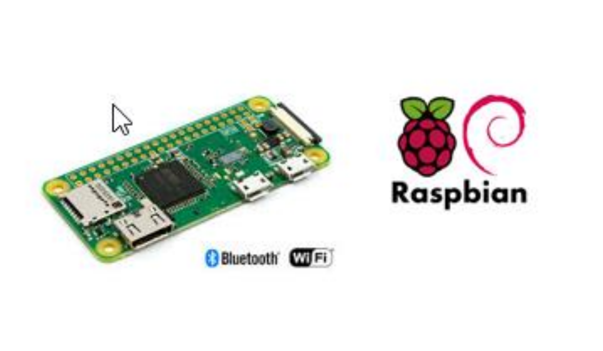
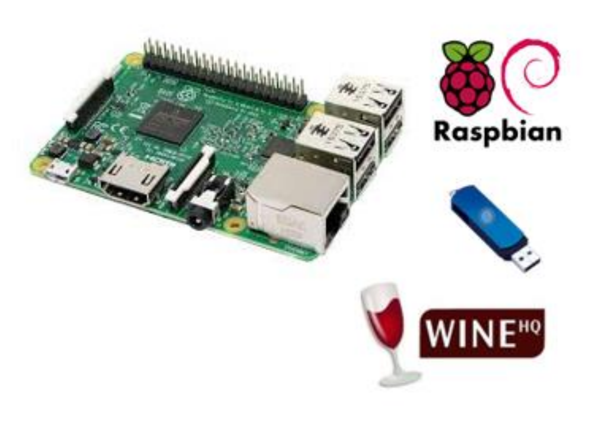
	**Pro:** Cheap **Cons:** Porting of software	170
Raspberry Pi Zero with onboard BT		
	**Pro:** Cheap Board in use in other modules **Cons:** Porting of software	30
Raspberry Pi 3 with Android		
	**Pro:** Cheap Software under development by vendor **Cons:** Stability issues	60
Raspberry Pi 3 with Wine Emulation		
	**Pro:** Use of existing software **Cons:** Dongle expensive Licensing cost	150

Table 12: Variations of gateways for data retrieval

5. Conclusions for GREAT

In the previous chapters we have shown that the percentage of PwD within our societies will increase over the next decades. We have also illustrated dementia-related psychological and behavioural symptoms, which can make caring especially difficult and increase the stress for carers. This leads to a challenging situation for the whole society, particularly the health care system.

On the other hand, several studies have been cited, proving the benefit of light interventions, aroma- and music therapy on many of these dementia-related challenges: Light is not only crucial for perception and spatial orientation, it can also improve cognitive functioning, circadian rhythm and sleep patterns.

Aroma treatment does not only create a pleasant room ambience, but depending on the type of aroma, can also have a stimulating or soothing effect. Audible and inaudible ultrasonic sounds also contribute to a pleasurable room ambience and can trigger changes in physical reactions like blood pressure, heart rate or muscle tone.

The basic idea of GREAT is to create with light, scent and sound room ambiences which have positive impacts on the present mood and condition of PwD and their carers and prepare them for certain activities. In the next chapter the light, scent and sound interventions are described more detailed.

5.1 Light module

Based on the literature research and experiences of Bartenbach GmbH and EMT AG a lighting concept that activates or relaxes PwD was developed.

The lighting concept contains a fixed biodynamic lighting curve, regulating activity-rest-patterns on the long term, and dynamically applicable light interventions leading to acute activation or relaxation. The biodynamic lighting curve integrates a light dose approach, dawn-dusk simulation (variations in light levels and additionally coupled with variations in colour temperature) and a variation of the lighting environment during the siesta.

Biodynamic lighting concept

The biodynamic lighting curve exists of variations in illuminance and colour temperature during day- and night-times:

- Very low light levels and low colour temperatures during the night: provide sufficient light for visual requirements but without disrupting circadian rhythms (physiological effects, endocrinological effects).
- Increasing light levels and colour temperature in the early morning: wakes the person up and activates to get ready to start daily activities.

