

MEDICAL  
APPLICATIONS  
OF  
ARTIFICIAL  
INTELLIGENCE



# MEDICAL APPLICATIONS OF ARTIFICIAL INTELLIGENCE

Edited by  
Arvin Agah



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## *Preface*

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As tools and techniques in artificial intelligence are being further enhanced, their applications to medicine are expanding. This book is an attempt to capture the breadth and depth of medical applications of artificial intelligence.

This book is composed of 28 chapters, written by 82 authors, with 50 unique affiliations, from 17 countries. The first five chapters provide a general overview of artificial intelligence, followed by 22 chapters that focus on projects that apply artificial intelligence to the medical domain. The final chapter provides a list of pertinent resources on artificial intelligence. Over 1200 entries are provided in the index.

The editor thanks all the authors for contributing to this book.

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**Dr. Arvin Agah** is associate dean for research and graduate programs in the School of Engineering and professor of electrical engineering and computer science at the University of Kansas. His research interests include applied artificial intelligence and autonomous robots. He has published more than 150 refereed articles in these areas. Dr. Agah has been a co-investigator on projects that represent more than \$32 million in research funding. He has supervised 13 PhD students and 40 master's degree students and has received multiple honors for his teaching excellence. Prior to joining the University of Kansas, he spent two years at the Bio-Robotics Division of Mechanical Engineering Laboratory in Tsukuba, Japan. He has been a researcher at the IBM Los Angeles Scientific Center, and Xerox Research Center in Rochester, New York. In addition to teaching courses at the University of Kansas, Dr. Agah has taught at the Department of Engineering Systems at University of Tsukuba in Japan, the Center of Excellence in Remote Sensing Education and Research at Elizabeth City State University in North Carolina, and the Department of Mechanical Engineering at the University of Canterbury in New Zealand. He is a senior member of IEEE and ACM.

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# 21

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## *Intelligent Light Therapy for Older Adults: Ambient Assisted Living*

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Joost van Hoof, Eveline J. M. Wouters, Björn Schröder, Harold T. G. Weffers, Mariëlle P. J. Aarts, Myriam B. C. Aries, and Adriana C. Westerlaken

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### 21.1 Introduction

Light therapy is increasingly administered and studied as a nonpharmacologic treatment for a variety of health-related problems, including treatment of people with dementia. It is applied in a variety of ways, ranging from being exposed to daylight (in sanatoria) to being exposed to light emitted from electrical sources. These include light boxes, light showers, and ambient bright light. Light therapy covers an area in medicine where medical sciences meet the realms of physics, engineering, and technology (van Hoof et al. 2012).

One of the areas within medicine in which light therapy is administered is geriatric psychiatry, which includes the care of older adults with dementia. Dementia can be caused by a number of progressive disorders that affect memory, thinking, behavior, and the ability to perform everyday activities. Alzheimer's disease is the most common cause of dementia. Other types include vascular dementia, dementia with Lewy bodies, and frontotemporal dementia. Dementia mainly affects older people, although there is a growing awareness of a substantial amount of cases that start before the age of 65. After age 65, the likelihood of developing dementia roughly doubles every 5 years.

In the 2009 World Alzheimer Report, Alzheimer's Disease International estimated that there would be 35.6 million people living with dementia worldwide in 2010, increasing to 65.7 million by 2030 and 115.4 million by 2050. Within Europe, nearly two-thirds live in low- and middle-income countries, where the sharpest increases in numbers will occur.

The societal cost of dementia is already enormous. Dementia is significantly affecting every health and social care system in the world. The economic impact on families is insufficiently

appreciated. New technological services and government policies may help to address this problem.

Low-income countries accounted for just under 1% of the total worldwide costs (but 14% of the prevalence), middle-income countries for 10% of the costs (but 40% of the prevalence), and high-income countries for 89% of the costs (but 46% of the prevalence). About 70% of the global costs occurred in just two regions: Western Europe and North America.

