The Impact and Benefits of Innovative, Intelligent Assistive Lightening for The Cognitive Decline of the MCI Independent Seniors

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***Abstract*— The Personalizable assisTive Ambient monitoring and Lighting (PETAL) Project represents a unique and innovative solution that aims to reduce the cognitive decline among Mild Cognitive Impairment patients through an assisted ambient environment, as well as through the use of neurocognitive stimulation applications. The functioning of the system is based on an online platform named "Rule Editor" that will act as both receptor for the information coming from the environment and transmitter of the information which will eventually materialize through the peripheral devices connected. One of the most important parts of the system is the Human Centric Lighting (the term was coined in 2013 and refers to lighting that induces positive health effects in human beings), which supports the following functions: sleep-wake rhythm, directs attention in a timely manner, supports structure of daily activities and spatial-temporal orientation. The system will also integrate motion and proximity sensors that will continuously monitor the presence of the patient inside the home through a smartwatch worn by the elderly. Using the same smartwatch, the platform can send warnings to different numbers prior set in the case the patient falls. Moreover, regarding the neurocognitive stimulation applications, the patients will perform exercises for maximum an hour, 3 times a week. Using this platform, we can monitor changes that might appear in some particular contexts – aspects regarding the user, time, environment, etc. Thus, the necessary adjustments that should respond to the patient's requirements could be performed. The platform will allow the caregivers to personalize the way in which the platform as well as the Lighting System and other connected devices and appliances will act using a set of "rules".**

Keywords – *MCI; elderly; light; cognitive functions; technology.*

I. INTRODUCTION

Lately, ageing and dementia have represented a main focus among both clinicians and researchers in terms of early diagnosis and interventions through predictive biomarkers. The term Mild Cognitive Impairment (MCI) was firstly introduced in 1988 [1] to describe a transitional state between the cognition of normal aging and mild dementia – the subjects were identified based on the Global Deterioration Scale when Stage 3 criteria were fulfilled.

In section II we will present the concept of MCI in detail by providing evidence-based information regarding clinical presentation, assessment and diagnostic criteria. In the `third section, the operating system of the PETAL project is explained while in the last sections – Conclusions, all the achievements are going to be summarized and the future work will be presented as well.

II. RELATED WORKS

The first clinical criteria for MCI were proposed by a group of investigators from the Mayo Clinic in the late 90's; In 1999 the concept of MCI has further been developed [2][3] and in order to reach an agreement on the clinical features of MCI, an international conference was held in 2003 (Key Symposium) that materialized in a revised criteria for this condition [4]. More recently, the National Institute on Aging and Alzheimer's Association (NIA-AA) put together a group in order to once again evaluate MCI clinical criteria along Alzheimer's Disease Spectrum [5] – the core criteria overlap with those proposed by the Key Symposium. The American Psychiatric Association has recently published new criteria for dementia in the fifth edition of the Diagnostic and Statistical Manual for Mental Disorders (DSM-5), which recognize the pre-dementia stage of cognitive impairment. The condition, which has many of the features of MCI, is termed mild neurocognitive disorder (NCD) [6]; see Table1.

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TABLE I. EVOLUTION OF MCI CRITERIA

Criteria	Mayo Clinic	Key Symposium	NIA-AA	DSM-5
Self- or informant-reported memory complaint	X			
Self- or informant-reported cognitive complaint		X	X	X
Objective memory impairment	X			
Objective cognitive impairment		X	X	X
Essentially preserved general cognitive functioning	X			
Preserved independence in functional abilities	X	X	X	X
No dementia	X	X	X	X

The prevalence of MCI can highly vary depending on the population. Using Winblad's 2004 diagnostic criteria [4], the prevalence of MCI was 28.3% in the U.S.[7], 24.3% in Austria[8], 17.2% in Germany [9] and 12.7% in China [10]. According to a recent review of population and community-based studies, the annual incidence rate of MCI ranged from 51 to 77 per 1,000 persons in those 60 years or older [11].

As seen in Table 1, MCI patients present cognitive disfunctions which do not fulfill the diagnostic criteria for dementia. Typically, **executive functions**, **attention**, **language** and **visuospatial skills** are the main domains in which MCI develops [12]. Clinical data suggesting a change in cognitive abilities is necessary for being classified as MCI. This information is generally gathered by using questionnaires addressed to the patient and or caregiver. People diagnosed with MCI have greater difficulty or need a longer period of time, compared to healthy individuals of the same age category, to complete daily activities that require greater use of cognitive functions - use of the phone, finding and organizing personal things, shopping, treatment compliance, moving and guiding or managing their own finances. In spite of these disorders, patients with MCI are in most cases independent - the accusations they invoke do not interfere with the abilities and the possibility of social activities within the family or the workplace [13]. The subjective cognitive complaint then needs to be confirmed by objective cognitive measures such as neuropsychological test batteries. Objective cognitive impairment is defined as a poor performance in one or more cognitive measures, which suggests deficits in one or more cognitive areas or domains. There is no gold standard to specify which neuropsychological test battery to use, but it is important that all the main cognitive areas are examined [12].