- Constant high light levels and colour temperature until the siesta after lunch: provides high light levels in a dose-dependent manner (target dose during the day should be 5000 Lux, respectively; divided through 10 hours of application, respectively). Hints for an activating room ambience for elderly with higher light levels (325 Lux) and colour temperatures (4000 K) came from Kujisters et al. (2014).
- Decreasing light levels and colour temperature during the siesta: as known from institutions and hospitals a siesta after lunch time is very common. Therefore, biodynamic lighting is adapted to this fact and provides a cosy ambience during this time. Again, there are recommendations from Kujisters et al. (2014) to create a cosy ambience for elderly with a lower colour temperature (2700 Kelvin). Recommendations for illuminance levels of 25 Lux, respectively, came from Bartenbach itself (MC).
- Increasing light levels and colour temperature in the early afternoon till noon: provides again an activating ambience.
- Decreasing light levels and colour temperature in the evening: calm down and prepare persons for going to bed.

The biodynamic lighting concept is visualized in Figure 17. It is expected that high light levels during the day and low light levels during the night coupled with the correct colour temperature positively influence circadian rhythms and sleep. Persons with dementia should develop improved activity levels during the early morning and afternoon and rest during the siesta and in the late evening and night. On the long-term, demented persons will be better prepared for daily activities and refreshing nights.