Recent research indicates that dementia could be slowed down significantly by treatments that reset the body's biological clock. This kind of research started with the work of van Someren et al. (1997), who conducted a study on the effects of ambient bright light emitted from ceiling-mounted luminaires. In a randomized controlled study by Riemersma-van der Lek et al. (2008), brighter daytime lighting was applied to improve the sleep of persons with dementia (PwDs) and slow down cognitive decline. Applying bright light techniques is expected to lengthen the period PwDs can continue to live in their own home. It can also reduce the speed of health decline once the PwD has been moved to a care facility. In these situations, the quality of life will be positively impacted, and the workload of the care professionals and assisting relatives is expected to decrease. At the same time, Forbes et al. (2009) concluded that due to the lack of randomized controlled trials, there are no clear beneficial outcomes of light therapy for older persons. Similar lighting systems have also been tested in school environments; however, these systems did not have any effect on school children in a controlled setting (Slegers et al. 2013).

PwDs do not venture outdoors as much as healthy younger adults, due to mobility impairments, and inside their homes, they are exposed to light levels that are not sufficient for proper vision, let alone yielding positive outcomes to circadian rhythmicity and mood (Aarts and Westerlaken 2005; Sinoo et al. 2011). Using light as a care instrument does not only apply to people with dementia, it also applies to ageing in general. Ageing impacts the circadian rhythm of people and increases the gap between level of sleep required and level of sleep achieved (older people do not get enough deep sleep). Moreover, it impacts the vision, since the eyes become affected due to biological ageing. These ageing effects include, among others, the yellowing of the lens and vitreous.

Although the evidence regarding the positive impact of light on well-being, especially of older people and PwDs or persons with other neurological diseases, is hopeful but not convincingly and scientifically affirmed (Forbes et al. 2009), these insights are already being converted to implementable solutions. Applying light as an instrument for care has tremendous benefits. It is noninvasive, it is cheap in implementation and maintenance, and it has a high level of intuitive use, creating a low threshold for acceptance.

Applying bright light techniques can slow down cognitive decline and reduce the speed of health decline. There is, however, no conclusive evidence on which lighting conditions are most favorable for yielding positive health outcomes. We also lack a clear definition of what technicians and product developers call healthy lighting. It is also not known how to design such healthy lighting systems, for instance, in relation to the emergence of new energy-friendly light sources such as LED (van Hoof et al. 2012). There is no validated set of algorithms as used in current lighting systems, including the effects of static versus dynamic lighting protocols (Barroso and den Brinker 2013), the contribution of the dynamic component of daylight, vertical and horizontal illuminance levels, and color temperature. The available knowledge has not yet been converted into widespread implementable lighting solutions, and the solutions available are often technologically unsophisticated, uneducated guesses and poorly evaluated from the perspective of end users. New validated approaches in terms of ceiling-mounted luminaires, the inclusion of low-energy light sources, and integration of computerized controls are needed.

This chapter will focus first on the effects of biological ageing and dementia on our lighting needs and second on the application of intelligent light therapies for older adults with dementia.

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## 21.2 The Effects of Biological Ageing and Dementia

The age-related sensory changes, involving sensory receptors in the eyes, ears, nose, buccal cavity, and peripheral afferent nerves, frequently affect the way we perceive the environment. Apart from the sensory changes, incorrect or malfunctioning visual aids and hearing aids may have negative effects, too. Sensory losses or impairments, together with cognitive deficits, make it difficult for the individual to interpret and understand the environment (perception and comprehension phase) (van Hoof et al. 2010).

### 21.2.1 Ageing-Related Changes in Vision

Ageing negatively affects vision. In general, the performance of the human eye deteriorates already at a relatively early age. Many people aged 45 and over wear glasses to compensate for impaired vision due to presbyopia, caused by reduced elasticity of the lens of the eye resulting in significant loss of focusing power. Older people are known to have vision impairments stemming from the normal ageing process, which include an impaired ability to quickly adapt to changes in light levels, extreme sensitivity to glare, reduced visual acuity, restricted field of vision and depth perception, reduced contrast sensitivity, and restricted color recognition. Changes in vision do not happen overnight and depend on the progress of age. After the age of 50, glare and low levels of light become increasingly problematic. People require more contrast for proper vision and have difficulty perceiving patterns. After the age of 70, fine details become even harder to see, and color and depth perception may be affected. Apart from the influence of ageing, there are pathological changes leading to low vision and eventual blindness, such as cataracts, macular degeneration, glaucoma, and diabetic retinopathy (van Hoof et al. 2010; Sinoo et al. 2011). In [Table 21.1](#) an overview of age-related eye pathology is given.

