Insights from Cognitive Neuroscience

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Abstract

We are interested in advancing the design of buildings that are well adapted to people who have been diagnosed with Alzheimers Disease and Related Dementias (AD/RD). This paper aims to discuss scientific findings regarding the impact of design and architectural stimuli on relevant neuropsychological states. For the purpose of this paper, we are assuming that the AD/RD population is mobile and living independently — in the sense that they live in their own private dwelling spaces and have access to common areas where they can gather with other members of the community. In addition to expert interviews, we review a 4 x 6 matrix of neuropsychological states and processes, where we found extensive research on effective design elements that could potentially help improve quality of life in care homes, geriatric facilities, retirement residences and more.

Keywords: Architecture, Design, Neuroscience, Alzheimers, Dementia, MCI

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Introduction

As the percentage of Dementia cases around the world continues to climb, efforts in researching the neurodegeneration behind cognitive impairment in older adults is quickly expanding. With Alzheimer's Disease (AD) making up around 60 to 70% of overall Dementia cases according to the World Health Organization [36], it has also moved to the forefront of these research advancements. Additionally, the Alzheimers Organization noted that there was a 146.2% increase in deaths reported from Alzheimers since 2000 — compared to decreases resulting from other major causes of death — and predicted that the number of AD cases will double to around 13 million by 2050. [1] Although such figures are often used to characterize the imperative nature of drug discovery and the development of a cure for AD/RD, they also highlight the growing number of people who will be living with the consequences of cognitive decline while a permanent solution is found.

In order to identify how we can help those living with AD/RD, it is important to first understand where the current research is headed. Over the past decade, scientists studying AD have been focusing on exploring biomarkers and the mechanisms behind neurodegeneration of AD, in order to diagnose at an earlier stage with more accuracy. [10, 15, 16] While this can help advance medicine closer to a cure, it also provides insight into factors that could be affecting aspects of cognition. Studies on cerebrospinal fluid (CSF), metabolism, proteins and more [3, 20, 38] have revealed the different causes responsible for changes or degeneration of memory systems, orientation, and executive functioning. These processes are highly complex and even though they sometimes involve physiological deterioration, meaning the brain is irreparably damaged, studies have found that perception of one's health and surroundings can also impact cognitive impairment. [24, 27] They demonstrate how affect and subjective experience can either slow down or speed up cognitive decline, and as such, innovative solutions can come not only from pharmacology but also from modulating a patient's environment.

In 2013, the World Dementia Council began an initiative towards guiding research progress in finding a disease modifying therapy or a cure for AD/RD by 2025 [35]. Even though at the time they focused mainly on drug related discoveries, quality of care, and socio-economic impact, others have taken inspiration from the collaborative endeavor suggesting alternative goals directed at prevention and lifestyle. Amongst the recommendations made by a joint taskforce of experts as part of a project on aging by the Alzheimers Society in the UK, was a focus on improving general quality of life through the promotion of independence and exercising functional capacity while also minimizing and managing negative consequences of Alzheimers and Dementia. [23] One way that this has taken shape is through thoughtful design, evaluating the effect that the environment has on human experience and how to incorporate daily activity, habits, and lifestyle into architecture. [13] Specifically for AD/RD design, this means creating

spaces that allow patients to maximize their cognitive functioning by effectively adapting the environment to their needs. [9, 22, 17]

Thus, based on interviews with experts in neuroscience and architecture, in this paper we review various architectural stimuli and their interaction with neuropsychological states related to AD/RD. The goal is to bridge the gap between two seemingly unrelated fields and spark conversation about effectively designing spaces for people living with Alzheimers and Related Dementias.

Characterization of Cognitive Decline

Cognitive impairment might look different for each person depending on what kind of dementia they have or how progressed their Alzheiemers is. Generally, it includes but is not limited to the deterioration in mental processes like memory, learning, concentrating, recognizing, ability to carry out functional tasks, and to what degree these affect daily life. [7] In some cases, the loss of cognitive ability may be mild while in others it can critically hinder a person's capacity to take care of themselves. While this characterization of AD/RD is inclusive, more research needs to be conducted. For this project we present the most relevant information.

There are intricate processes implicated in neurodegeneration. Pathologic loss of neurons and changes in neuronal connections affect certain systems in the brain that can impact cognitive decline in AD/RD [18]. In Alzheimers, components of the disease include inflammation, amyloid beta plaques, neurofibrillary tangles and cardiovascular health [29]:

- Chronic Inflammation

When inflammation occurs in the body, cytokines are circulated to help it fight the infection, illness, or injury. In crossing the blood brain barrier they signal the CNS to activate microglia, which in turn initiate an immune response, further releasing pro-inflammatory cytokines and increasing inflammation. Although this seems counterintuitive, microglial activation and release of pro-inflammatory cytokines have been shown to be neuroprotective by promoting phagocytosis (removal of bacteria and other toxic debris). However, long term activation has been associated with Alzheimers pathology as microglia fails to remove the harmful material and pro-inflammatory cytokines can produce chronic inflammation. [32, 34, 26]

- Amyloid Beta (Aβ) plaques

Amyloid Beta (Aβ) is a molecule produced by Amyloid Precursor Protein (APP) that in very low doses is thought to aid in brain development and potentially aid in protecting against neurotoxicity. However, Aβ can accumulate in cerebral blood vessels (cerebral amyloid angiopathy) and cause senile plaques that impair blood flow and accelerates neuronal dysfunction. This is thought to be one of the hallmark pathologies of Alzheimer's disease, has

been a driver for the amyloid cascade hypothesis, been studied and debated extensively since the 90's. [11, 5, 25]

- Neurofibrillary tangles (NFT)

Tau is a protein associated with the stabilization of microtubules, which are important for axonal transport and maintaining the structure of a cell. Hyperphosphorylation of tau prevents the assembly of microtubules and induces the accumulation of tau oligomers. These lead to the formation of neurofibrillary tangles, which in recent years have been discovered to be highly prevalent in AD patients. [8, 19]

- Cardiovascular health

While cardiovascular health may not be a direct cause of degeneration in the brain, hypoperfusion (decreased blood flow) as a result of cardiovascular complications can lead to oxidative stress, neuronal death, and decreased neuronal signaling. The impact on cognitive ability is dependent on which structure has reduced blood flow. Additionally, vascular deficits can lead to aggregation of neuronal plaques (amyloid beta) which usually would be cleared out through the vascular system in healthy individuals. [33, 28]

Even though some of these are also applicable, reasons for cognitive decline in dementia extend to physical brain trauma, stroke, infections and substance abuse. Through these processes, cell death can damage the brain structures or systems highly involved in important cognitive abilities, leading to impairments. Diagnosing dementia and Alzheimers can also get tricky. There are neuropsychological tests that evaluate different aspects of cognitive functioning like mood, behavior, decision making and problem solving and can relatively precisely identify the severity of cognitive impairment Recently, more research is being conducted on biomarkers, which could also help indicate decline in AD/RD by anticipating or identifying neurodegenerative processes like the Aβ deposition, cardiovascular health etc. While there have been important advancements in studying these biomarkers, it remains difficult to determine exactly which type of dementia someone might have because of how similar the symptoms are between dementias. [31] Furthermore, a confirmed diagnosis of Alzheiemers is not possible until after a patient has died [30].

This reiterates the importance of understanding the ways that cognitive decline manifests itself in AD/RD. By studying the cognitive processes — their systems, mechanisms and biomarkers — research can be aimed not only towards finding a cure, but also towards bettering a patient's overall quality of life through preventative solutions or management of the decline.

Opportunities for Architecture

There are various fields researching alternatives to prevent and manage cognitive decline, discovering effects of physical activity, diet, sleep and social interaction on various aspects of cognition. [19, 2, 4, 12] Amongst those fields is the study of design and the built environment. [37] Taking into consideration how a space and specific architectural elements can impact not only the emotional wellbeing of a person, but potentially other neuropsychological states as well [14].

Additionally, around 50% of elders living in care homes have some form of dementia. [6] Unfortunately a lot of these facilities lack proper application of effective design elements, meaning a consideration of how architectural features (aspects related to the built environment) like materials used, positioning or size of windows, location of building, functionality and space planning can modify architectural stimuli such as temperature, wayfinding, brightness, noise, and colors — ultimately playing a role in cognition.

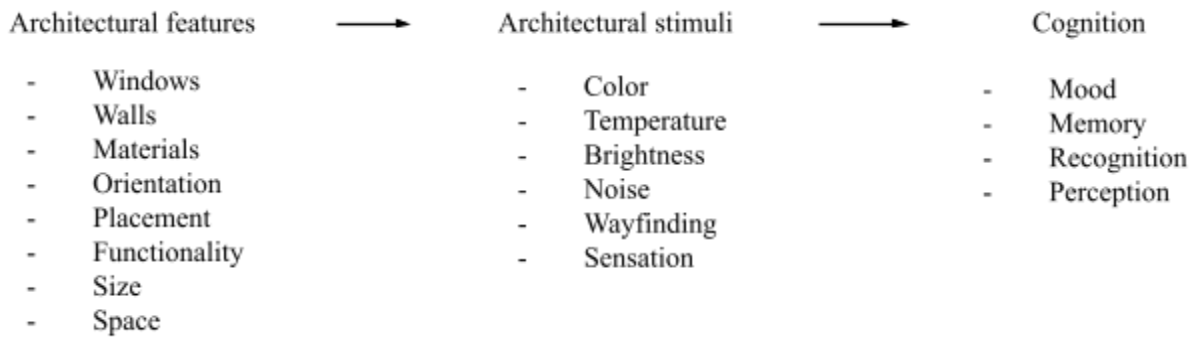

Figure 1. Interaction between architectural features, architectural stimuli and cognition.

There is a lot of research that still needs to be done, in turn creating opportunities for more studies on the interaction between neuroscience and architecture that can be utilized to improve quality of life for patients with AD/RD.

Affiliation with ANFA

This project was created in affiliation with the Academy of Neuroscience for Architecture with the intention of publishing it on their website. The goal is that this project will be available for Architects and Neuroscientists to review and generate their own ideas on the topic, the data is presented intending to make scientific data more accessible and transform it into information that could encourage design ideas and concepts.

Relevant Neuropsychological Measures of Human Performance

There are various types of tests, both psychological and physiological, that can be used to measure different states. Depending on whether someone aims to assess objective or subjective experiences, studies may involve the use of MRI's and blood tests or scales and questionnaires — respectively.

Definition of Key Measures

This review consists of diverse hypotheses, methodologies, and experimental conditions. As such, researchers may choose to use a particular test depending on the neuropsychological state they are measuring and their procedure. Even though some studies may have used the same ones, here we explain and give reference for each test, including reviews of validity.

Alertness

- The Karolinska Sleepiness Scale (KSS) is a verbally anchored scale based on a subjective level of sleepiness during the day. It was developed in 1990 by Swedish researchers and includes selecting the level that best reflects the psycho-physical state of a subject in the past 10 minutes. It ranges from 1 (Extremely alert) to 9 (Very sleepy, fighting sleep). It has been used in a variety of different experimental settings including assessing alertness, and has been validated as a tool that closely reflects EEG activity in measuring sleepiness [50]. More information and the test can be requested from the authors [39] or through the journal STOP, THAT and One Hundred Other Sleep Scales (2012) [56].
- While similar to the KSS, the Borg CR-10 Rating Scale is a more generic 10 point physical exertion scale that can be used for various perceptions and experiences, including alertness. It ranges from 0 (Nothing at all) to 10 (Extremely strong) and was also developed in Sweden in 1998. While both scales are verbally anchored, they are aimed at assessing different components of alertness, the KSS focuses on sleepiness and Borg CR-10 on exertion. While to our knowledge there have not been studies done on the validity of the Borg CR-10 as a measure for alertness specifically, it has been shown to accurately muscular fatigue relevant to subjective experience [49]. More information and the test can be requested from the authors [43].
- Generally the Visual analog scale (VAS) is a measurement instrument that measures subjective experiences or characteristics that can't always be physiologically measured. It was first created in 1921 and can be presented in different ways, usually involving some form of continued scale. Scales can be found throughout the internet and are used in a variety of different research studies. [48, 61]

Engagement

Both of these measures were created mainly by Jiska Cohen-Mansfield along with other researchers on various engagement papers.

- Created in 2017, Group Observational Measurement of Engagement (GOME) consists of number of participants in the group, positive interactions (e.g. smiling, encouraging each other among group members) rated on a 6 point scale from 0=none to 5=very many and negative interactions (e.g. angry comments to each other) among group members - rated on a 6-point scale from 0=none to 5=most or all of the time. [45]
- Created in 2009 Observational Measurement of Engagement (OME) evaluates rate of refusal, duration, attention, and attitude. Activity is defined as the following: The participant *held* the stimulus, The participant *manipulated* the stimulus, The participant *talked* to the stimulus, The participant *talked* about the stimulus, The participant was *disruptive,* The participant *inappropriately* manipulated the engagement stimulus, other. [CM 2009]

Ability to Concentrate

- Comprehensive Trail Making Test 3 can evaluate attention, visual search and scanning, sequencing and shifting, psychomotor speed, abstraction, flexibility, ability to execute and modify a plan of action, and ability to maintain two trains of thought simultaneously. TMT 3 increases the complexity of the sustained attention and visual search features of the task by adding simple both simple and complex distractor stimuli to the visual array. [41] The test can be found and purchased online or through the original book. [54]
- Stroop Color Word Test is widely used to measure the ability to inhibit cognitive interference; previous literature also reports its application to measure other cognitive functions such as attention, processing speed, cognitive flexibility [55] The test can be found with the original author. [57]

Stress

- Cohen-Mansfield Agitation Inventory/Frequency (CMAI-F) systematically assesses agitation. CMAI was developed to assess behaviors of older adults living in nursing homes, respondents rate the frequency on a seven-point scale ranging from “1-never engages in” to “7-manifests the behavior on the average of several times an hour.[40] The test itself and more information can be found through the original paper. [46]
- Littles Personal Project Analysis evaluates the internal and external dynamics of personal goals and projects and clearly demonstrates that human flourishing is enhanced when individuals are engaged in the pursuit of personal projects [51] A more in depth explanation by the author can be found in their paper. [52]

Ability to Recognize

- Word Fragment Completion Task is a test designed to measure memory of words presented to participants, words that were previously shown to participants are presented again in a fragmented form with the task of retrieving the missing letters from memory to complete it. [59] One of its first uses can be found on this paper for reference. [58].
- Pattern recognition memory is test of visual pattern recognition memory in a 2-choice forced discrimination paradigm, in the recognition phase, the participant is required to choose between a pattern they have already seen and a novel pattern. [53] More information on the origin of the test. [42]

Ability to Recall

- MMSE is a 30-point test used to measure thinking ability and is the most common tool for assessing the severity of a person's Alzheimer's disease. Details on administration and the test itself can be found online. [47]
- CVLT-II measures episodic verbal learning and memory, and demonstrates sensitivity to a range of clinical conditions. The test does this by attempting to link memory deficits with impaired performance on specific tasks. It assesses encoding, recall and recognition in a single modality of item presentation. [60] The test can be purchased on their website [44]