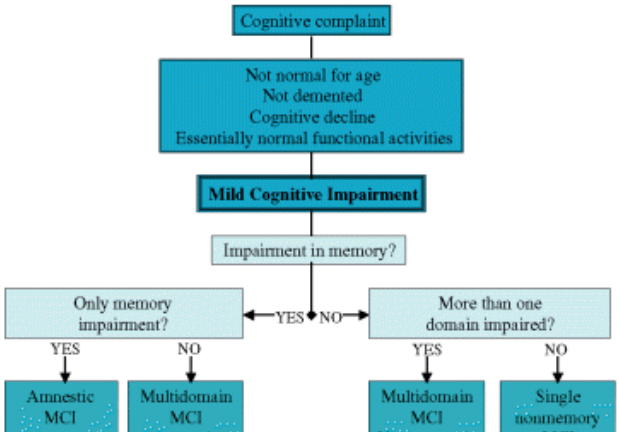

Figure 1. MCI Subtypes Classification (adapted with permission from Lippincott-Raven Publishers, Williams & Wilkins)

Considering impairment in the memory domain as well as in a single domain or multiple ones, MCI can be classified in 4 major subtypes – amnestic MCI (aMCI) and non amnestic MCI (naMCI), single or multiple domain as follows: **aMCI – single domain** (impairment only in memory), **aMCI – multiple domain** (impairment in memory and other cognitive domain**), naMCI – single domain** (impairment in a single cognitive domain, but not memory), **naMCI – multiple domain** (impairment in at least two cognitive domains, but not memory).

Risk factors are a subject relatively new to research, the current information being gathered in the last ten years. The most important risk factors are: *old age, low level of education, male gender, presence of Ɛ4 allele on APOE gene, comorbidities* – cardiovascular diseases and diabetes having a more impact, *depression*. **Physical activity** as well as **social and cognitive stimulation** can both contribute to postponing or preventing MCI [12]. A review of 41 cohort studies with a ten-year maximum follow-up was conducted and revealed that, on average, a **32%** of people with MCI progress to dementia [14]. In a multiethnic community-based study of 2,364 participants, the investigators specifically examined the reversion rate of MCI, the results being as follow: **47%** remained unchanged and **31%** reverted to normal within an average of **4.7 years** follow-up [15]. While the reasons for these different outcomes remain unknown, additionally, the risk of mortality increased by 50% to 150% in persons with MCI compared to those without MCI [16][17][18].

In terms of MCI interventions that aim to prevent, slow down or even reverse the progression of this pathology can be grouped in the following categories: **pharmacological**, **physical training / exercise**, **cognitive interventions** and **psychotherapy** [19]. Recommendations focus more on non-pharmacological interventions, one of the main reasons being that they produce no adverse effects. Among the non-pharmacological interventions, **cognitive training** and **physical exercise** (specifically aerobic exercise) may attenuate the cognitive impairment. A recent review showed how the efficacy of cognitive training in MCI measured as improvements in tests of global cognitive

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functioning, memory and meta-memory [20][21]. A limitation of these findings is the small samples of the individual studies. Only seven RCTs (randomized controlled trials) were identified by a systematic review [20], with a total of 296 MCI subjects who were cognitively treated. Most of these studies in fact included samples of fewer than 50 individuals; therefore, replication of the findings in larger RCTs is warranted.

To conclude, MCI is by all means a heterogenous entity limited by inconsistent findings. In many ways, the rapid transition from research to clinical setting has been premature. However, this does highly reflect the clinical need of standardized criteria and diagnostic algorithms given the high level of awareness of cognitive disorders in population. The major controversial issues for MCI research are centered on the **subjects** – source (memory clinics or general population) and age (middle aged or elderly), **implementation of the criteria** – test batteries, cut-offs and norms, **data collection** – prospective vs retrospective case findings as well as **classification** – standardized algorithm vs clinical judgement, **blindness** – awareness vs blindness (to clinical history) and **follow-up** (short-term vs long-term predictivity)[12].

III. PETAL PROJECT

As previously mentioned, the current focus regarding MCI interventions is directed more towards the non-pharmacological interventions.

PETAL Project - PErsonalizable assisTive Ambient monitoring and Lighting aims to extend the time older people can live in their home environment by increasing their autonomy and assisting them in carrying out activities of daily living. In particular, the goals are to provide older adults affected by MCI with useful and usable means to increase their awareness and control of their current lifestyle by providing them with relevant and tailored information in an intuitive and natural manner. The PETAL system is comprised of 2 main components – **the Lighting system** and a **cognitive-stimulation exercises mobile app**. The lighting system will be in charge of the non-visual light effects as well as the photometric factors (triggers of the non-visual light effects) whereas the cognitive stimulation app will focus directly on the cognitive improvements.