### 21.2.2 Ageing and Nonvisual Effects of Light

Apart from being indispensable for proper vision, light plays a role in regulating important biochemical processes, immunologic mechanisms, and neuroendocrine control (for instance, melatonin and cortisol pathways), via the skin and via the eye (Hughes and Neer 1981). Light exposure ( $\lambda \sim 460\text{--}480\text{ nm}$ ) is the most important stimulus for synchronizing the biological clock, suppressing pineal melatonin production, elevating core body temperature, and enhancing alertness (van Hoof et al. 2010, 2012). The circadian system, which is orchestrated by the hypothalamic suprachiasmatic nuclei (SCN), influences virtually all tissues in the human body. In the eye, light activates intrinsically photosensitive retinal ganglion cells (Brainard et al. 2001; Thapan et al. 2001), which discharge nerve impulses that are transmitted directly to the SCN and, together with the photoreceptors for scotopic and photopic vision, participate in mammalian circadian phototransduction.

In older adults, the orchestration by the SCN requires ocular light levels that are significantly higher than those required for proper vision, but the exact thresholds are unknown

**TABLE 21.1****Age-Related Sensory Changes to Vision**

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- Lid elasticity diminished, leading to pouches under the eyes.
  - Loss of orbital fat, leading to excessive dryness of eyes.
  - (1) Decreased tears; (2) arcus senilis becomes visible; (3) sclera yellows and becomes less elastic; (4) yellowing and increased opacity of cornea, which may lead to a lack of corneal luster.
  - (1) Increased sclerosis and rigidity of the iris and (2) a decrease in elasticity and convergence ability of the lens, leading to presbyopia.
  - Decline in light accommodation response leads to lessened acuity.
  - Diminished pupillary size leads to a decline in depth perception.
  - Atrophy of the ciliary muscles (holding the lens) leads to a diminished recovery from glare.
  - Night vision diminishes leading to night blindness.
  - Yellowing of the lens may lead to a diminished color perception (blues and greens).
  - Lens opacity may develop, leading to cataract.
  - Increased ocular pressure may lead to seeing rainbows around lights.
  - Shrinkage of gelatinous substance in the vitreous, which may lead to altered peripheral vision.
  - Vitreous floaters appear.
  - Ability to gaze upward decreases.
  - Thinning and sclerosis of retinal blood vessels.
  - Atrophy of photoreceptor cells.
  - Degeneration of neurons in visual cortex.
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Sources: Hughes, P.C., and Neer, R.M., *Hum. Factors*, 23(1), 65–85, 1981. Ebersole, P. et al., editors, *Toward Healthy Aging*, sixth edition, Mosby, St. Louis, MO, 2004.

to date. Research by Aarts and Westerlaken (2005) in the Netherlands has shown that light levels, even during daytime, are too low both to allow for proper vision and, consequently, also for non-image-forming effects, even though the semi-independently living older persons were satisfied with their lighting conditions. A similar study was carried out among 40 community-dwelling older people in New York City by Bakker et al. (2004). Even though nearly all of them had inadequate light levels for both image-forming and non-image-forming effects, subjects rated their lighting conditions as adequate.

An additional problem is formed by the ageing of the eye, which leads to opacification and yellowing of the vitreous and the lens, limiting the amount of bluish light reaching the retinal ganglion cells. This can be as much as a 50% reduction in 60-year olds compared to 20-year olds.

Many older adults are not exposed to high-enough illuminance levels, due to decreased lens transmittance, poorly lit homes (up to 400 lx), and the short periods of time spent outdoors. The indoor illuminance levels are too low for any non-image-forming effects to take place.

### 21.2.3 Dementia-Related Changes in Vision

Dementia has a severe impact on the human visual system (Guo et al. 2010), and the effects of biological ageing often aggravate the visual dysfunctions stemming from dementia. Persons with Alzheimer's disease frequently show a number of visual dysfunctions, even in the early stages of the disease (Kergoat et al. 2001; Redel et al. 2012). These dysfunctions include impaired spatial contrast sensitivity, motion discrimination, and color vision, as well as blurred vision. Altered visual function may even be present if people with dementia have normal visual acuity and have no ocular diseases (Kergoat et al. 2001). Another dysfunction is diminished contrast sensitivity, which may exacerbate the effects of other

cognitive losses and increase confusion and social isolation (Boyce 2003). Impaired visual acuity may be associated with visual hallucinations (Desai and Grossberg 2001). According to Mendez et al. (1996), persons with Alzheimer's disease have disturbed interpretation of monocular as well as binocular depth cues, which contributes to visuospatial deficits. The impairment is largely attributed to disturbances in local stereopsis and in the interpretation of depth from perspective, independent of other visuospatial functions.