Discussion of Additional Potential States and Measures

Overall there are numerous neuropsychological measures that could be considered in the realm of architecture and neuroscience. Although we chose to focus on 6 specific ones, different states could be further researched in their relationship to architectural stimuli. We suggest the following, including but not limited to:

Neuropsychological state	Potential Neuropsychological Measure	Notes
Gregariousness	Big Five Personality Inventory (BFI) [76] and The Interpersonal Adjective Scale (IAS) [74]	• Propensity to be social • Does light impact desire to be around people?
Efficiency	WAIS-IV processing speed index and the Trail Making Test Part A [70]	• Processing speed • Coordination of how you think, feel and act • Could different colors play a role?
Ability to follow instructions	Directions test [68]	• Type of intelligence test • Implicitly measures ability to understand directions and instructions
Wandering	Observation and DeLeon Caregiver Checklist [69]	• Navigation performance • What different architectural stimuli can guide a person with AD/RD?
Irritability	Born–Steiner Irritability Scale (BSIS) [72]	• Multi-item irritability scales have strong reliability and assess a range of thoughts • Color, noise, temperature and how it can impact a person's irritability
Depression	Clinical Dementia Rating, Dementia Rating Scale and Montgomery–Asberg Depression Rating Scale (MADRS) [73, 77]	• Degree to which different stimuli could decrease levels of depression temporary or long-term • How much stimulus would be needed to reduce depression levels?
Optimism	The Revised Optimism–Pessimism Scale (PSM-R) [71]	• Outlook on life • Can positive perspective be induced with stimuli
Mood/Affect	Dementia Mood Assessment Scale (DMAS) [75]	• Temperature and Color could impact overall mood • Affect towards other people and life in general could be considered

Table 1. Alternative neuropsychological states and measures

Summary Table

Neuropsych performance measures	Architectural stimulus			
	Brightness (lumens)	Noise level (db)	Color (rgbiv)	Temperature (F)
Alertness	Karolinska Sleepiness Scale (KSS)	Borg CR-10 Rating Scale	Karolinska Sleepiness Scale (KSS)	Visual Analog Scale (VAS) & Karolinska Sleepiness Scale (KSS)
Engagement	Group observational measurement of engagement (GOME)	Observational measurement of engagement (OME) and Independent Testing*	No data	Group observational measurement of engagement (GOME)
Ability to concentrate	Comprehensive TMT 3	EEG's	Eye movement tracking	Stroop Color Word Test
Stress	Cohen-Mansfield Agitation Inventory-Frequency (CMAI-F)	Little's Personal Project Inventory, the Somatic Symptom Checklist and Independent Testing*	Induced stress**	Cohen-Mansfield Agitation Inventory-Frequency (CMAI)
Memorability: Ability to recognize	Word Fragment Completion Task	Speech-in-noise tests (SNTs)	Color-Form Memory Cards	Pattern recognition memory
Memorability: Ability to recall	No data	Mini Mental State Examination (MMSE)	California Verbal Learning Test II (CVLT II)	Independent Testing*

* Neuropsych measures that do not follow a standardized test
** Inducing neuropsych state

Table 2. Key measures for neuropsychological states

Results

Overall, we found numerous research papers exploring the general effect of architectural stimuli such as brightness, noise, color and temperature on neuropsychological states like alertness, engagement, ability to concentrate, stress, and memorability. While some papers do address this impact on an AD/RD population, many of these papers report findings that apply to the general population, so more research is needed to establish their definitive effect on people with AD/RD. Additionally, some results may conclude in no data or statistically insignificant data — these conclusions are not exhaustive, rather encourage research.

Alertness

Definition for the purpose of this project

Alertness refers to the state of being awake and aware [99]. Many of these papers focus on subjective alertness (can be tested through sleepiness or other scales), rather than physiological measures like sweat and heart rate.

Overview

Results indicated several potential approaches for architecture.

- In terms of Brightness, it was found that exposure to bright lights for fatigued patients increases their alertness. Having larger windows or skylights in hallways, eating areas, and even bedrooms could help decrease tiredness from AD/RD insomnia and also increased exposure to natural light. There is also an emphasis on light exposure increasing alertness at eye level, where it could be less beneficial to have brightness coming from above (as is typically the case with lighting).
- Additionally, studies have shown decreased alertness with increasing noise, thus soundproofing or secluding rooms where increased alertness is important like kitchens could be useful.
- Strategically placing blue light in spaces where higher alertness would be favorable, avoiding blue light in places like bedrooms at night, as well as utilizing reds and greys for backgrounds might be effective in modulating alertness.
- Regulation of temperature in a bedroom versus a living room or activity area should also be considered as higher body temperature is associated with higher alertness.

I. Brightness

Improvements on alertness were correlated with increasing brightness measured in lux (unit of illuminance). Smolders, K. C., & de Kort (2014) [90] found that fatigued participants (n = 28) reported statistically significant higher levels of alertness (KSS) compared to controls (Figure 2). After 30 minutes of exposure to 1000 lux at eye level (Fig. 2), sleepiness levels decreased by ~10%. Although they used wall-mounted luminaires for the experiment, they suggest that increasing brightness through architectural features like larger windows could help fatigued individuals feel more alert and energized.

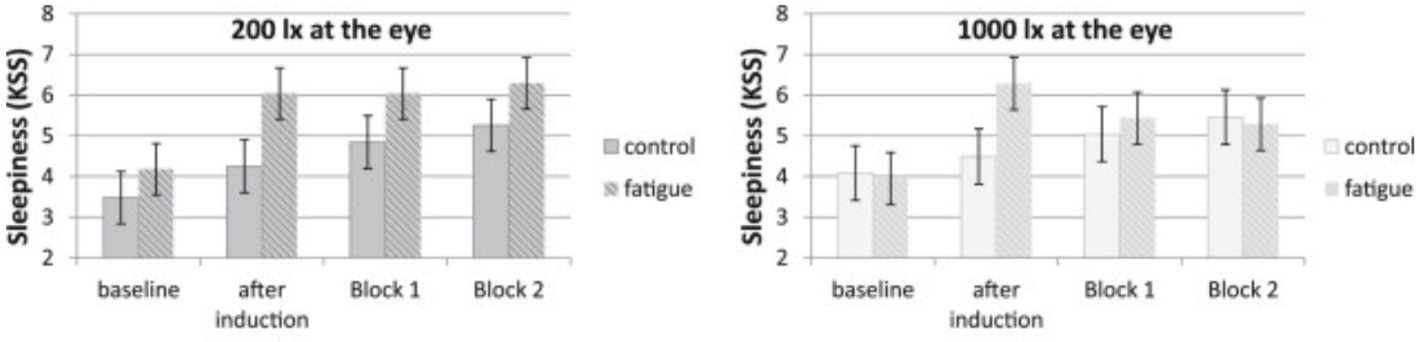

Figure 2. Development of sleepiness over time in different lux conditions.

Similarly, de Vries et al., (2018) [77] evaluated alertness relative to wall luminance over three conditions. They found an 18% increase in subjective alertness (KSS) from the low luminance (206 lux) to the high luminance (254 lux) condition at eye level (Fig. 3). Participants (n = 37) experienced all brightness levels over the course of three sessions, each lasting 90 minutes, with alertness being tested before and after. Due to the minimal difference in lux between conditions, further research on the mechanism behind this increase in alertness was suggested. However, they also conclude that the findings might not suggest acute effects of wall luminance, but instead could implicate more long-term impacts.

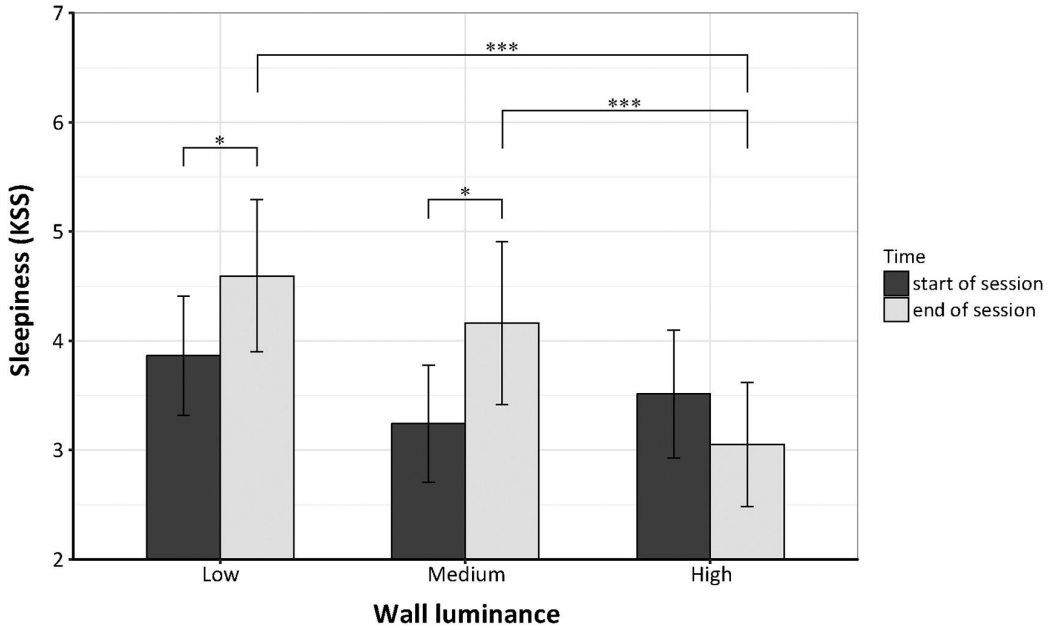

Figure 3. Mean KSS scores - whiskers represent the 95% confidence interval of the mean, *p < 0.05, ***p < 0.001.

II. Noise

Overall, noise conditions decreased alertness while whole-body vibration conditions were shown to increase alertness. In their study, Ljungberg, J. K., & Neely, G (2007) [85] also wanted to investigate the differences in subjective noise sensitivity, discovering that those in the high noise sensitivity category demonstrated a significant decrease in alertness scores compared to the low noise sensitivity group (Table 3). Participants (n = 54) took Borg CR-10 tests after 44 minute exposure to each condition, with noise specifically being at 78 dB (about the same as a loud alarm clock). Additionally they found that pairing noise with whole-body vibrations increased alertness, using chairs fitted with rotating vibrating devices.

	Search and memory task			
	Accuracy	Speed	Errors	Rated Alertness
Noise only	1.5 (0.5)	926 (298)	14.8 (7.8)	3.1 (1.5)
Vibration only	1.7 (0.5)	948 (350)	16.6 (9.4)	4.0 (1.7)
Combined	1.6 (0.5)	943 (335)	15.8 (9.7)	3.5 (1.6)
Control	1.5 (0.5)	891 (325)	14.0 (8.5)	3.5 (1.8)

Table 3. Means and standard deviations showing rated alertness and accuracy (% of errors), speed (number of letters scanned) and number of errors in the search and memory task.

III. Color

Varying color temperatures have different effects on psychological states. Chellappa, S. L., et al,. (2011) [74] discovered that Blue light at 6500K increases alertness by around 22%, and decreases reaction times for sustained attention compared to other color temperatures (Figure 4). Participants' (n = 16) salivary melatonin was decreased under blue light, while orange light increased sleepiness levels the most. Following a two hour dark adaptation, subjects were then exposed to two hours of the lighting condition in a highly reflective white painted room. This means that subjects were fully integrated in the lighting condition.

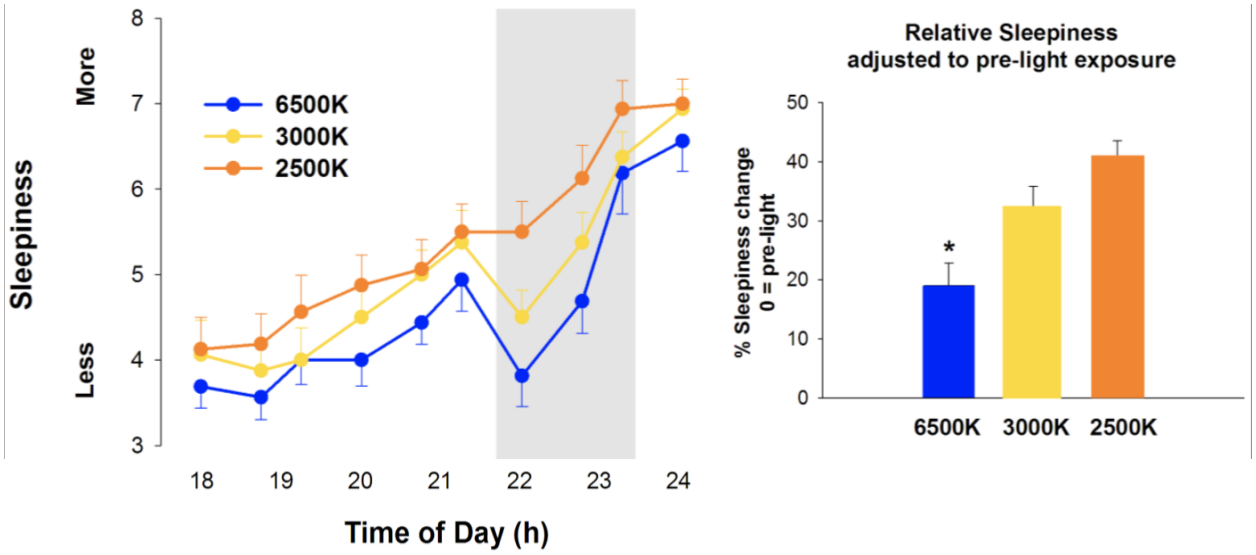

Figure 4. Sleepiness and well-being during pre-light, 2-h light (grey bar) at 6500K, 2500K and 3000K, and post-light.

In this study Wang, X et al,. (2016) [95] reported that grey and red backgrounds increased alertness more than a blue background (Figure 5). They also found that participants (n = 22) the effect of colored backgrounds is task-dependent, so depending on what neuropsychological state a person is trying to enhance, varying colors will have different effects. They measured the efficiency of attentional networks using an ANT task where participants were exposed to different background colors and asked to complete tasks as quickly as possible. For this experiment, longer reaction times indicated a higher alerting score and each subject underwent 3 blocks of 96 trials each.