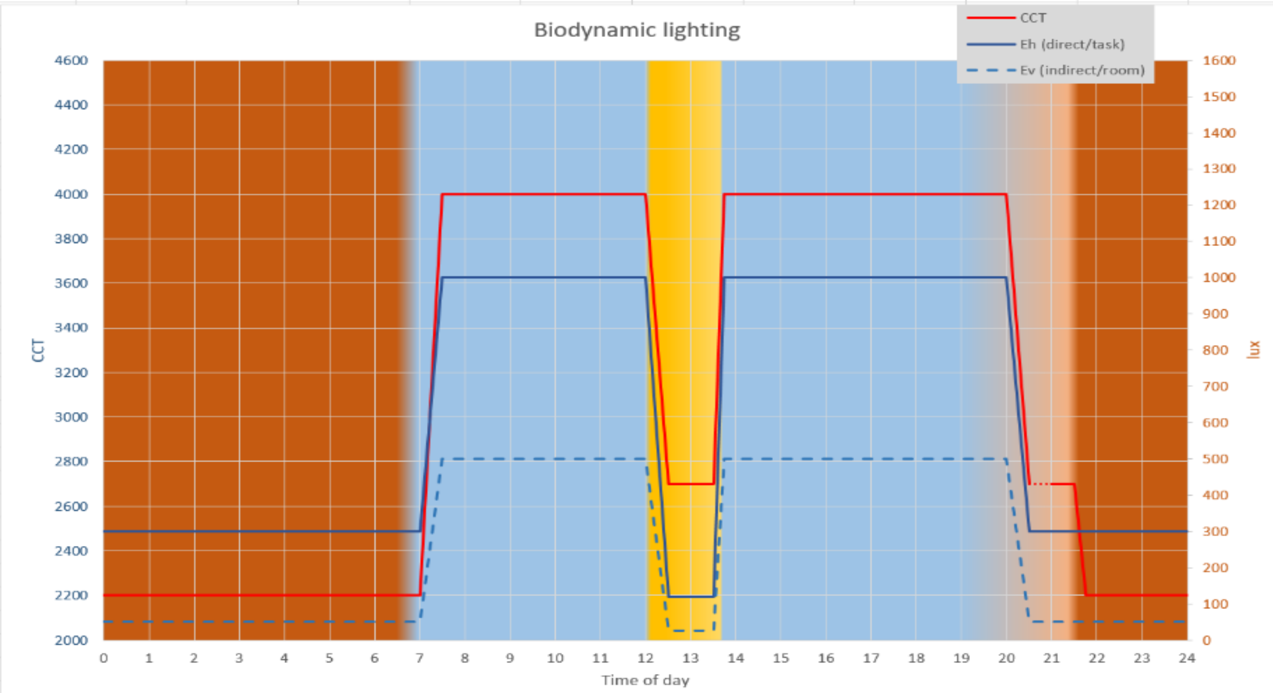


Figure 17: Biodynamic lighting concept varying illuminance and colour temperature over 24 hours

In detail, the algorithm will be as follows:

- Dawn-simulation (7 am) = Wake-up signal
- Illuminance increase from zero to 500 Lux at the eye level, colour temperature increases from 2200 to 4000 Kelvin.
- Morning until midday (7.30 – 12 pm) = first activity phase
- Illuminance stay constant at 500 Lux at the eye level, colour temperature stays constant at 4000 Kelvin.
- Siesta (12 – 1.30 pm) = first resting phase
- Illuminance decrease from 500 to 25 Lux at the eye level, colour temperature decreases from 4000 to 2700 Kelvin. Levels stay constant until 1.30 pm.
- Afternoon until evening (1.30 – 8 pm) = second activity phase
- Illuminance increase from 25 to 500 Lux at the eye level, colour temperature increases from 2700 to 4000 Kelvin. Levels stay constant untin 8 pm.
- Evening (8-9.30 pm) = second resting phase
- Illuminance decrease from 500 to <50 Lux at the eye level, colour temperature decreases from 4000 to 2700 Kelvin.
- Night mode (9.30 pm – 7 am) = sleep phase

- Usually light is turned off during the night. If light is needed, the illuminance constantly provide 25 Lux at the eye level and a colour temperature of 2200 Kelvin. This are recommendations from Bartenbach for night lights to account on visual requirements and to avoid negative effects on physiology due to wrong lighting at night.

Light interventions: acute activation and relaxation

Acute activation or relaxation will be provided by so called light cues. There is an activating light cue and a relaxing light cue. In addition, there will be a TV scene provided, creating a cosy ambience during watching TV.

1. The activating light cue contains a not recognizable reduction in light intensity and a short, recognizable increase in light intensity.

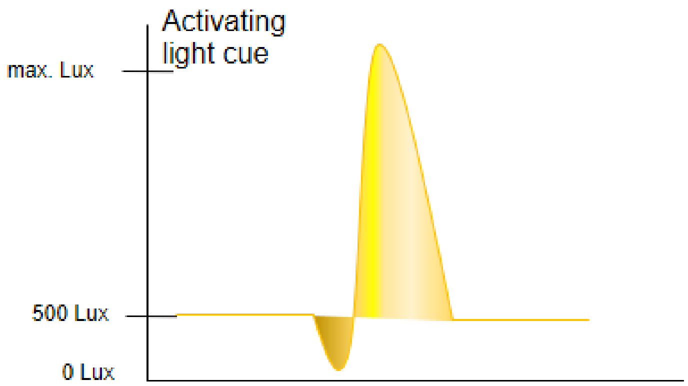


Figure 18: Activation light cue

2. The relaxing light cue contains a moderately longer reduction in light intensity and colour temperature.

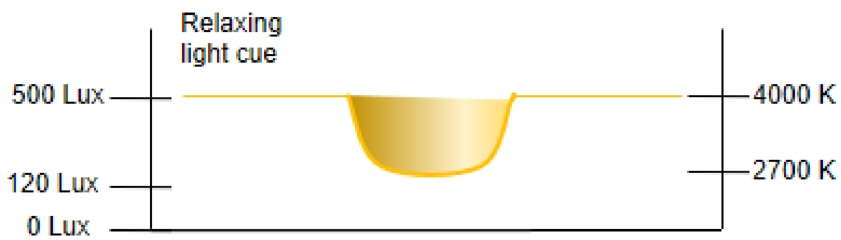


Figure 19: Relaxing light cue

3. The “TV”-scene provides a very low intense task (to see TV controller) and ambient light (to see surrounding, e.g. walls, floor) with about 10 Lux reaching the eye and in dependency of day- or night time adapted colour temperature (3000 K during the day, 2700 K during the siesta and in the evening, 2200 K during the night).