The current definition of light is based on its physical explanation as being the visible part of the electromagnetic spectrum. However, the human eye cannot see a spectrum, it is rather the photoreceptors – rods and cones, which collect, decipher and transpose the emission or reflectance of electromagnetic waves in a specific range or photons into meaningful visual signs in our brains. It is only two decades since the entraining and phase-shifting capacity of light on human circadian rhythms was discovered. Relatively little attention has been paid to other light effects on human brain, such as its alerting properties. As of 1995, only a handful of studies had directly or indirectly examined the immediate activating effects of light on alertness, performance and/or mood [22][23]. This has recently changed since a novel, third type of photoreceptor in the retina of mammals has been detected [24]. This novel photoreceptor cell type, an intrinsic photosensitive retinal ganglion cell, is considered to play a crucial role in many of the non-visual biological effects of light also in humans. The existence of such a photoreceptor can explain why pupil constriction, melatonin suppression and circadian entrainment are still possible in rodless and coneless transgenic mice [25][26].

Personalizable Lighting is a term that has become more and more popular in the lighting industry during the last years. Although the term is used on a large scale, there is no precise definition of this term. In the Human-Computer Interaction area, two main approaches are considered for personalization: **adaptive interfaces** - which dynamically adjust the interface in a way that is intended to support the user and **adaptable interfaces** - which provide customization mechanisms but rely on the user to use those mechanisms to do the adaptation [27]. Thus, these approaches differ with respect to who is in control of the personalization: **adaptive interfaces are system-controlled whereas adaptable interfaces are user-controlled.**

PETAL System aims to trigger the non-visual lighting effects - **regulation of sleep-wake cycle, regulation of appetite, impact on mood, impact on activity-rest-pattern, impact on behaviour** by exploiting and modulating the photometric light parameters, such as *light intensity, light spectrum – colour temperature, time and duration of the exposure as well as light history*. Thus, the project is a classic exponent of the Human Centric Lighting (term introduced in 2013 into the lighting industry that describes all kinds of lighting that positively affect human being's mood, alertness, performance, health and well-being).

The lighting system is composed of hue bulbs, hue light stripes for guidance and a central luminaire which consists of 3 lighting components: up-light (indirect light for ambient room illumination), down-light (diffuse task-light for facial brightening) and flexible spot (direct task-light for high visual requirements in the task area). The system will also integrate a set of sensors – proximity and motion sensors, temperature, humidity pressure, smoke and gas sensors, as well as door and window sensors; all this equipment will be integrated through an online platform that allows the user to program and control the system according to the subject needs, preferences and schedule. Moreover, monitoring the presence of the subject inside the home is possible, through a smartwatch worn by the elderly. Using the same smartwatch, the platform can send warnings to different numbers prior set in the case of a fall.

In conclusion, the PETAL - Lighting System is an adaptable lighting system that represents a first step towards

an adaptive lighting solution in private homes for elderly with MCI. In connection with the PETAL platform, a flexible solution was created that is adaptable to a great variety of requirements that can occur in this setting. Further development that integrates automatic algorithms that produces necessary lighting rules because of gathered information from sensors can be the next step towards an optimized, adaptive lighting solution.

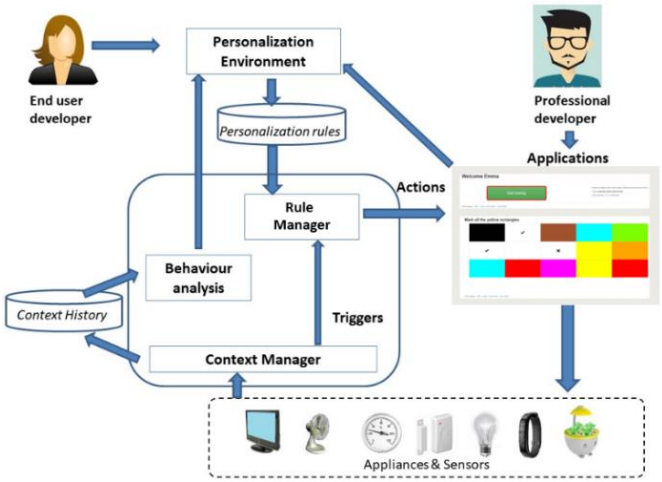

Figure 2. Integration of Applications with the Personalization Platform

IV. CONCLUSIONS

To sum up, PETAL System is part of the cognitive interventions among MCI patients that aims to prevent, slow down or even reverse the progression of this pathology. Through its personalizing lighting system and adaptive interface it is going to extend the time older people can live in their home environment by assisting them during the activities of daily living as well as increase their autonomy by triggering the non-visual effects of light.

Until now all the components of the PETAL system have been tested and integrated with each other in order to be fully operable and a mock-up trial has been successfully performed. Thus, the system is ready to be installed in our patient's homes so that it can be evaluated whether it is able to reduce the neurocognitive progression. In order to objectify this hypothesis, we performed neuropsychiatric tests on our patients (Neuropsychiatric inventory, Mini Mental State Examination, Activities of Daily Living and Instrumental Activities of Daily Living Questionnaires, Quality of Life Questionnaire, Rey Auditory and Verbal Fluency Test, as well as Raven Matrices, Wisconsin Card Sorting Test and Stroop Test) prior to the field trial of the system and it will be performed once again after the end of the testing phase. What is more, using the Zarit Burden interview we will be able to measure the impact PETAL System has on caregivers as well.

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