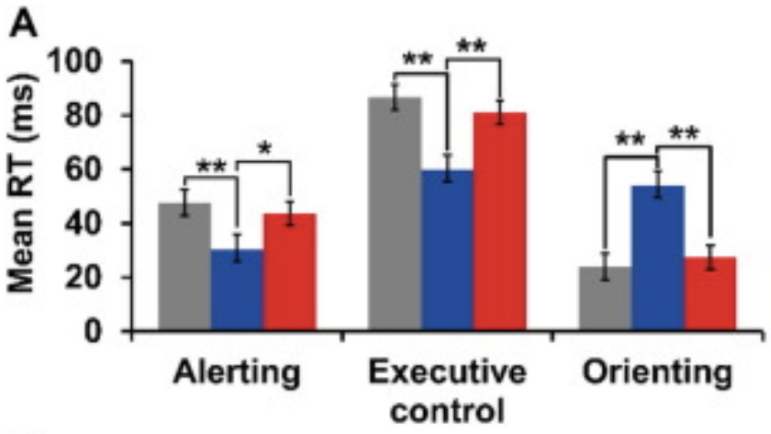

Figure 5. Color modulated attentional network differences

IV. Temperature

Alertness was found to be highest when body temperature was higher, during hours awake (Figure 6). To do this Wright Jr, K. P., Hull, J. T., & Czeisler, C. A (2002) [98] evaluated performance tests of participants (n = 14) over 12 days while monitoring their internal temperature every minute. They used the Visual Analog Scale to test for alertness throughout the duration of the experiment. Essentially they discovered that changes in temperature were associated with neurobehavioral changes.

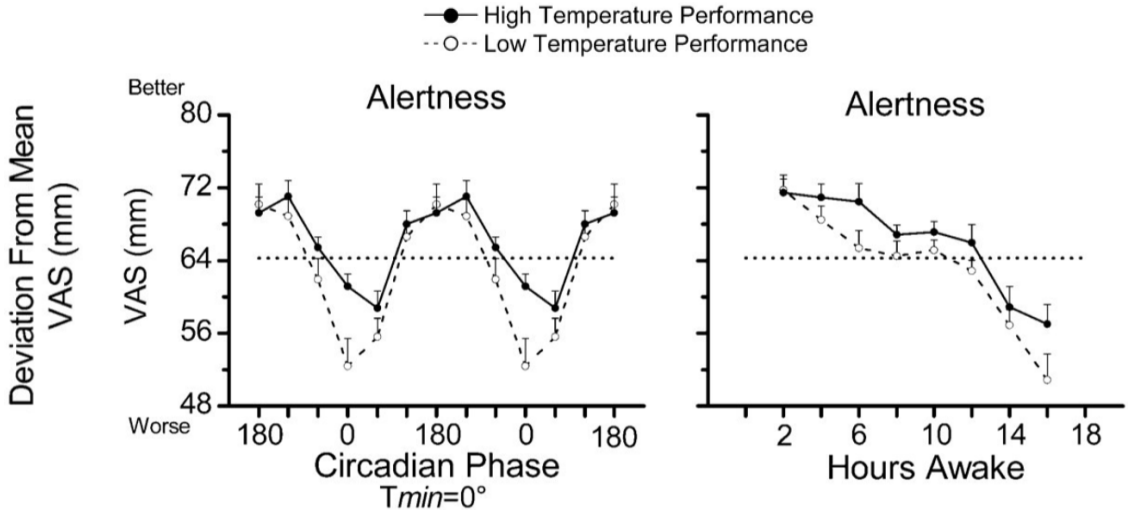

Figure 6. Variation in subjective alertness relative to high and low body temperature

Low ambient temperature was correlated with higher alertness scores amongst participants (n = 19). Te Kulve et al,. (2017) [92] found sleepiness scores on the KSS to be increased with warmer temperatures by placing participants in different temperature rooms (cool, 26 °C; thermo-neutral, 29 °C; and warm, 32 °C) for 75 minutes, during which they took the KSS questionnaire every 15 minutes (Figure 7).

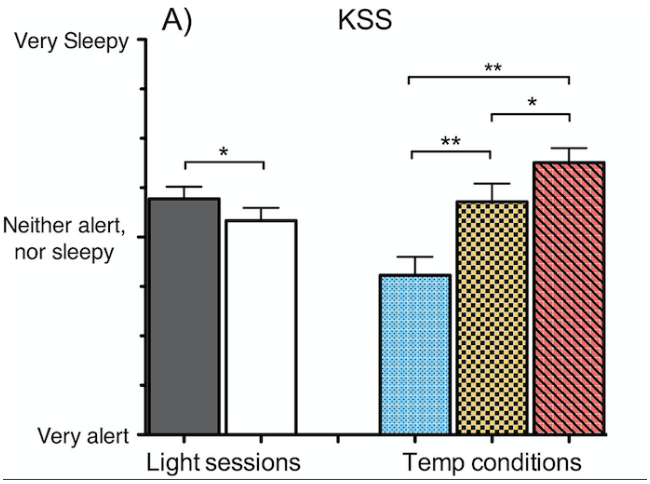

Fig. 7. Sleepiness as rated on the KSS

Engagement

Definition for the purpose of this project

We followed the definition of engagement as outlined by Cohen-Mansfield, J., Dakheel-Ali, M., and Marx, M. S. in their 2009 paper "Engagement in Persons with Dementia: The Concept and its Measurement" [105] which describes engagement as the act of being occupied or involved with an external stimulus.

Overview

Engagement was overall higher when the appropriate conditions were created.

- Regarding sounds, high noise environments ultimately resulted in decreased engagement. When applying this to architecture, avoiding placing living rooms or other social areas close to a high noise source like entrances or outdoor areas. Furthermore, creating multiple social spaces to prevent background noise from reaching hindering levels. More studies on sounds should be conducted to evaluate how low levels of music or other soothing sounds would impact engagement.
- In terms of lighting, normal or natural lighting conditions seemed to be most effective at increasing engagement, connections to secluded outdoor areas that provide quiet but include natural sunlight could be beneficial. More detailed examples needed on exact lux specifications.
- No data was found clearly linking color with engagement, this highlights an excellent opportunity for novel research.
- While temperature was mentioned and briefly investigated, researchers did not have sufficient data to characterize a relationship between temperature and engagement.

I. Brightness

Duration of engagement was longest under normal lighting conditions, compared to darker and brighter conditions for patients with dementia (Table 3). Cohen-Mansfield, J., Thein, K., Dakheel-Ali, M., & Marx, M. S. (2010) [76] discovered that the duration of engagement was 46 seconds longer in the normal lighting conditions versus the dark condition for participants (n = 193). Although there was a significant difference between the bright and normal lighting conditions, the difference was only 8 seconds. They utilized the Observational measurement of engagement (OME) to evaluate engagement with one of 22 stimuli, and lighting conditions were obtained through the environment portion of the Agitation Behavior Mapping Inventory. Overall, they suggest more detailed research to be done on the specific impact that lux has on engagement, however they report that properly regulating the lighting environment can positively impact engagement.

Modeling	Duration, mean (SD)
Light	
Dark	147 (194.00)
Normal	193 (127.78)
Bright	185 (266.89)
t-value dark versus normal (two-tailed)	$t_{(73)} = 2.24_{*}$
t-value normal versus bright (two-tailed)	$t_{(46)} = 0.12$

Table 4. Engagement duration for setting characteristics

II. Noise

In a 2020 study regarding environmental factors and their impact on engagement for people with dementia [75], Cohen-Mansfield found that high background noise was associated with significantly less engagement in participants (n = 69). The study included 6 different nursing home units that were placed in a larger geriatric center and lasted 3 - 4 months. Subjects were exposed to a total of 20 sessions, during which they participated for 30 minutes in one of 10 group activities like reading, singing/choral, baking, creative story-telling, brain games/fitness, active games, exercise, poetry, holiday newsletter, and holiday discussion. At the end of each session, engagement was assessed with the Group Observational Measurement of Engagement (GOME), while participants rated background noise on a scale from 1-4 (absence of noise, not distracting, normal with a few noisy outbursts, normal with a moderate amount of noisy outbursts or unpleasant).

Although minimal, engagement score was found to decrease for the highest exposure to noise level, compared to low noise levels. Weuve et al,. (2021) [96] report that higher long-term exposure to community noise (57 - 78 dBA) was associated with higher prevalence of MCI and AD as well as worse cognitive performance, like engagement. They chose to collect a degree of engagement through home-interviews and then analyzed the data compared to predicted noise levels (universal kriging model) at participants' (n = 5227) residential address. The study lasted 5 years and participants were all given baseline cognitive tests.

III. Color

After extensive research, to our knowledge, no data has been specifically collected on the effects of color on engagement. While some studies have assessed engagement in the context of websites and advertisements, they are not within the scope of this project. Relevant articles on color that were not included in our review can be found on page 57 in the "Other Articles" portion of this paper.

IV. Temperature

In their study, Cohen‐Mansfield, J. (2020) [75] attempted to evaluate temperature and light relative to engagement, however they had to exclude that data as there was not enough variation for a statistical analysis. That the idea of discovering a connection between temperature and engagement was explored however data should be replicated in a more controlled environment to determine if there is a relationship.

Ability to Concentrate

Definition for the purpose of this project

Concentration is defined as the act of focusing one's thought process to bear on a central problem. [100] For this paper we also use selective attention interchangeably with concentration as it similarly reflects focus on certain stimuli in the environment and not on others. [103]

Overview

- Brightness showed no significant effect on selective attention
- White noise and irrelevant speech interfered with selective attention in EEG recordings. In spaces like a kitchen it would be best to take into consideration the effect of noise, designing spaces that creatively block low level noise and preventing gathering of larger groups of people.
- By increasing fixation color was shown to have an effect on visual attention. Overall color increased focus more than a greyscale module. Specific colors were not discussed in this paper but it paves way for more research on different colors on attention.
- A colder condition increased selective attention, potentially indicating a mechanism by which room temperature could allow people to increase concentration. Applications for

activity rooms, kitchens and other places where increased concentration might be important.

I. Brightness

Rubiño et al,. (2020) found no statistically significant effects between selective attention and bright light therapy in participants (n= 37) with dementia. [89] They used the Comprehensive TMT 3 to evaluate selective attention where participants were exposed to normal lighting conditions for two weeks and 7000–10,000 lux for one week. Sessions lasted 90 mins and participants were instructed to carry out routine daily tasks and social activities.

II. Noise

Noise interfered with selective attention for participants (n = 48), challenging the attentional processes involved in concentrating. Trimmel, K., Schätzer, J., & Trimmel, M. (2014) [93] found that noise conditions (white noise and irrelevant speech) modulated the mechanism behind selective attention . This led to a positive switch in electroencephalogram potentials (EEG) from rejection of environmental stimuli (reject) and focusing on memory/planning processes in the control condition, to an environmental information processing and noise rejection mode (intake) (Figure 8). Four separate tests were used, two for rejection and two for intake measured through EEG potentials.

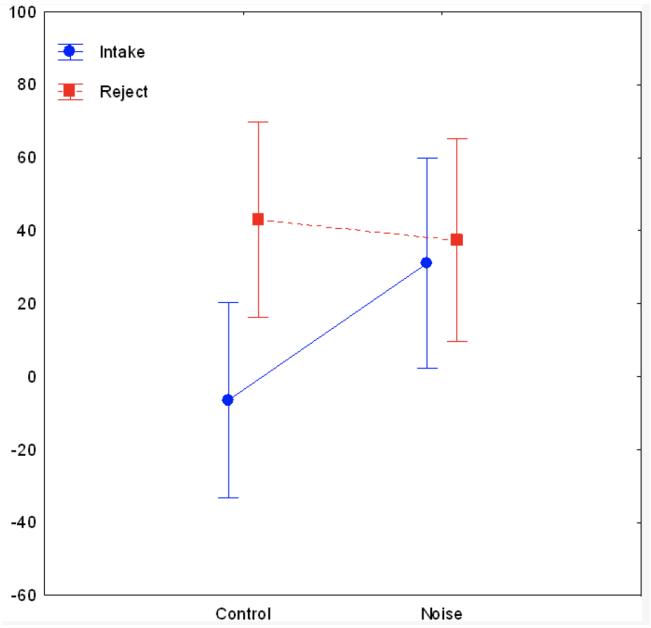

Figure 8. Mean values (±95% CI) of brain potentials for intake and rejection tasks in control condition and noise condition.

III. Color

Color models increase visual fixation more than greyscale models (Figure 9). Jost et la,. (2005) [83] compared computer models of visual attention with human attention by measuring eye movement in participants (n = 20). They created a saliency map to carry out this comparison and evaluated the average quantitative contribution of adding the chromaticity cue to a monochrome computer model of visual attention. Visual attention was measured using a spatial pattern of fixations since visual attention and eye movements are tightly coupled. They conclude by highlighting the usefulness of a chromatic cue in the saliency map model demonstrates the important influence of color on human visual attention. The paper goes into more detail on the computational neuroscience aspect of visual attention and saliency maps, but more in depth research on which colors specifically would increase fixation would be an interesting topic.

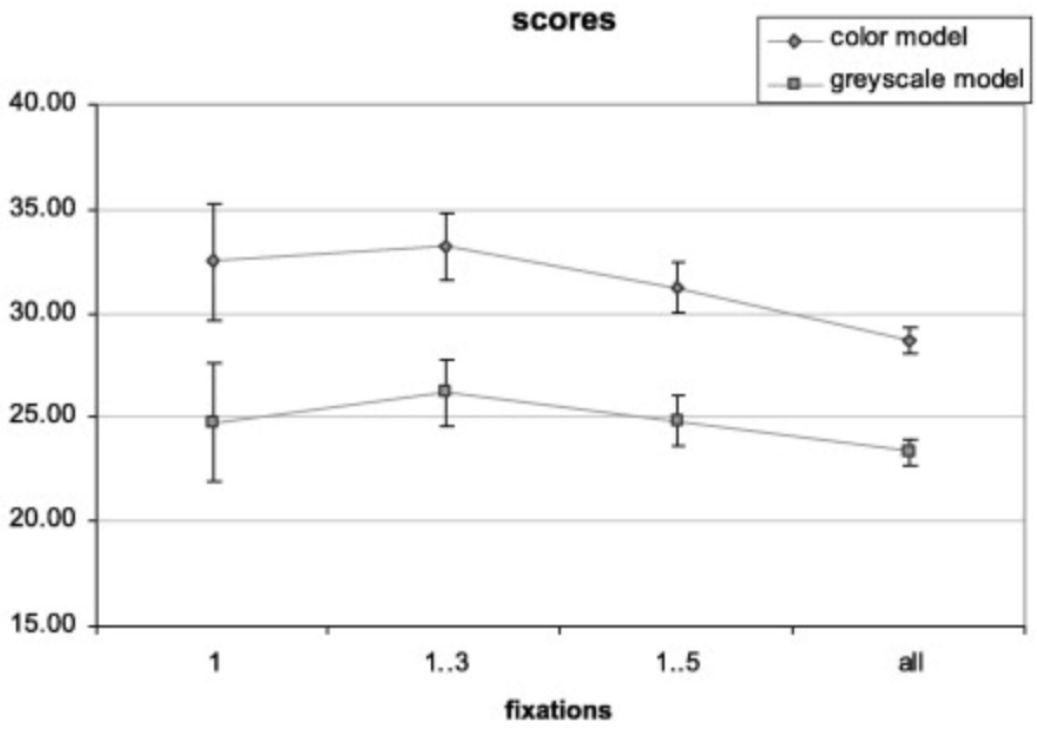

Figure 9. Overall score saliency score vs. number of fixations

IV. Temperature

Stroop Color Word Test (SCWT) revealed higher selective attention after cold water hand immersion (CWHI). Gerhart et al,. (2019) [80] conducted this experiment to evaluate selective attention with altered oxygen levels and oxygen pressure, however the study revealed that CWHI at 5℃ for 15 mins improved selective attention in participants (n = 10) compared to the resting

condition (Figure 10). They propose that this result may have been modulated by increased sympathetic nervous activity in response to decreased finger temperature and increased ratings of thermal sensation during CWHI. Although no causal relationship was investigated, this could indicate an association between selective attention and different temperatures.