5.2 Sound module

The sound module offers playlists for relaxation and activation. Sound stimuli are intended to be natural sounds, that also contain ultrasonic components (just like in nature). We choose to use natural sounds, since music and songs are underlying more individual preferences and are often linked to certain memories and emotions.

Based on available research findings the stimulus for relaxation will feature ultrasonic components up to 30kHz. For activation, there will be ultrasonic components up to 80kHz enabled.

The sound hardware will be limited to max. sound pressure level (SPL) of 82dB. Due to speakers limited sound reproduction capabilities at high frequencies, the ultrasonic range for the module will be limited and is expected to be about 1m (-20dB for 30kHz signals, -35dB for 80kHz signals).

As stimulus, in the initial phase, sounds of nature/environment will be used. For activation, irregular sounds will be played, such as singing birds or frogs. The activation stimulus will be played for 20 minutes to match the duration of the light activation stimulus.

For relaxation, periodic and regular sounds with no relevant direct information will be played, like the sound of ocean waves or waterfalls. The relaxing sound stimulus will be played for 60 minutes, to reflect the duration of the light relaxation stimulus. Sound stimuli will contain either audible or inaudible components or both.

5.3 Scent module

The modules, which were built for the first test phase, are similar to common, automated air refreshers.

Its very first prototype was built to fit into a bought unit, with changes according to the needs of the project. Almost all purchasable systems work on a simple time schedule, which might be adjusted on a very limited scale at most (for instance every half or full hour, 3 hours, 6 hours). For this project, it's required to disperse the chosen scent whenever necessary. Therefore, it was unavoidable to program a microcontroller with a quickly responding interface (Bluetooth in this case). Since the project requires biological odours, the original bottles (pressurized) and mechanism, (push and release) had to be replaced with a pumping action. The existing motor was adapted so it would create a linear movement to repeatedly push the spray. This prototype proofed the concept it was built for in all but one points (batteries would not suffice the frequent cycles we aim for).

The modules that will actually be used in the first test phase consist of three sub-modules – the electronics (microcontroller, motor driver and interface) and two scent modules (identical hardware, just different scents in the respective bottles). With the lessons learned from the proof-of-concept prototype, the design focuses on easy maintenance and durability. The main components are all screwed together, no glue was used, and the casing is held in place by friction. To replace an empty bottle or one with an unwanted scent, one simply has to slide out the casing and switch them. The access to the electronic sub-modules is the same; they are held in place by two or four screws and can be replaced within minutes. The motor and pumping mechanism are designed to be durable and are not expected to fail – in a worst-case scenario, replacing any part and reassembling the module should take less than 10 minutes. The items required to build one module are mostly off-the-shelf. One component is manufactured from a third party company, the rest at the University of Applied Sciences Vorarlberg.

The concept is designed for modularity. The prototypes will have mounts to add additional scent modules if desired. The casing will scale according to the number of scents required. As it's made of acrylic glass the casing can have various colours and it can be cut or engraved to fit the overall design of the prototypes. Smaller sized bottles with different scents fit into a scent module by using appropriate adapters.

6. Abbreviations

AD	Alzheimer dementia
BPSD	Behavioural and psychological symptoms of people with dementia
CCT	Colour temperature
hz	Hertz
K	Kelvin
kHz	kilohertz
MCI	Mild cognitive impairment
PwD	Person/people with dementia

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8. Secondary literature

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9. List of Figures

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