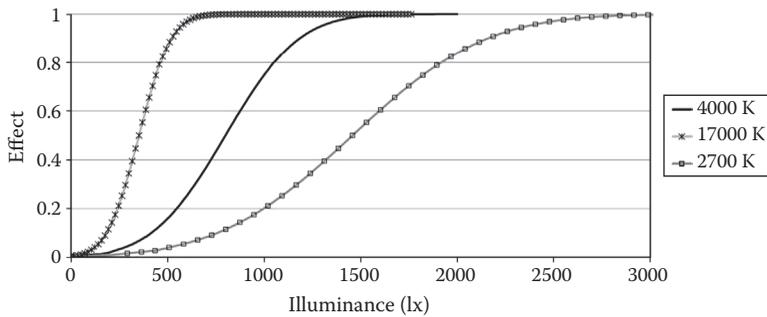
#### 21.2.4 Dementia and Nonvisual Effects of Light

In people with Alzheimer's disease, the SCN is affected by the general atrophy of the brain, leading to nocturnal restlessness due to a disturbed sleep-wake rhythm and wandering (van Someren 2000; Waterhouse et al. 2002). The timing of the sleep-wake cycle can show a far wider variation; times of sleep and activity can vary substantially from day to day or can be temporarily inverted (Waterhouse et al. 2002), which has great implications for both the PwD and his/her family carer. Restlessness and wandering form a high burden for carers and are among the main reasons for institutionalization (Health Council of the Netherlands 2002; Abbott 2003; Harper et al. 2005). Marshall (1995) stated that lighting technology deserves more attention as a means to help with managing problem behavior. Hopkins et al. (1992) have suggested a relation between illuminance levels and this type of behavior before, and today, light therapy is used as a treatment to improve sleep in people experiencing sundowning behavior (Brawley 2006). Sundowning is associated with increased confusion and restlessness in PwDs in the evening.

It is hypothesized that high-intensity lighting, with vertical (instead of horizontal, as our eye is located in a vertical plane) illuminance levels of well over 1000 lx (eye height), may play a role in the management of dementia. Bright light treatment with the use of light boxes is applied to entrain the biological clock, to modify behavioral symptoms, and to improve cognitive functions, by exposing people with dementia to high levels of ocular light (see, for instance, Lovell et al. 1995; Thorpe et al. 2000; Yamadera et al. 2000; Graf et al. 2001; Dowling et al. 2005). This intervention requires supervision to make PwDs follow the total protocol and may cause a bias in the outcomes of the therapy, for instance, as the level of personal attention is higher. The results of bright light therapy on managing sleep and behavioral, mood, and cognitive disturbances show preliminary positive signs, but there is a lack of adequate evidence obtained via randomized controlled trials to allow for widespread implementation in the field (Kim et al. 2003; Terman 2007; Forbes et al. 2009).

Another approach that is gaining popularity, from a research, ethical, and practical point of view, is to increase the general illuminance level in rooms where people with dementia spend their days in order for non-image-forming effects of light to take place (Boyce 2003). Studies by Rheume et al. (1998), van Someren et al. (1997), Riemersma-van der Lek et al. (2008), and van Hoof et al. (2009a,b) that exposed institutionalized PwDs to ambient bright light through ceiling-mounted luminaires showed short-term and long-term effects, such as lessened nocturnal restlessness, a more stable sleep-wake cycle, possible improvement to restless and agitated behavior as well as better sleep quality, increased amplitude of the circadian body temperature cycle, and a lessening of cognitive decline.