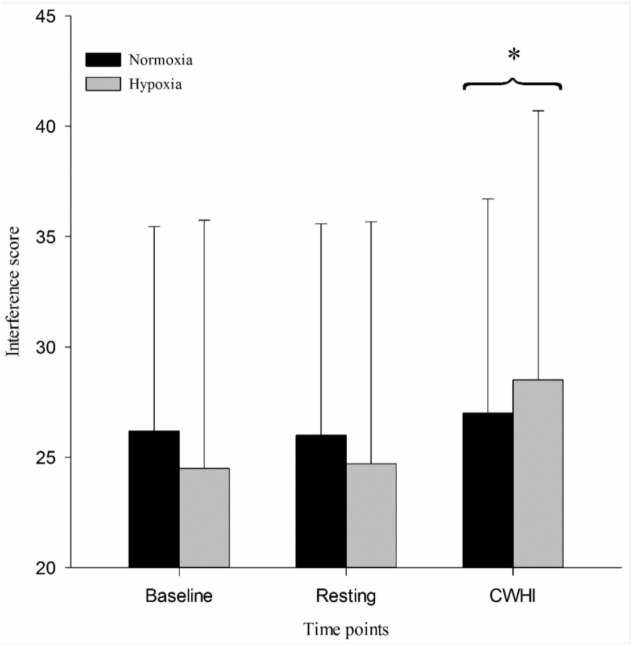

Figure 10. Interference score of the Stroop Color Word Test during baseline, resting, and Cold Water Hand Immersion

Stress

Definition for the purpose of this project

Stress is defined as the physiological or psychological response to internal or external stressors [104]. We utilize agitation as a means to measure those responses as well as subjective stress tests.

Overview

- Subjective general health was decreased as a result of increased noise and personal project stress. Personality differences aside, this could provide an opportunity for design to insulate sound better in rooms or consider the general noise level in different areas throughout the facility.
- For dementia patients, bright light conditions could help reduce agitation. Besides exposure to natural light and activity in the outdoors, bright and even light should be

present throughout the space, especially because residents may live there for many years, decrease in depression and agitation is important.

- The effects were not a main conclusion of the study and evaluating the relationship was not within the scope of the experiment, however, blue light was found to reduce the time it takes for post-stress relaxation. This could be implemented into hallways as a means to protect patients following a stressful situation.
- Temperature was found to be very important in regulating agitation. Depending on weather, seasons and other factors, special materials should be considered to maintain proper temperature. Placement of windows or open spaces could be designed to maintain even temperatures throh guotu the day and avoid increasing agitation in patients.

I. Brightness

Agitation decreased 20% following exposure to the bright light condition for patients with dementia (Figure 11). Onega, L. L., Pierce, T. W., & Epperly, L. (2016) [87] found that participants (n = 30) exposed to the brighter light condition (10,000 lux) for an hour a day, five times a week over an 8 week period showed decreased levels of depression and agitation compared to the low intensity light condition (250 lux). They utlizied the Cohen-Mansfield Agitation Inventory-Frequency (CMAI-F) to asses agitation. The researchers suggest this finding should encourage more research on optimal locations for permanent bright lights in homes and long-term care facilities,while also considering novel strategies for including exposure to bright light in daily patterns of an individual with dementia.

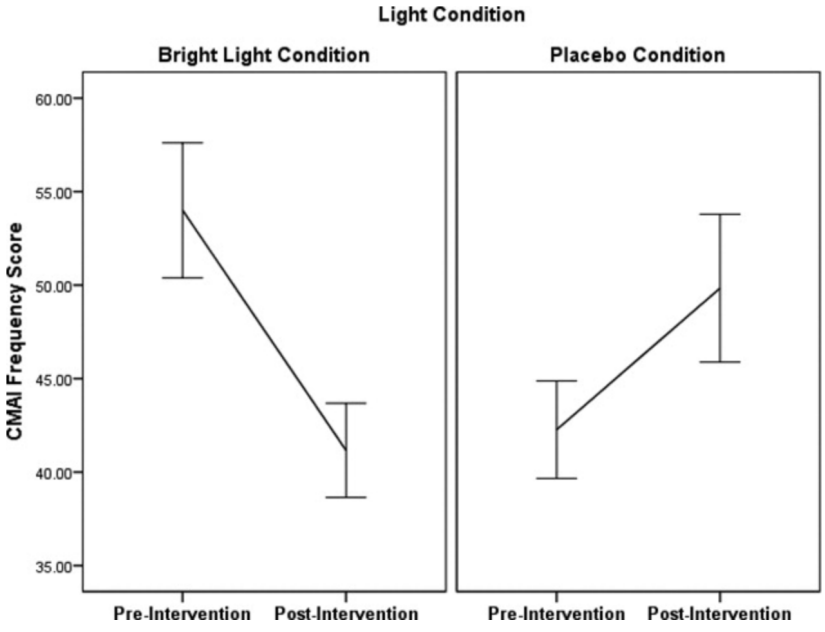

Figure 11. Effects of bright light condition and time of testing on Agitation

II. Noise

Noise annoyance and disturbed daily activities are related to poorer subjective general health. Wallenius, M. A. (2004). [94] found that if participants (n =193) have high personal project stress, then noise stress variables increase general health and somatic symptoms too. Using Little's Personal Project Inventory, the Somatic Symptom Checklist, questions concerning noise annoyance and disturbed daily activities, the results reveal an interactive effect of noise stress, self-rated general health and somatic symptoms, as adaptive costs of coping with multiple stressors. For example, they found that annoyance due to noise inside the house as well as disturbed daily activities providing restoration or demanding concentration (e.g. sleeping, relaxing, reading or studying) interacted with personal project stress (Figure 12). They ultimately explain how in stressing life situations, noise annoyance either demands additional cognitive effort to concentrate or inhibits recovery from stress and fatigue at the cost of elevated psychophysiological functioning.

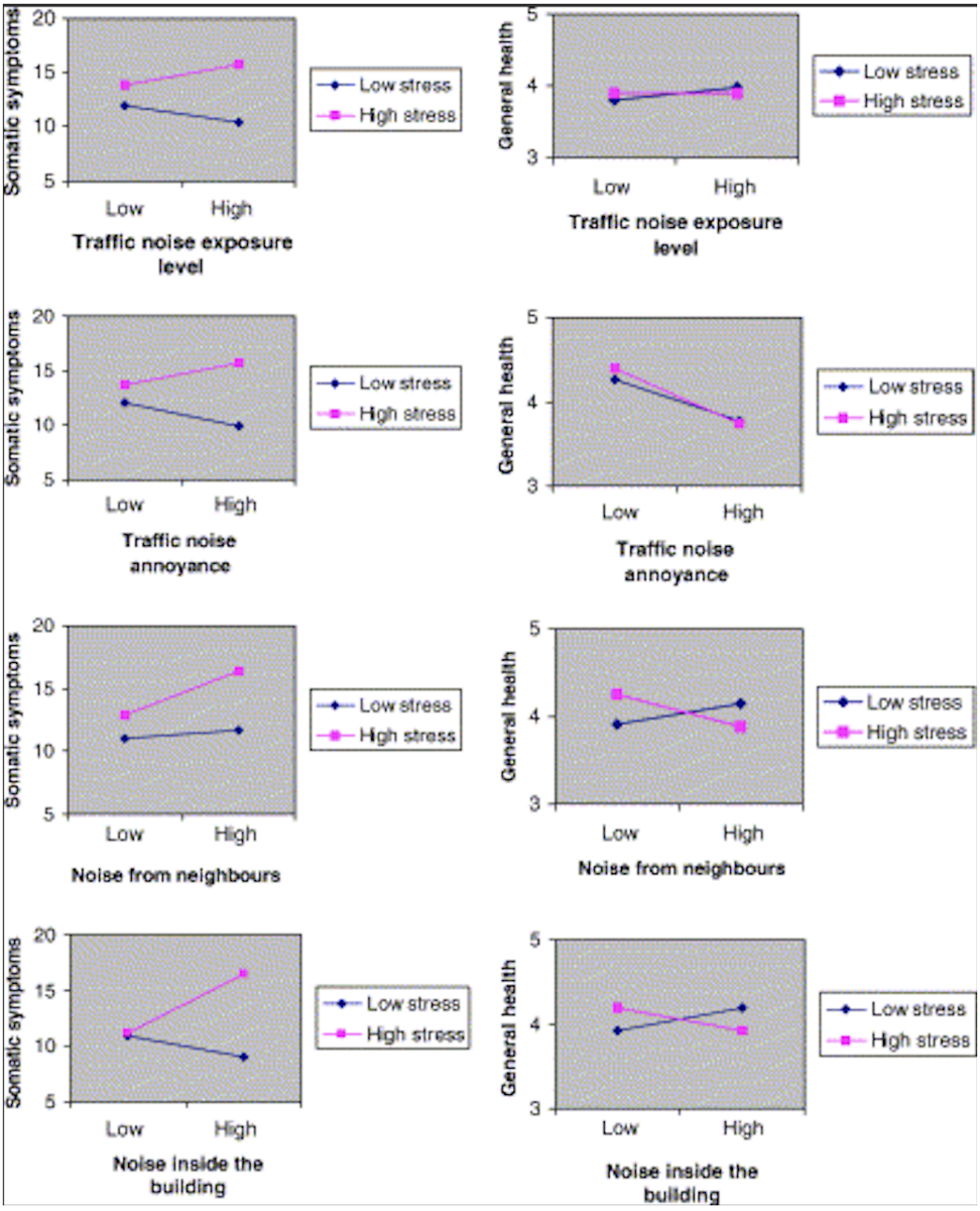

Figure 12. The interaction of noise stress variables and personal project stress in the prediction of somatic symptoms and self-rated general health

III. Color

Blue light was found to accelerate the post-stress relaxation in comparison with conventional white light after induction of a stress condition through MIST (n = 12). Although Minguillon et

al,. (2017) [86] identified this relationship, they emphasize that physiological and psychological mechanisms underlying the influence of color on human beings are out of the scope of their study. So more research needs to be done on the specific effects that blue light may have on stress.

IV. Temperature

Tartarini, F., Cooper, P., Fleming, R., & Batterham, M. (2017) [91] found that agitation in the was significantly correlated with the amount of hours that residents were exposed to temperatures higher than 26℃ and lower than 20℃ over a 10 month period. Using the Cohen-Mansfield Agitation Inventory (CMAI) they report that disruptiveness in participants with dementia (n = 21) decreased when the average indoor air temperature was approximately 22.5℃ (Figure 13, Figure 14). They conclude that their research provides quantitative evidence regarding the specific impact that the thermal environment had on the manifestation of agitated behaviors in residents with dementia

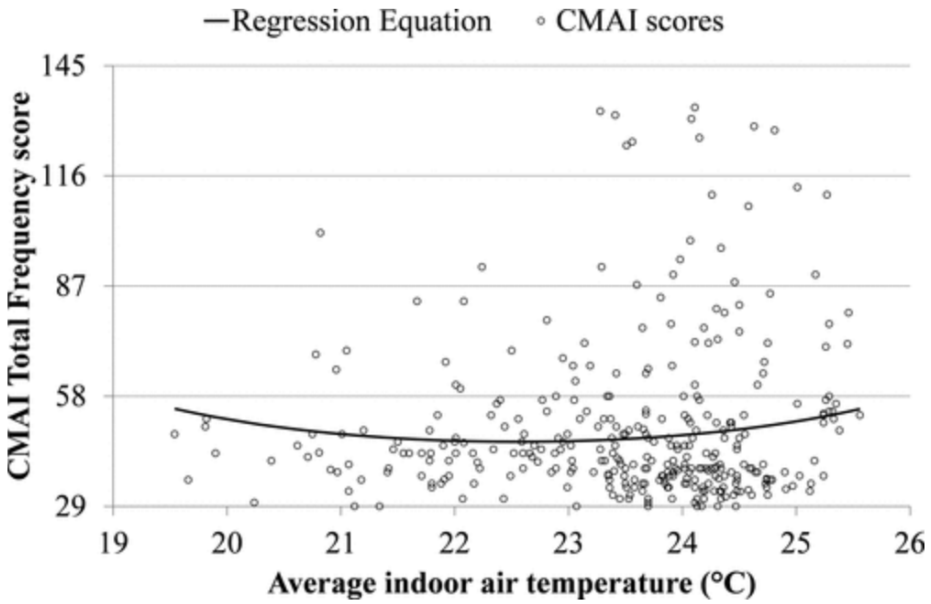

Figure 13. CMAI Total Frequency scores against the average temperature

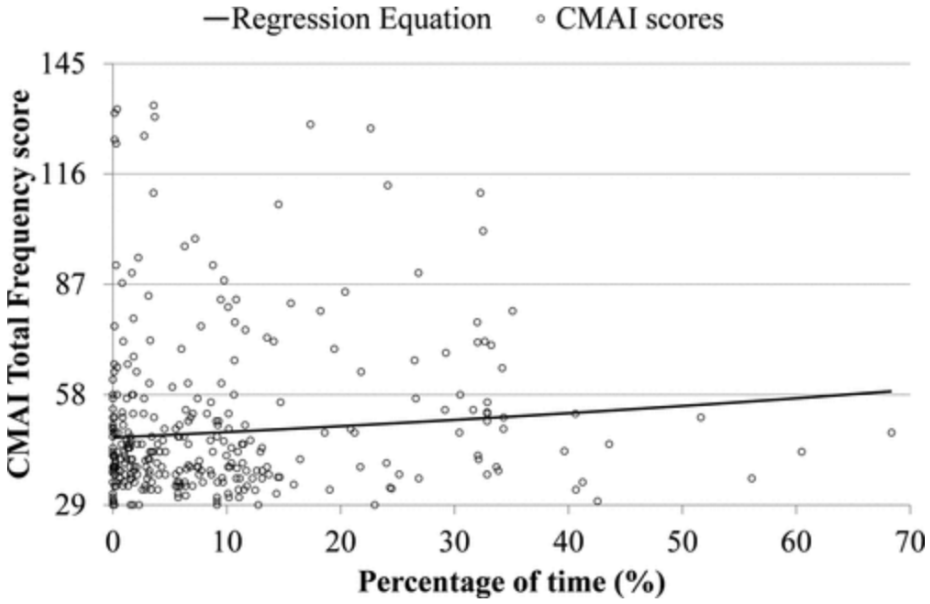

Figure 14. CMAI Total Frequency scores against the cumulative percentage of time that temperatures were outside the comfort range

Memorability: Ability to Recognize

Definition for the purpose of this project

We focus on recognition memory based on a sense of awareness and familiarity experienced after encounters with people, events, or objects that have been encountered before. This could also include recognizing material that has been learned before. [102]

Overview

- Color cues significantly shorten recognition time, where hallways, doors and certain rooms could be adapted by including colors that would increase recognition. More details are needed on specific colors that could be used as markers, however, this data is a step towards having identifiable markers to increase recognition.
- Recognition rates were found to be higher for a specific amount of lux, where lighting conditions could be modified during moments where recognition is important. Having a space where light changes when family members come to visit to encourage as much recognition as possible. This could also be applied generally throughout a facility.
- Findings on noise could benefit the organization of a facility more than specific design features, making sure to plan spaces that minimize confusing noise. As people get older they lose their ability to recognize words and sometimes even sounds so also having

visual signals that could help them recognize where they are or what is going on rather than solely depending on hearing.

- Room temperature aside, the body temperature of patients should also be strongly considered. This could mean creating different rooms with alternating wall thicknesses tailored to a person's ability to thermoregulate.

I. Brightness

Recognition rate was 15% higher in the 400 lux condition than the 300 lux condition (Table n). Lee, C. W., & Kim, J. H. (2020) [84] evaluated long-term memory recognition over 4 brightness levels, the 500 lux and 1000 lux conditions showed similar recognition rates, with 300 lux having the lowest rate (Table 5). Using the Word Fragment Completion Task, participants' (n = 18) long-term memory was assessed as they correctly recognized words out of a 20 item nonsensical list.

Illuminance levels (lux) (lx)	Attention (a number of times)		Long-term memory (%)		*N*
	Mean	SD	Mean	SD	
300	16.22	3.78	43.33	19.10	18
400	17.50	5.54	58.06	22.57	18
500	18.00	5.18	48.89	20.33	18
1000	19.39	5.42	45.83	23.53	18

Table 5. Descriptive statistics of attention and long-term memory according to illuminance of LED lighting

II. Noise

Significant decline in cognitive ability of older persons to recognize speech in noisy environments was found. Pronk et al,. (2013) [88] evaluated participants (n =1298) over 3 - 7 years to characterize decline in hearing. While not the focus of their study, these findings can also indicate higher levels of stress, depression, anxiety and loneliness in older populations along with the inability to properly recognize certain sounds. This research could pave the way for more examples on how these states could be attenuated through mechanisms that improve recognition.

III. Color

Recognition was 5-10% higher for colored versus black-and-white images, independent of exposure duration (Figure 15). In their study, Wichmann, F. A., Sharpe, L. T., & Gegenfurtner, K. R. (2002) [97] report that color played an important role in recognition memory for participants (n = 36) where the proportion of correctly recognized images was higher for the color condition. Instead of using a neuropsychological measure, they assessed recognition through proportion of correct responses.While they explore the factors that contribute to recognition memory through four other experiments, they conclude that unlike color, presentation duration and contrast play a more important role in short term memory rather than long term memory.

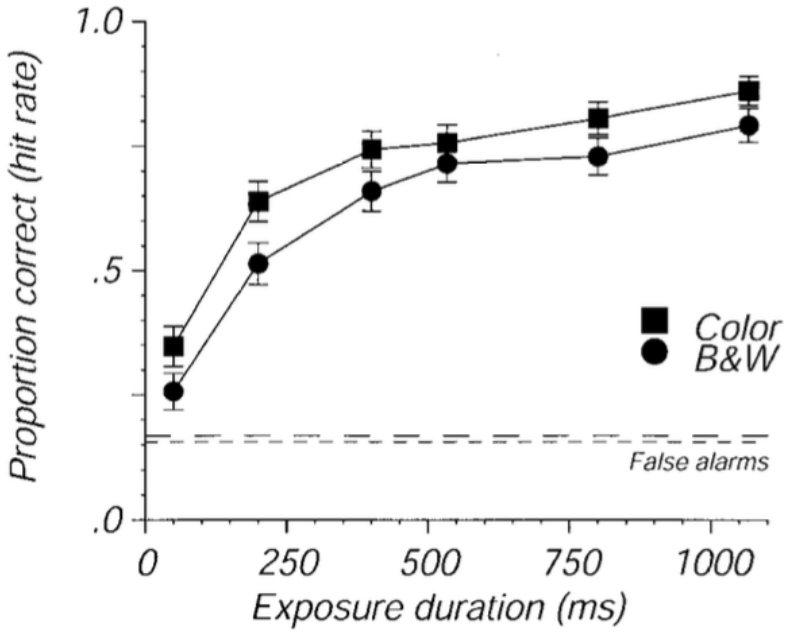

Figure 15. Proportion of correctly recognized images (hit rate) as a function of exposure duration of the images

Color cues significantly shorten recognition times than from cues (Figure 16). Cernin, P. A., Keller, B. K., & Stoner, J. A. (2003) [73] found that the use of color in the environment as a memory aid may ultimately improve day-to-day functioning. Using Color-Form Memory Cards, participants' (n = 63) recognition was assessed. Overall, they suggest that it may be possible to color-code certain aspects of the environment, such as room doors in a long-term care facility.

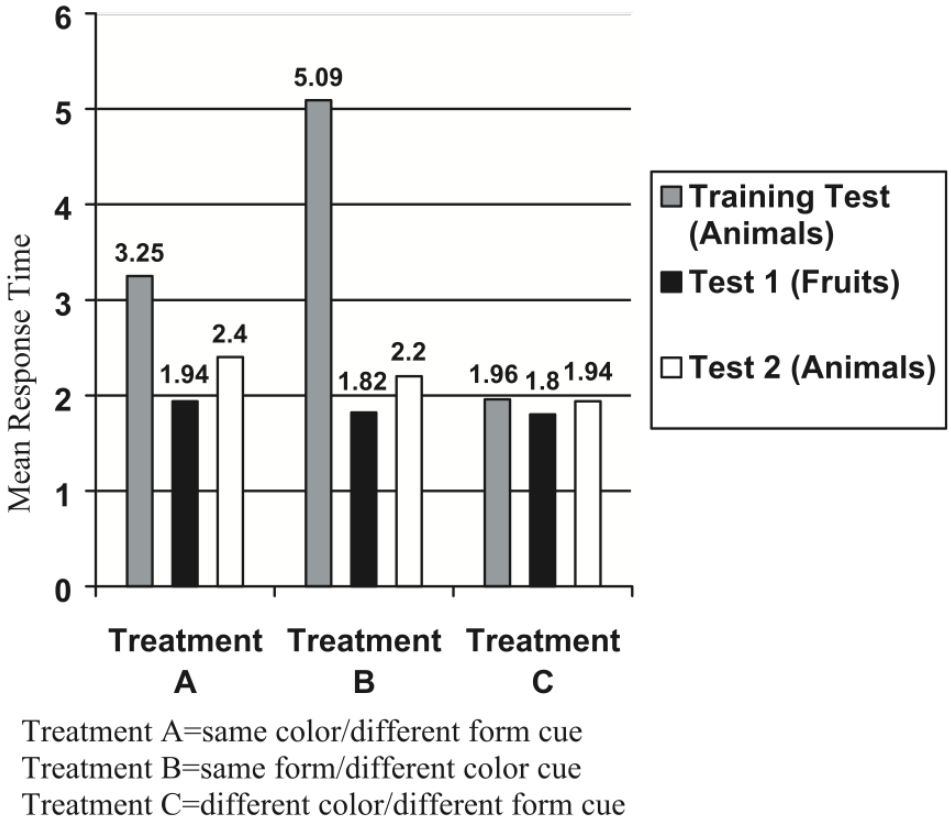

Figure 16. Mean response times for training tests, Test 1 and Test 2 for the three treatment conditions.

IV. Temperature

Recognition scores were lowest in the hot condition compared to a control and hot with head cooling conditions. Gaoua, N., Racinais, S., Grantham, J., & El Massioui, F. (2011) [79] found that participants (n =16) whose heads were cooled down did not show as much decreased recognition as the full body hot condition (Figure 17). A wireless Mini Mitter Jonah™ ingestible thermometer pill was swallowed at least 5 h before each trial. Although both memory task performances decreased in HOT, the regular application of cold packs on the head only prevented the detrimental effect of hyperthermia on short-term memory capacity. This could be explained by a physiological alteration of the brain, related to the heating of the cortical neurons.

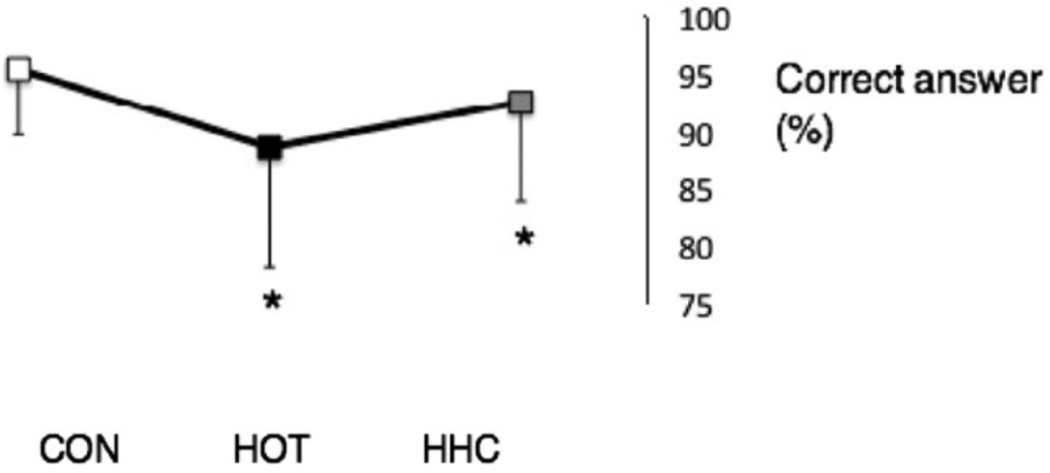

Figure 17. Pattern recognition memory in a hot condition

Memorability: Ability to Recall

Definition for the purpose of this project

Recall is defined as the ability to retrieve and reproduce information that has been previously learned. [101]

Overview

- Everyday sounds have been shown to help with the ability to recall, but specifically familiar music can increase this ability substantially compared to other more regular sounds. While familiarity may be subjective, more studies could be done on generalizable familiar music to potentially help a broader range of patients with their ability to recall.
- Increased body temperature resulted in no significant differences in ability to recall.
- No effect relationship was explored between brightness and ability to recall, however we propose that more research be done on this topic as it can potentially have very positive impacts that could be implemented into design desatures at care facilities.
- Although increased ability to recall following blue light exposure was acute, it highlights potential uses of specific colors in moments where recall may be important. This study however exposed participants to the light during the memory consolidation portion of the experiment rather than active recall, therefore it may be relevant to consider if there are ways to benefit recall at that moment.

I. Brightness

No data was found linking brightness to recall. While there was an effect on brightness on recognition, studies could focus more on the ability to retrieve information once recognized.

II. Noise

Background music was found to facilitate autobiographical recall in dementia patients (n = 29). Foster, N. A., & Valentine, E. R. (2001) [78] found that background noise specifically from novel music and familiar music, increased recall scores by 13% in participants, more than a quiet or cafeteria noise condition (Figure 18). Their assumption is that auditory stimulation can potentially mask the effect of other distracting stimuli as long as the recall task does not require full processing capacity. Based on previous studies, they selected music matched in tempo, which has been found to play a role in recall. They extracted 27 questions from the Mini Mental State Examination (MMSE), exposed participants to the music, and then rated their accuracy out of 30 points (date of birth counts for 3 points).

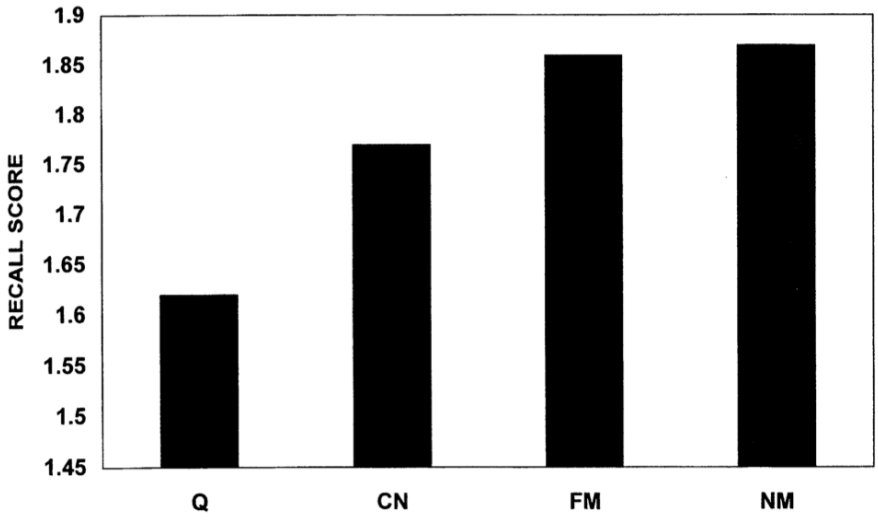

Figure 18. Autobiographical recall in quiet, cafeteria noise, familiar music and novel music.

This qualitative paper on dementia patients found that exposure to everyday sounds triggered personal associations, memories of the past and emotional responses. Houben et al,. (2019) [82] studied how sound-based interventions can help in enriching the everyday lives of people with dementia. The researchers highlight the importance of taking personal experience into consideration and provide quotes from participants to support their statements. They explain that incorporating every day sounds (Table 6) in design and proving spaces of tranquility can help with well-being, reduction of stress and memory. To do this, they utilized a soundscape device

that replicated everyday sounds along with an object where participants (n = 11) were encouraged to share experiences, recall, and have group conversations for an hour and a half.

Soundscape/ Layer	*Beach*	*Forest*	*City*	*Home*
Human	*Children*	*Footsteps*	*Market*	*Kitchen*
Animal	*Gulls*	*Birds*	*Pigeons*	*Cat*
Water	*Waves*	*Creek*	*Fountain*	*Thunder*
Background	*Wind*	*Trees*	*Traffic*	*Fireplace*

Table 6. Soundscape layers used to elicit memories in dementia patients

III. Color

Acute exposure to blue wavelength light during memory consolidation was found to improve verbal memory recall performance (Figure 19). Alkozei et al,. (2017). [72] found that exposure to half an hour to blue light increased participants (n = 12) verbal memory recall (assessed through California Verbal Learning Test II (CVLT II)) compared to amber light exposure (n = 18). They suggest that these findings may have important implications for clinical populations with memory impairments, as well as for healthy individuals who want to improve their ability to retain newly learned material.