The occurrence of nonvisual effects of light does not only depend on light intensity. As stated before, certain parts of the light spectrum (specific short wavelengths) are more effective than others. The human circadian photoreception sensitivity peaks at approximately 480 nm, which is associated with the neuroendocrine and neurobiological systems. This sensitivity is graphically represented in the so-called  $C(\lambda)$  curve, which is used



**FIGURE 21.1**

Hypothesized size of nonvisual effects of light during daytime for different illuminance levels at the eye and different color temperatures. (Adapted from Górnicka, G.B., *Lighting at Work. Environmental Study of Direct Effects of Lighting Level and Spectrum on Psychophysiological Variables*. Dissertation, Eindhoven University of Technology, Eindhoven, 2008. Reprinted from *Building and Environment*, 44(9), van Hoof, J. et al., High colour temperature lighting for institutionalised older people with dementia, 1959–1969, Copyright 2009, with permission from Elsevier. License number: 3087171431049.)

in lighting research and practice (Pechacek et al. 2008). Generally, required illuminance levels are higher than average, and so is the (correlated) color temperature of the light (Górnicka 2008) (Figure 21.1). The (correlated) color temperature is one of the measures for the amount of short-wavelength light present in the spectrum. As stated, there are several short-term and long-term effects (van Hoof et al. 2012). A cluster-unit crossover intervention trial by Sloane et al. (2007) on the effects of high-intensity light found that nighttime sleep of older adults with dementia improved when exposed to morning and all-day light, with the increase most prominent in participants with severe or very severe dementia. Hickman et al. (2007) studied the effects on depressive symptoms in the same setting as Sloane et al. (2007). Their findings did not support the use of ambient bright light therapy as a treatment for depressive symptoms. To date, it is unknown if the light therapy is effective, how long effects of bright light last, and how to predict which persons (may) respond favorably to light treatment. These points were already made by the Health Council of the Netherlands in 2002.

### 21.3 Technological Solutions: Design and Practice

The increasing numbers of older people with dementia in combination with the lack of available care professionals go together with a need for technological solutions and services to support activities of daily living and reduce the burden on carers. Light therapy is hypothesized to play a role in improving the well-being and quality of life of PwDs. To date, the administration of light therapy via ceiling-mounted luminaires is a relatively new area of study and innovation. As the current state of science permits us to design and model healthy lighting solutions, it is time to improve the quality of life of PwDs. In order to do so, we need to investigate the recent innovations in the field of lighting technology in relation to the underlying algorithms of the lighting equipment's steering mechanism.

New dynamic lighting protocols are being implemented in the lighting solutions offered to older adults (Figures 21.2 and 21.3). The underlying assumption of such systems is that

**FIGURE 21.2**

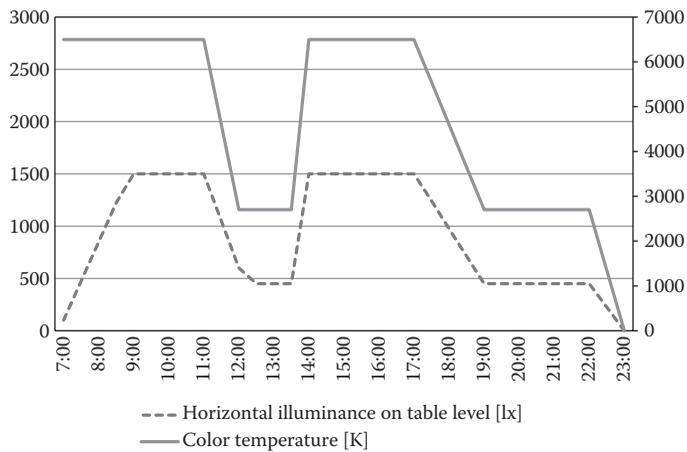
(See color insert.) Examples of dynamic lighting installed in Dutch nursing homes: Amadea by Derungs (left), Biosun by Van Doorn (middle), and Strato by Philips (right).

**FIGURE 21.3**

Examples of dynamic lighting systems in Dutch nursing homes. Figure upper right. (Reprinted from *Building and Environment*, 44(9), van Hoof, J. et al., High colour temperature lighting for institutionalised older people with dementia, 1959–1969, Copyright 2009, with permission from Elsevier. License number: 3087171431049.)

human beings evolved in daylight conditions and that the dynamic component further contributes to the positive effects of the lighting systems. As there is no validated set of algorithms as used in current lighting systems, including the relative effects of static versus dynamic lighting protocols (Rea et al. 2002; Figueiro 2008; Barroso and den Brinker 2012), there is still plenty of room for innovation and research. Figure 21.4 shows the rationale behind a dynamic lighting protocol and the way it has been shaped in practice. As can be seen in the figure, both illuminance and color temperature are controlled through dedicated software. In most projects, only the main luminaire in the living room is steered via a dynamic protocol.