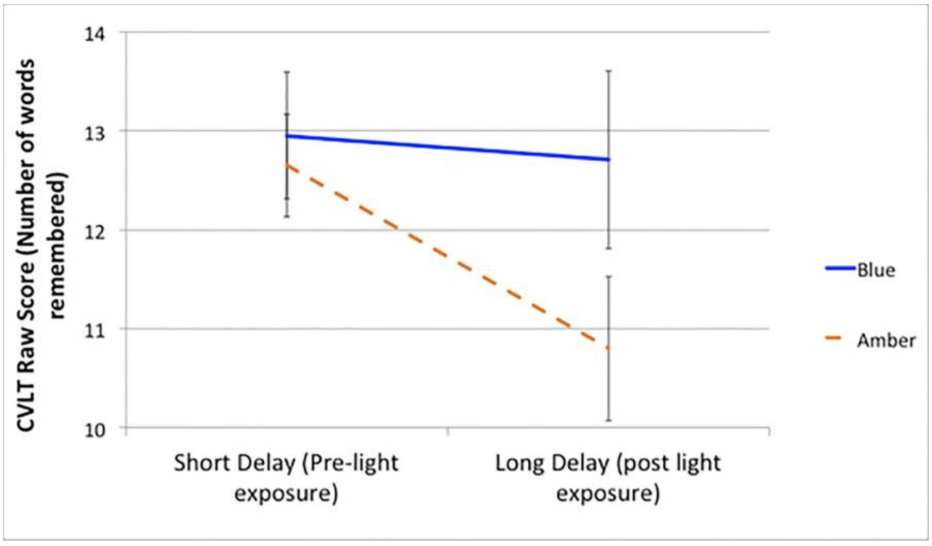

Figure 19. Recall scores for individuals in the blue (n = 12) and amber (n = 18) light groups.

IV. Temperature

Ability to recall was unaffected by increased body temperature, whereas speed of performance was positively impacted. This study by Holland et al, (1985). [81] was done over 36 years ago, does not utilize any standardized neuropsychological measures and to our knowledge no studies have attempted to replicate the findings or evaluate the relationship between memory recall and temperature.

Summary Table

What effect do different architectural features have on neuropsychological states and processes				
Neuropsych performance measures	**Architectural stimulus**			
	Brightness (lumens)	Noise level (db)	Color (rgbiv)	Temperature (F)
Alertness	Longer exposure to higher lux appears to have a larger effect (18%) on alertness than brief exposure to higher lux (10%).	Exposure to noise decreases alertness, while noise paired with whole-body vibrations can increase alertness.	Blue light increases alertness during the evening (avoid using blue light in spaces designated for sleep) while blue color decreases alertness in other conditions.	Low ambient temperatures and high body temperature increase alertness.
Engagement	Increased engagement under normal conditions compared to dark or brighter	Higher chronic background noise exposure results in decreased engagement	No data	Not enough data and variability to carry out the test
Ability to concentrate	No statistically significant effects between sustained attention and bright light	Noise condition interferes with selective attention and concentration	Color condition increases fixation attention by 25%	Exposure to lower temperatures increases selective attention
Stress	Brighter light condition decreases agitation by 20%	Noise annoyance related to poor subjective health outcomes and increased stress	Blue light accelerates relaxation following stress induction	Agitation is correlated with amount of hours spent above 26°C and below than 20°C
Memorability: Ability to recognize	15% increase in recognition for specific illuminance levels	Significant decline for elders in ability to recognize speech in high noise environments	Color cues linked to shorter recognition response times and higher recognition rates.	Higher body temperature associated with lower recognition scores
Memorability: Ability to recall	No data	Noises like music and everyday sounds have been found to increase ability to recall.	Acute exposure to blue light during memory consolidation improves verbal memory recall performance	Ability to recall was unaffected by increased body temperature

Table 7. Effect of architectural features on neuropsychological states and processes

Discussion

A lot of the concepts were first studied in the 70's and 80's, and with a significant amount of data, modern researchers have been able to take those original ideas and continue investigating relationships and connections. That said, there is a lot of research that still needs to be done, either to reinforce existing findings or to discover new ones based on relationships that have not been previously studied. Overall this paper serves to point out just how much research still needs to be conducted, new ideas for topics that could be studied and how all of it connects to dementia to create more effective and efficient environments.

Future implications

We encourage researchers to investigate these kinds of relationships between neuroscience and architecture, be it from the same categories or others inspired from this review. The intention is to continue bridging the gap between the two fields by collecting information, analyzing it, and presenting it in a more accessible manner. We hope architects take this as inspiration to delve into these topics as they design spaces and to look further into features that could be adapted for more effective environments.

Interviews

We conducted interviews with experts (n = 5) in their respective fields and the average interview time was 60 minutes. After filling out a consent form, the interview started with three general questions, followed by field-specific questions, and ended with 3 concluding questions. Overall, participants were contacted through personal networks and their identity will remain anonymous. From the interview responses, we narrowed the set of salient factors in both design and neuroscience to conduct the literature review from this paper.

Consent forms found in Appendix A

Open Questions

I. General

- How much do you know about Dementia?
  - 1 - Not at all familiar
  - 2 - Slightly familiar
  - 3 - Somewhat familiar
  - 4 - Moderately familiar
  - 5 - Extremely familiar

- How much do you know about design for Dementia?
    1 - Not at all familiar
    2 - Slightly familiar
    3 - Somewhat familiar
    4 - Moderately familiar
    5 - Extremely familiar

- If at all, how long have you known someone with Dementia?
    A. 0 years, some, many years

II. Architects

All architects are experts in the field, 2/3 are familiar with Dementia design and are somehow involved in a project related to this concept, but 1/3 has had some experience designing for Dementia, however not as a lead architect.

- Have you ever designed specifically for Dementia?
    - If yes
        - Briefly describe some things you designed for Dementia. Please identify the specific Dementia adaptations.
        - What were the key concepts that informed your design?
        - What attributes of people with Dementia were hardest to design for?
        - Did your design process require you to depart from your standard design method or your repertoire of prior ideas?
    - If no
        - What do you think are the most important concepts that should inform your design?
        - If you have visited a care facility for people with Dementia, briefly describe one or more things you saw that were an interesting adaptation you would consider using yourself. Were you the designer of that facility?
- What are challenges when designing for Dementia?
- Have you heard of any new/surprising up and coming ideas regarding design for Dementia?
- Related to Architecture & Alzheimers: What would you ask a neuroscientist?
- Do you know anyone we can contact who has designed or built specifically for Dementia?

III. Neuroscientists

Both neuroscientists are knowledgeable but not experts in the field. They are both involved in projects closely related to Dementia and have had some exposure to designing for Dementia.

- Have you done any reading in the area of Dementia?
    - If yes,
        - Have you done research on any of the topics yourself?
        - What were the main takeaways of your research?
- Questions regardless of background
    - What symptoms or manifestations of the disease do you think are particularly relevant when designing for Dementia?
    - What are some neuroscientific findings you think architects should keep in mind when designing for Dementia?
    - Are any of these things derived from your own research?
    - Do you have any suggestions for architectural designs that you think would be beneficial?
    - Do you know anyone we can contact who has designed or built specifically for Dementia?

IV. Conclusion questions

- Do you have some suggestions for improving this questionnaire?
- What should we have asked you that we did not?
- How important do you think the topic of design for AD/MCI is?

    1 -Not important
    2 - Somewhat important
    3 - Important
    4 - Extremely important

Excerpts from Interviews with Architects

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Architect #	Excerpts
1	• On wayfinding ○ "What is it that you can do within the physical space that can make the navigation accomplish what it should be accomplishing. We were talking about ways in which horizontal or vertical surfaces could change, what text if anything there should be, are there destination points that give you a sense of where you are, that are very distinct in this roadway that you are on. How do you actually enter one space from another, how is it enclosed, does it change in terms of light quality, whether natural or electric." • On adaptations for dementia ○ "[Design] is the means by which you can maybe over emphasise in order to compliment the deficiencies that the individual may have, how can you take the building to a level that is comprehensible to that person with the physical discounts that they have." ○ "[Evidence] still may not be more than a laboratory condition, but still if you can show that this has worked under certain conditions then I think we'll see more and more facilities attempting to make these small modifications until it becomes an industry-standard." ○ "There is something called universal design and the purpose of it is to say that we shouldn't necessarily just have design changes for a specific group, but that certain things can be incorporated in all design, that doesn't necessarily impinge upon people who don't have a disability, for instance. That it is so intricate that you don't necessarily perceive it as being unusual or inappropriate, and that is what you really want to try and achieve and there may be certain things that we can do within an Alzheimer's facility that is just standard good architecture." • On lighting ○ "Lighting is extremely important. And it needs to change depending on the time of day, so it has a connection to circadian rhythm and it also has a very important connection to the spaces that you're going through and obviously the condition of the person. But can you generalize enough … where you are aiding them in such a way where it deals with the disability and provides additional assistance towards navigation." ○ "Investigations on LED lighting whether it's organic or not, the kind of light and where you put the light fixture and is it above or is it below at where is it in the room, its intensity its color all those things make a big difference and that's the kind of thing that i was beginning to look into." ○ "Lighting is definitely on the list and the more sophisticated we get in that area of engineering and design, the better we are going to be, where lighting can actually know who's coming and account for certain needs." • On memory ○ "One accepts memory is not where it should be, and therefore you need to support them, or support them in such a way where they need to do less on their own" • Concluding remark ○ "If you account for the fact that we have an aging population and we probably don't have enough congregate care facilities or care workers to take care of everyone, this is a big problem for senior citizens in the future anyway. I think that we need to move very quickly to see where architecture can help."
2	• On wayfinding ○ "I think one of the things that we need to work with patients with dementia is navigation, wayfinding, orientation and maybe recreating some of the traditional ways of understanding what it means to be cozy and create that secure environment for them. Most of the time people feel lonely or threatened, so

	I think one of the things that we need to work on is a little bit more with those memories and stimuli that were from the past and maybe recreate them."
	• On designing for dementia
	  ○ "As architects we need to change the way we design, we need to focus more on the methodology of finding information, and one of the things that happens is that we normally go for the intuitive rather than the scientific"
	  ○ "A lot of the time we create spaces for dementia, like geriatric facilities, that are designed with the traditional methodologies of creating buildings for normal people with certain adaptations instead of focusing on the strategies specifically for people who already have dementia."
	• On color
	  ○ "I saw this strategy from an architect, who believed that color could help a patient find their own floor and where their bedroom is. So he painted the hallway yellow and when the patient moved in they told them what color they were assigned to in the hope that they would recognize it. But I don't believe that is the right answer, I think that is not the right strategy because the yellow doesn't mean something for the patient, maybe they will learn in the process but maybe they won't because maybe it's too late to learn something"
	• On senses
	  ○ "There are other senses that implicate more than just seeing a color but rather combine different affordances, multisensory and whole body. Sometimes it is about creating the right atmosphere for these facilities using more than once classic constraints."
	  ○ "We think that sight is the most important rather than other senses. We never talk about how someone moves in space, how the elements are closer to someone's body, what is the smell or sound of a material, how it feels, cold, heat … it is a dialogue that is already there but needs to be discussed more."
	• Closing remark
	  ○ "I find myself asking a lot of questions about what happens in our brains, let's say while we're in a dementia facility, is it possible to have neuroplasticity? Is it possible to recover function? Can Alzheimer's ideas be reversible? How can architectural elements stop the degeneration process, can we slow it down, can we help recover function?"

3	• On designing for dementia
	  ○ "I know it in terms of short term memory loss, wayfinding, increased anxiety and fear, panic attacks, aggression. Regarding design, I know there has been an attempt at creating design appropriate for people with special needs or certain cognitive impairments"
	  ○ "There is a certain philosophy based on medicine where colors, shapes, forms are considered to better an environment for people with specific impairments. Those kinds of spaces go to show that there is a lot of variety in people, they have different needs. More people might need higher consideration of colors, space, organization and people who have more severe forms of impairment need to be considered even more."
	  ○ "We need to consider that people move at different rhythms, especially at that age and with impairments. Making sure that there are opportunities to engage them in the kitchen, bathroom, bedroom and increasing their likelihood of recall."
	  ○ "They have to be surrounded by familiarity. Especially if their impairment is severe it is harder for them to live independently. A lot of places have a very institutional look, even though medicine needs to be considered, there needs to be comfort and consideration of social needs. It is not meant to be a hospital or make them feel trapped, rather to encourage independence as much as possible while the more complex tasks are taken care of."
	• On wayfinding

	○ "Creating communities that allow for spaces to be better adapted for people with particular impairments that highly considers wayfinding and orientation. It is important to make it easy for people to move around space." ● On dementia ○ "It would be important to have a study where the specific impairments of cognitive decline are assessed, how wayfinding, colors and space interact together. It is essential, however, to do this while conserving as much autonomy as possible. Being in an environment when you constantly feel accompanied or dependent must be very frustrating if they have gone their whole life with a certain degree of autonomy." ● On multisensory features ○ "Sound is very important, the space needs to be acoustically absorbent so as to not set the sympathetic nervous system in overdrive. Maybe considering colors that are less harsh, more soothing while avoiding white and other colors that make it look institutionalized, it should feel like a home. Also considering furniture and texture, haptics that encourage comfort, avoiding sharpness and coldness. I also think it should be rather minimalistic, having decorations that will allow you to move freely in a space without cluttering, lots of vegetation and keeping personal things to their room"

Excerpts from Interviews with Neuroscientist

Neuroscientist #	Excerpts

1	• On designing for dementia
	  ○ "I would say that probably the most important one would be confusion. I'm assuming that most of these people move into these independent living facilities post-diagnosis or like post start of the symptoms and another with Alzheimer's a lot of the time new memories that are formed after the diagnosis or what has a really hard time sticking and the beginning of course all of it goes towards like the more Progressive stages but I'd say in the beginning like when they're still able to live independently most of their memory that's going to be still good is stuff from before so like living in a new place."
	  ○ "Keeping people oriented and informed In case they forget something or get confused or nervous. I was thinking about how frustrating it must be to be aware, because in the beginning stages you notice that your memory is deteriorating, it must be incredibly frustrating and sad to realize that that's happening"
	• On sound and music
	  ○ "There's a so much research and case studies on how music and like memory of you're playing music is like the one thing that seems to stick with Alzheimer's patients like you can play a song from their childhood and they'll remember the words to it but they can't remember the names of their children"
	• On building and organization
	  ○ "The structure of the building, the way that it's laid out, is very geometrically predictable. Straight lines, one type of room on one side and maybe all the activity rooms in another area. The dining hall and the kitchen area on the other side, because if I had Alzheimer's it would be really confusing if I had to like trying to find my way through a building that had a disorganized layout."

2	• On designing for dementia
	  ○ "Knowing that people with Alzheimer's disease often struggle with attention, that can be built into the architecture and the design of their environment and it is related to trying to make sure that people aren't over stimulated. It's recommended to try to reduce distractions like having televisions on in the background because it is so easy for people with dementia to kind of become like confused and disoriented"
	• On neuropsychological states
	  ○ "Distractions and over-simulations also increase stress which of course leads to a lot of other symptoms like sleep, while they also increases the likelihood of people wandering which is a big thing that a lot of people with Alzheimer's do"
	• On lighting
	  ○ "To ensure that people have a good sleep schedule and a routine, I think one of the big ways that we could really help this is by making sure that there's really good Lighting in their environment. So I think lighting probably plays a really big role, having artificial light in places where you don't get enough natural light."
	  ○ "Another thing that happens with people with Alzheimer's disease especially as the days are kind of drawing to a close in the evening and the lighting is going down is this process called sundowning where they can become very anxious and agitated and stressed out. Maybe the shadows that are occurring can can cause distress and so I think that got something really critical not only considering the lighting in the space but as the lighting goes down how like the design of the space you know cast certain Shadows"
	• Concluding remarks
	  ○ "Some of the relevant aspects are symptoms of the disease that should be considered in particular when designing a space, for example not all of them necessarily can be addressed through design and some of them might be more relevant than others. This sundowning and agitation and its relevance to lighting or overstimulation. It's not only about what we should implement but what parts do you think we should consider before making decisions about the design"

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Bibliography

1. Alzheimer's disease facts and figures. (2020). *Alzheimer's & Dementia*, *16*(3), 391–460. https://doi.org/10.1002/alz.12068
2. Berendsen, A. M., Kang, J. H., Feskens, E. J., de Groot, C. P. G. M., Grodstein, F., & van de Rest, O. (2018). Association of long-term adherence to the mind diet with cognitive function and cognitive decline in American women. *The journal of nutrition, health & aging*, *22*(2), 222-229.
3. Bos, I., Vos, S., Verhey, F., Scheltens, P., Teunissen, C., Engelborghs, S., ... & Visser, P. J. (2019). Cerebrospinal fluid biomarkers of neurodegeneration, synaptic integrity, and astroglial activation across the clinical Alzheimer's disease spectrum. *Alzheimer's & Dementia*, *15*(5), 644-654.
4. Brasure, M., Desai, P., Davila, H., Nelson, V. A., Calvert, C., Jutkowitz, E., ... & Kane, R. L. (2018). Physical activity interventions in preventing cognitive decline and Alzheimer-type dementia: a systematic review. *Annals of internal medicine*, *168*(1), 30-38.
5. Caselli, R. J., Knopman, D. S., & Bu, G. (2020). An agnostic reevaluation of the amyloid cascade hypothesis of Alzheimer's disease pathogenesis: The role of APP homeostasis. *Alzheimer's & Dementia*, *16*(11), 1582-1590.
6. Centers for Disease Control and Prevention. (2021, March 1). *Alzheimers Disease*. Centers for Disease Control and Prevention. https://www.cdc.gov/nchs/fastats/alzheimers.htm.
7. Centers for Disease Control and Prevention. (2011, February). *Cognitive Impairment: A Call for Action, Now!* Healthy Brain Initiative . https://www.cdc.gov/aging/pdf/cognitive_impairment/cogimp_poilicy_final.pdf.
8. Chong, F. P., Ng, K. Y., Koh, R. Y., & Chye, S. M. (2018). Tau proteins and tauopathies in Alzheimer's disease. *Cellular and molecular neurobiology*, *38*(5), 965-980.
9. Coburn, A., Vartanian, O., & Chatterjee, A. (2017). Buildings, beauty, and the brain: A neuroscience of architectural experience. *Journal of Cognitive Neuroscience*, *29*(9), 1521-1531.

10. Fink, H. A., Linskens, E. J., Silverman, P. C., McCarten, J. R., Hemmy, L. S., Ouellette, J. M., ... & Butler, M. (2020). Accuracy of Biomarker Testing for Neuropathologically Defined Alzheimer Disease in Older Adults With Dementia: A Systematic Review. *Annals of internal medicine*, *172*(10), 669-677.
11. Hardy, J. A., & Higgins, G. A. (1992). Alzheimer's disease: the amyloid cascade hypothesis. *Science*, *256*(5054), 184-186.
12. Hikichi, H., Kondo, K., Takeda, T., & Kawachi, I. (2017). Social interaction and cognitive decline: Results of a 7-year community intervention. *Alzheimer's & Dementia: Translational Research & Clinical Interventions*, *3*(1), 23-32.
13. Karakas, T., & Yildiz, D. (2020). Exploring the influence of the built environment on human experience through a neuroscience approach: A systematic review. *Frontiers of Architectural Research*, *9*(1), 236-247.
14. Karol, E., & Smith, D. (2019). Impact of design on emotional, psychological, or social well-being for people with cognitive impairment. *HERD: Health Environments Research & Design Journal*, *12*(3), 220-232.
15. Khan, S., Barve, K. H., & Kumar, M. S. (2020). Recent advancements in pathogenesis, diagnostics and treatment of Alzheimer's disease. *Current Neuropharmacology*, *18*(11), 1106-1125.
16. Khoury, R., & Ghossoub, E. (2019). Diagnostic biomarkers of Alzheimer's disease: A state-of-the-art review. *Biomarkers in Neuropsychiatry*, *1*, 100005.
17. Kuliga, S., Berwig, M., & Roes, M. (2021). Wayfinding in people with Alzheimer's disease: Perspective taking and architectural cognition—A vision paper on future dementia care research opportunities. *Sustainability*, *13*(3), 1084.
18. Larson, E. B., Kukull, W. A., & Katzman, R. L. (1992). Cognitive impairment: dementia and Alzheimer's disease. *Annual review of public health*, *13*(1), 431-449
19. Naseri, N. N., Wang, H., Guo, J., Sharma, M., & Luo, W. (2019). The complexity of tau in Alzheimer's disease. *Neuroscience letters*, *705*, 183-194.
20. Nho, K., Kueider-Paisley, A., Ahmad, S., MahmoudianDehkordi, S., Arnold, M., Risacher, S. L., ... & Alzheimer Disease Metabolomics Consortium. (2019). Association of altered liver enzymes with Alzheimer disease diagnosis, cognition, neuroimaging

measures, and cerebrospinal fluid biomarkers. *JAMA network open*, *2*(7), e197978-e197978.

21. Palmer, K., Mitolo, M., Burgio, F., Meneghello, F., & Venneri, A. (2018). Sleep disturbance in mild cognitive impairment and association with cognitive functioning. A case-control study. *Frontiers in aging neuroscience*, *10*, 360.
22. Pektaş, Ş. T. (2021). A scientometric analysis and review of spatial cognition studies within the framework of neuroscience and architecture. *Architectural Science Review*, 1-9.
23. Pickett, J., Bird, C., Ballard, C., Banerjee, S., Brayne, C., Cowan, K., ... & Walton, C. (2018). A roadmap to advance dementia research in prevention, diagnosis, intervention, and care by 2025. *International journal of geriatric psychiatry*, *33*(7), 900-906.
24. Roehr, S., Luck, T., Pabst, A., Bickel, H., König, H. H., Lühmann, D., ... & AgeCoDe Study Group. (2017). Subjective cognitive decline is longitudinally associated with lower health-related quality of life. *International Psychogeriatrics*, *29*(12), 1939-1950.
25. Sadigh-Eteghad, S., Sabermarouf, B., Majdi, A., Talebi, M., Farhoudi, M., & Mahmoudi, J. (2015). Amyloid-beta: a crucial factor in Alzheimer's disease. *Medical principles and practice*, *24*(1), 1-10.
26. Smith, J. A., Das, A., Ray, S. K., & Banik, N. L. (2012). Role of pro-inflammatory cytokines released from microglia in neurodegenerative diseases. *Brain research bulletin*, *87*(1), 10–20. https://doi.org/10.1016/j.brainresbull.2011.10.004
27. Stites, S. D., Harkins, K., Rubright, J. D., & Karlawish, J. (2018). Relationships between Cognitive Complaints and Quality of Life in Older Adults with Mild Cognitive Impairment, Mild Alzheimer's Disease Dementia, and Normal Cognition. *Alzheimer disease and associated disorders*, *32*(4), 276.
28. Takeda, S., Rakugi, H., & Morishita, R. (2020). Roles of vascular risk factors in the pathogenesis of dementia. *Hypertension Research*, *43*(3), 162-167.
29. U.S. Department of Health and Human Services. (n.d.). *What Happens to the Brain in Alzheimer's Disease?* National Institute on Aging. https://www.nia.nih.gov/health/what-happens-brain-alzheimers-disease#:~:text=At%20first%2C%20Alzheimer's%20disease%20typically,%2C%20reasoning%2C%20and%20social%20behavior.

30. U.S. Department of Health and Human Services. (n.d.). *How Is Alzheimer's Disease Diagnosed?* National Institute on Aging. https://www.nia.nih.gov/health/how-alzheimers-disease-diagnosed.
31. U.S. Department of Health and Human Services. (n.d.). *What Is Dementia? Symptoms, Types, and Diagnosis*. National Institute on Aging. https://www.nia.nih.gov/health/what-dementia-symptoms-types-and-diagnosis.
32. Walker, K. A., Ficek, B. N., & Westbrook, R. (2019). Understanding the role of systemic inflammation in Alzheimer's disease.
33. Wanleenuwat, P., Iwanowski, P., & Kozubski, W. (2019). Alzheimer's dementia: pathogenesis and impact of cardiovascular risk factors on cognitive decline. *Postgraduate medicine*, *131*(7), 415-422.
34. Whittington, R. A., Planel, E., & Terrando, N. (2017). Impaired resolution of inflammation in Alzheimer's disease: a review. *Frontiers in immunology*, *8*, 1464.
35. World Dementia Council. (2013). Defeating dementia: the road to 2025.
36. World Health Organization. (n.d.). *Dementia*. World Health Organization. https://www.who.int/news-room/fact-sheets/detail/dementia#:~:text=Worldwide%2C%20around%2050%20million%20people%20have%20dementia%2C%20with%20nearly%2060,is%20between%205%2D8%25.
37. Wu, Y. T., Prina, A. M., Jones, A., Matthews, F. E., & Brayne, C. (2017). The built environment and cognitive disorders: results from the cognitive function and ageing study II. *American journal of preventive medicine*, *53*(1), 25-32.
38. Yang, X., Yao, C., Tian, T., Li, X., Yan, H., Wu, J., ... & Lu, Y. (2018). A novel mechanism of memory loss in Alzheimer's disease mice via the degeneration of entorhinal–CA1 synapses. *Molecular psychiatry*, *23*(2), 199-210.

Key Measures

39. Åkerstedt, T., & Gillberg, M. (1990). Subjective and objective sleepiness in the active individual. *International Journal of Neuroscience*, *52*(1-2), 29-37.
40. American Psychological Association. (n.d.). *Cohen-Mansfield Agitation Inventory*. American Psychological Association.

https://www.apa.org/pi/about/publications/caregivers/practice-settings/assessment/tools/cohen-mansfield.

41. Anderson, V., & Catroppa, C. (n.d.). *Comprehensive Trail-Making Test (TMT)*. http://movingahead.psy.unsw.edu.au/documents/research/outcome%20measures/paediatric/Neuropsychological%20Impairment/Website%20Comprehensive%20Trail%20Making%20Test%20-%20Paediatrics.pdf.
42. Biederman, I. (1987). Recognition-by-components: a theory of human image understanding. Psychological review, 94(2), 115.
43. Borg, G. (1998). Borg's perceived exertion and pain scales. Human kinetics.
44. *California Verbal Learning Test: Second Edition*. Pearson. (n.d.). https://www.pearsonassessments.com/store/usassessments/en/Store/Professional-Assessments/Cognition-%26-Neuro/California-Verbal-Learning-Test-%7C-Second-Edition/p/100000166.html.
45. Cohen-Mansfield, J., Hai, T., & Comishen, M. (2017). Group engagement in persons with dementia: the concept and its measurement. Psychiatry Research, 251, 237-243.
46. Cohen-Mansfield, J., Marx, M. S., & Rosenthal, A. S. (1989). A description of agitation in a nursing home. Journal of gerontology, 44(3), M77-M84.
47. Dementia Care Central.com. (2020, October 7). *Mini-Mental State Exam (MMSE) Alzheimer's / Dementia Test: Administration, Accuracy and Scoring*. Dementia Care Central. https://www.dementiacarecentral.com/mini-mental-state-exam/#:~:text=The%20MMSE%20is%20a%2030,or%20%E2%80%9Ccognitive%20impairment%E2%80%9D).&text=The%20test%20is%20also%20used,used%20test%20for%20assessing%20dementia.
48. Hayes, M. H. (1921). Experimental developement of the graphics rating method. Physiol Bull, 18, 98-99.
49. Jakobsen, M. D., Sundstrup, E., Persson, R., Andersen, C. H., & Andersen, L. L. (2014). Is Borg's perceived exertion scale a useful indicator of muscular and cardiovascular load in blue-collar workers with lifting tasks? A cross-sectional workplace study. *European journal of applied physiology*, *114*(2), 425-434.

50. Kaida, K., Takahashi, M., Åkerstedt, T., Nakata, A., Otsuka, Y., Haratani, T., & Fukasawa, K. (2006). Validation of the Karolinska sleepiness scale against performance and EEG variables. *Clinical neurophysiology*, *117*(7), 1574-1581
51. Little, B. R. (2011, October 24). *Assesment tools*. Dr. Brian R. Little. https://www.brianrlittle.com/Topics/research/personal-projects-analysis/?doing_wp_cron=1623405254.1787090301513671875000.
52. Little, B. R., & Gee, T. L. (2007). The methodology of personal projects analysis: Four modules and a funnel.
53. *Pattern Recognition Memory (PRM)*. Cambridge Cognition. (n.d.). https://www.cambridgecognition.com/cantab/cognitive-tests/memory/pattern-recognition-memory-prm/.
54. Reitan, Ralph M. (1993). The Halstead-Reitan neuropsychological test battery : theory and clinical interpretation. S. Tucson, Arizona :Neuropsychology Press
55. Scarpina, F., & Tagini, S. (2017). The stroop color and word test. *Frontiers in psychology*, *8*, 557
56. Shahid, A., Wilkinson, K., Marcu, S., & Shapiro, C. M. (2011). Karolinska sleepiness scale (KSS). In *STOP, THAT and One Hundred Other Sleep Scales* (pp. 209-210). Springer, New York, NY.
57. Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of experimental psychology*, *18*(6), 643.
58. Warrington, E. K., & Weiskrantz, L. (1970). Amnesic syndrome: Consolidation or retrieval?. *Nature*, *228*(5272), 628-630.
59. Wikimedia Foundation. (2021, March 15). *California Verbal Learning Test*. Wikipedia. https://en.wikipedia.org/wiki/California_Verbal_Learning_Test.
60. Wikimedia Foundation. (2020, May 7). *Indirect tests of memory*. Wikipedia. https://en.wikipedia.org/wiki/Indirect_tests_of_memory#Word_fragment_completion_(WFC).
61. Wikimedia Foundation. (2021, May 6). *Visual analogue scale*. Wikipedia. https://en.wikipedia.org/wiki/Visual_analogue_scale

Additional Measures

62. Apa dictionary of psychology. (n.d.). Retrieved June 09, 2021, from https://dictionary.apa.org/directions-test
63. Edgerly, E. S., & Donovick, P. J. (1998). Neuropsychological correlates of wandering in persons with Alzheimer's disease. *American Journal of Alzheimer's disease*, *13*(6), 317-329
64. 5 Cognitive Tests and Performance Validity Tests." Institute of Medicine. 2015. *Psychological Testing in the Service of Disability Determination*. Washington, DC: The National Academies Press. doi: 10.17226/21704.
65. Griffith, N. M., Smith, K. M., Schefft, B. K., Szaflarski, J. P., & Privitera, M. D. (2008). Optimism, pessimism, and neuropsychological performance across semiology-based subtypes of psychogenic nonepileptic seizures. *Epilepsy & Behavior*, *13*(3), 478-484.
66. Holtzman, S., O'Connor, B. P., Barata, P. C., & Stewart, D. E. (2015). The Brief Irritability Test (BITe) A Measure of Irritability for Use Among Men and Women. *Assessment*, *22*(1), 101-115.
67. Neuropsychological tests. (n.d.). Retrieved June 09, 2021, from https://www.gracepointwellness.org/5-depression-depression-related-conditions/article/8220-neuropsychological-tests
68. Rankin, K. P., Baldwin, E., Pace-Savitsky, C., Kramer, J. H., & Miller, B. L. (2005). Self awareness and personality change in dementia. *Journal of Neurology, Neurosurgery & Psychiatry*, *76*(5), 632-639.
69. Sunderland, T., & Minichiello, M. (1997). Dementia mood assessment scale. *International Psychogeriatrics*, *8*(s 3), 329-331.
70. Ucheagwu, V., Okoli, P., & Ugokwe-Ossai, R. (2019). Some Neuropsychological Profiles and Personality Traits of Undergraduate Regular Online Football Gamblers (a New Online Gambling Game) in Nigeria. *Journal of gambling studies*, *35*(1), 171-180.
71. Weiland-Fiedler, P., Erickson, K., Waldeck, T., Luckenbaugh, D. A., Pike, D., Bonne, O., ... & Neumeister, A. (2004). Evidence for continuing neuropsychological impairments in depression. *Journal of affective disorders*, *82*(2), 253-258.