In all the studies concerning light therapy, the exposure to daylight is often an ill-described aspect. We therefore do not fully understand the effects of these interactions. Daylight has a dynamic character, which is mimicked by dynamic lighting systems. With new technologies, lighting can be supplemented to the available daylight, which also has positive effects on energy consumption. This requires that new lighting solutions are to



**FIGURE 21.4**

Example of a protocol for dynamic lighting. The horizontal illuminance on the table level varies between 0 and 1500 lx. The color temperature of the light varies between 0 and 6500 K. The so-called post-lunch dip can be found in the first hour of noon.

be integrated within a framework of the digitalization of the home (including sensor-based networks, ambient assisted living, and e-health) (van Hoof et al. 2011a,b) and smart façade systems (measuring incoming daylight and its spectral composition), which can go together with an optimization of exposure to certain light levels and, hence, energy use. Moreover, the exposure to light can be part of a digital patient or care file and form an additional source of information to medication protocols. Ambient intelligence in the home environment can thus lead to new improvements in the administration of ambient bright light, starting with institutional settings.

New lighting solutions should combine all sources of light (including daylight); novel lighting technologies such as LED technology (with energy-efficient options for a high output in the blue region of the spectrum) or ceiling- or wall-mounted lighting applications (also referred to as ambient bright light); smart sensors that measure the quality and quantity of light needed at a specific moment for a specific individual; and the platform that both controls the supply of light and, in parallel, measures the effectiveness of the light. The intricate balance between daylight and electrical light sources calls for smart sensors in the dwelling and dedicated software to steer the lighting exposure of persons. These sensors should also measure the presence of occupants and the type of activity they are engaged in. The dip in lighting protocols (Figure 21.4) is related to the length of the lunch break. If this break takes longer, perhaps the dip in the protocol should be longer too. The protocol should ideally follow the care regime. Apart from manual controls, a sensor-based network can help achieve accounting for the regime.

In addition, light therapy also calls for an attractive design of the lighting equipment. Indoor lighting conditions may be perceived as unfavorable from the perspective of personal preferences and taste, particularly with higher color temperature lighting or light with a dedicated, spectrum which accounts for the human circadian photoreception sensitivity that peaks at approximately 480 nm [following from the  $C(\lambda)$  curve (Pechacek et al. 2008)]. This can be solved by adding an additional decorative luminaire underneath the luminaires used for light therapy.

One other factor that makes it hard to implement innovations in the field is that to date, there are no extensive documents on lighting for older people, which can serve as an underlying basis when conducting research and for product and service innovation. There is, however, a growing interest within the building community in the nonvisual aspects of light (Webb 2006; McNair et al. 2010). CEN EN 12464-1 (2011) summarizes recommendations of lighting of indoor work places. The standard specifies horizontal illuminances for health care facilities, such as waiting rooms, corridors, examination rooms, and spaces for diagnostics in hospitals. Nursing homes are not included in this standard. The standard does not specifically include color temperature for health care facilities in general, too. There need to be more efforts to improve current standards and guidelines to account for light therapy and ambient bright light. We need to look at how science can find its way into practice in order to improve the quality of life of PwDs and the work of their carers and the installers.

At the same time, we need to be critical. There is still a lot we do not know. To date, we do not know if dynamic systems have better outcomes than static lighting systems and how such systems (should) interact with available daylight. We do know that vision can be improved by raising general illuminance levels and glare control; the nonvisual benefits cannot be quantified yet. Therefore, the economic and well-being benefits of accounting for these parameters are not yet clear. As long as there are many uncertainties, maybe we should suggest exposing our older citizens to plenty of daylight, for instance, by taking them out for a stroll. The innovations in the realm of sensors and ambient intelligence in the home environment hold a promise that, in the future, the nursing home can administer the right amount of lighting to its residents, which allows them to enjoy the highest degree of quality of life.

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