Results

72. Alkozei, A., Smith, R., Dailey, N. S., Bajaj, S., & Killgore, W. D. (2017). Acute exposure to blue wavelength light during memory consolidation improves verbal memory performance. *PLoS One*, *12*(9), e0184884.
73. Cernin, P. A., Keller, B. K., & Stoner, J. A. (2003). Color vision in Alzheimer's patients: Can we improve object recognition with color cues?. *Aging, Neuropsychology, and Cognition*, *10*(4), 255-267.
74. Chellappa, S. L., Steiner, R., Blattner, P., Oelhafen, P., Götz, T., & Cajochen, C. (2011). Non-visual effects of light on melatonin, alertness and cognitive performance: can blue-enriched light keep us alert?. *PloS one*, *6*(1), e16429.
75. Cohen‐Mansfield, J. (2020). The impact of environmental factors on persons with dementia attending recreational groups. *International journal of geriatric psychiatry*, *35*(2), 141-146.
76. Cohen-Mansfield, J., Thein, K., Dakheel-Ali, M., & Marx, M. S. (2010). Engaging nursing home residents with dementia in activities: the effects of modeling, presentation order, time of day, and setting characteristics. *Aging & mental health*, *14*(4), 471-480.
77. de Vries, A., Souman, J. L., de Ruyter, B., Heynderickx, I., & de Kort, Y. A. (2018). Lighting up the office: The effect of wall luminance on room appraisal, office workers' performance, and subjective alertness. *Building and Environment*, *142*, 534-543.
78. Foster, N. A., & Valentine, E. R. (2001). The effect of auditory stimulation on autobiographical recall in dementia. *Experimental aging research*, *27*(3), 215-228.
79. Gaoua, N., Racinais, S., Grantham, J., & El Massioui, F. (2011). Alterations in cognitive performance during passive hyperthermia are task dependent. *International Journal of Hyperthermia*, *27*(1), 1-9.
80. Gerhart, H. D., Seo, Y., Kim, J. H., Followay, B., Vaughan, J., Quinn, T., ... & Glickman, E. L. (2019). Investigating effects of cold water hand immersion on selective attention in normobaric hypoxia. *International journal of environmental research and public health*, *16*(16), 2859.

81. Holland, R. L., Sayers, J. A., Keatinge, W. R., Davis, H. M., & Peswani, R. (1985). Effects of raised body temperature on reasoning, memory, and mood. *Journal of Applied Physiology*, *59*(6), 1823-1827.
82. Houben, M., Brankaert, R., Bakker, S., Kenning, G., Bongers, I., & Eggen, B. (2019, June). Foregrounding everyday sounds in dementia. In *Proceedings of the 2019 on Designing Interactive Systems Conference* (pp. 71-83).
83. Jost, T., Ouerhani, N., Von Wartburg, R., Müri, R., & Hügli, H. (2005). Assessing the contribution of color in visual attention. *Computer Vision and Image Understanding*, *100*(1-2), 107-123.
84. Lee, C. W., & Kim, J. H. (2020). The influence of LED lighting on attention and long-term memory. *International Journal of Optics*, *2020*.
85. Ljungberg, J. K., & Neely, G. (2007). Cognitive after‐effects of vibration and noise exposure and the role of subjective noise sensitivity. Journal of occupational health, 49(2), 111-116.
86. Minguillon, J., Lopez-Gordo, M. A., Renedo-Criado, D. A., Sanchez-Carrion, M. J., & Pelayo, F. (2017). Blue lighting accelerates post-stress relaxation: Results of a preliminary study. *PloS one*, *12*(10), e0186399.
87. Onega, L. L., Pierce, T. W., & Epperly, L. (2016). Effect of bright light exposure on depression and agitation in older adults with dementia. *Issues in mental health nursing*, *37*(9), 660-667.
88. Pronk, M., Deeg, D. J., Festen, J. M., Twisk, J. W., Smits, C., Comijs, H. C., & Kramer, S. E. (2013). Decline in older persons' ability to recognize speech in noise: the influence of demographic, health-related, environmental, and cognitive factors. *Ear and hearing*, *34*(6), 722-732.
89. Rubiño, J. A., Gamundí, A., Akaarir, M., Canellas, F., Rial, R., & Nicolau, M. C. (2020). Bright Light Therapy and Circadian Cycles in Institutionalized Elders. *Frontiers in Neuroscience*, *14*, 359
90. Smolders, K. C., & de Kort, Y. A. (2014). Bright light and mental fatigue: Effects on alertness, vitality, performance and physiological arousal. *Journal of environmental psychology*, *39*, 77-91.

91. Tartarini, F., Cooper, P., Fleming, R., & Batterham, M. (2017). Indoor air temperature and agitation of nursing home residents with dementia. *American Journal of Alzheimer's Disease & Other Dementias®*, *32*(5), 272-281.
92. Te Kulve, M., Schlangen, L. J., Schellen, L., Frijns, A. J., & van Marken Lichtenbelt, W. D. (2017). The impact of morning light intensity and environmental temperature on body temperatures and alertness. *Physiology & behavior*, *175*, 72-81.
93. Trimmel, K., Schätzer, J., & Trimmel, M. (2014). Acoustic noise alters selective attention processes as indicated by direct current (DC) brain potential changes. *International journal of environmental research and public health*, *11*(10), 9938-9953
94. Wallenius, M. A. (2004). The interaction of noise stress and personal project stress on subjective health. *Journal of Environmental Psychology*, *24*(2), 167-177.
95. Wang, X., Zhao, X., Xue, G., & Chen, A. (2016). Alertness function of thalamus in conflict adaptation. *NeuroImage*, *132*, 274-282.
96. Weuve, J., D'Souza, J., Beck, T., Evans, D. A., Kaufman, J. D., Rajan, K. B., ... & Adar, S. D. (2021). Long‐term community noise exposure in relation to dementia, cognition, and cognitive decline in older adults. *Alzheimer's & Dementia*, *17*(3), 525-533.
97. Wichmann, F. A., Sharpe, L. T., & Gegenfurtner, K. R. (2002). The contributions of color to recognition memory for natural scenes. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *28*(3), 509.
98. Wright Jr, K. P., Hull, J. T., & Czeisler, C. A. (2002). Relationship between alertness, performance, and body temperature in humans. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology*.

Definitions

99. American Psychological Association. (n.d.). *Alertness*. American Psychological Association.https://dictionary.apa.org/alertness
100. American Psychological Association. (n.d.). *Concentration*. American Psychological Association.https://dictionary.apa.org/concentration
101. American Psychological Association. (n.d.). *Recall*. American Psychological Association.https://dictionary.apa.org/recall.

102. American Psychological Association. (n.d.). *Recognition*. American Psychological Association.https://dictionary.apa.org/recognition.

103. American Psychological Association. (n.d.). *Selective Attention*. American Psychological Association.https://dictionary.apa.org/selective-attention.

104. American Psychological Association. (n.d.). *Stress*. American Psychological Association.https://dictionary.apa.org/stress.

105. Cohen-Mansfield, J., Dakheel-Ali, M., & Marx, M. S. (2009). Engagement in persons with dementia: the concept and its measurement. *The American journal of geriatric psychiatry*, *17*(4), 299-307.

Other Articles

Links for Architecture

Hayne, M. J., & Fleming, R. (2014). Acoustic design guidelines for dementia care facilities.

Jakob, A., & Collier, L. (2017). Sensory enrichment for people living with dementia: increasing the benefits of multisensory environments in dementia care through design. *Design for Health*, *1*(1), 115-133.

Jafari, Z., Kolb, B. E., & Mohajerani, M. H. (2019). Noise exposure accelerates the risk of cognitive impairment and Alzheimer's disease: Adulthood, gestational, and prenatal mechanistic evidence from animal studies. *Neuroscience & Biobehavioral Reviews*.

Leung, M. Y., Wang, C., & Wei, X. (2020). Structural model for the relationships between indoor built environment and behaviors of residents with dementia in care and attention homes. *Building and Environment*, *169*, 106532.

Lok, R., Smolders, K. C., Beersma, D. G., & de Kort, Y. A. (2018). Light, alertness, and alerting effects of white light: a literature overview. *Journal of biological rhythms*, *33*(6), 589-601.

O'Connor, Z. (2020). Color Design and Dementia: Harnessing HCI to Improve Environmental Visual Literacy. In *HCI and Design in the Context of Dementia* (pp. 223-235). Springer, Cham.

Van Vracem, M., Spruytte, N., Declercq, A., & Van Audenhove, C. (2016). Agitation in dementia

and the role of spatial and sensory interventions: experiences of professional and family caregivers. *Scandinavian journal of caring sciences*, *30*(2), 281-289.

Weuve, J., D'Souza, J., Beck, T., Evans, D. A., Kaufman, J. D., Rajan, K. B., ... & Adar, S. D. (2021). Long‐term community noise exposure in relation to dementia, cognition, and cognitive decline in older adults. *Alzheimer's & Dementia*, *17*(3), 525-533.

Links for Neuroscience

Berman, M. H., Halper, J. P., Nichols, T. W., Jarrett, H., Lundy, A., & Huang, J. H. (2017). Photobiomodulation with near infrared light helmet in a pilot, placebo controlled clinical trial in dementia patients testing memory and cognition. *Journal of neurology and neuroscience*, *8*(1).

Cabeza, R., Nyberg, L., & Park, D. C. (Eds.). (2016). *Cognitive neuroscience of aging: Linking cognitive and cerebral aging*. Oxford University Press.

Treadaway, C., Fennell, J., Prytherch, D., Kenning, G., Prior, A., Walters, A., & Taylor, A. (2018). Compassionate Design: How to Design for Advanced Dementia–a toolkit for designers

Tsapanou, A., Vlachos, G. S., Cosentino, S., Gu, Y., Manly, J. J., Brickman, A. M., ... & Mayeux, R. (2019). Sleep and subjective cognitive decline in cognitively healthy elderly: results from two cohorts. *Journal of sleep research*, *28*(5), e12759.

Appendix A: Interview Consent Form

Interview Consent Form, page 1

Interview Consent Form — Neuroscience in Architecture: Concepts and Context for Alzheimers Design

Thank you for your interest in participating in our study. This study is being conducted under the Cognitive Science Honors Program at the University of California, San Diego.

We are interested in advancing the design of buildings that are well adapted to people who have been diagnosed with Alzheimers Disease or Mild Cognitive Impairment (MCI).

For this portion of the study, we are conducting interviews to develop a better understanding of existing research, design ideas, important questions, and experts' opinions within the Architecture & Neuroscience fields.

This form should take no more than 3 minutes and consists of three consents to sign: one for the interview itself, one for an audio recording of the interview and a third for the zoom video recording.

The interview should take approximately 30 minutes to complete. Your participation in this portion of the study is voluntary and your Personal Identifiable Information will be kept confidential. You have the right to withdraw at any point during the interview for any reason and without prejudice.

By clicking the button below, you acknowledge that your participation in the study is voluntary and that you are aware that you may choose to terminate you participation in the interview at any time and for any reason.

Interview Consent Form, page 2 & 3

Audio Recording Release Consent Form

As part of this project, an audio recording will be made of you during your participation in this research project. Please indicate below the uses of these audio recordings to which you are willing to consent. This is completely voluntary and up to you. In any use of the audio recording, your name will not be identified. You may request to stop the recording at any time or to erase any portion of your recording.

The audio recording can be studied by the research team for use in the research project *

- I consent
- I do not consent

The audio recording can be used for scientific publications. *

- I consent
- I do not consent

The audio recording can be reviewed at meetings of scientists interested in the study of Architecture and Neuroscience *

- I consent
- I do not consent

The audio recording can be reviewed in classrooms to students. *

- I consent
- I do not consent

The audio recording can be reviewed in public presentations to non-scientific groups. *

- I consent
- I do not consent

The audio recording can be used on television and radio. *

- I consent
- I do not consent

You have the right to request that the recording be stopped or erased in full or in part at any time. You have read the above description and give your consent for the use of audio recording as indicated above. Please print your full name. *

Your answer

Video Recording Release Consent Form

As part of this project, a video recording will be made of you during your participation in this research project. Please indicate below the uses of these video recordings to which you are willing to consent. This is completely voluntary and up to you. In any use of the video recording, your name will not be identified.

The video recording can be studied by the research team for use in the research project *

- I consent
- I do not consent

The video recording can be shown to subjects in other experiments. *

- I consent
- I do not consent

The video recording can be used for scientific publications. *

- I consent
- I do not consent

The video recording can be shown at meetings of scientists interested in the study of Architecture and Neuroscience *

- I consent
- I do not consent

The video recording can be shown in classrooms to students. *

- I consent
- I do not consent

The video recording can be shown in public presentations to non-scientific groups. *

- I consent
- I do not consent

The video recording can be used on television and radio. *

- I consent
- I do not consent

You have the right to request that the recording be stopped or erased in full or in part at any time. You have read the above description and give your consent for the use of video recording as indicated above. Please print your full name. *

Your answer