From the Nobel prize for medicine to the future Lighting Design in interiors: when colour matters

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The 2017 Nobel Prize for Physiology or Medicine was awarded to American scientists Jeffrey C. Hall, Michael Rosbash and Michael W. Young for their 1980s research into the molecular and genetic mechanisms controlling the circadian rhythm. This news, which went almost unnoticed in the design field, actually has very important implications regarding the evolution of interior lighting design, with particular reference to colour. In this article we highlight the elements of the relationship between lighting and colours, hoping for a new approach to interior design in the future. Many research has been done on the psychology of colours and on colour preferences, if we instead evaluate the effect of colour, with the scientific method, from the physiological point of view, there are researches that focus on the spectral distribution of light that reaches the eyes, but they ignore the effect of interior colours on the light that actually reaches our eyes in daily life. This element of multidisciplinary thinking can pave the way for much design research in the field of colour, also because this could be important for our health.

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Introduction

Jeffrey Connor Hall is professor emeritus of biology at the Brandeis University in Massachusetts. His contribution was essential for the development of this field of investigation, because he developed a strategy for the isolation and neurological characterisation of genetic mutants of Drosophila melanogaster, also known as fruit fly. Michael Rosbash, a professor of genetics at the Brandeis University, used the then nascent technologies of recombinant DNA to characterise the mutant flies isolated from Hall, eventually identifying numerous genes involved in the circadian cycle. Also Michael Warren Young, geneticist and biologist, while working at the Rockefeller University, has conducted research on circadian synchronisation of the fruit fly. In his Nobel lecture, Young presented interesting data on sleep alterations in humans, showing that hundreds of genes are involved in the circadian rhythm and that alterations in the expression of these genes are the basis of many sleep disorders having serious consequences for human health [1].

Although these research were conducted on the fruit fly, the Nobel jury wanted to award the prize to these three researchers, surprising the scientific community of the sector and also the three scientists, if it is true that Rosbash replied "You are kidding me" and Hall said, "Is this a prank?" when they were told that they had won the prize [2]. With this Nobel Prize, the jury wanted to highlight research that can have a practical impact on everyday life. Similarly to what happened in 2014, with the awarding of the Nobel Prize in Physics to scientists Isamu Akasaki, Hiroshi Amano and Shuji Nakamura for the invention of the blue LED, thanks to which the current LED lighting systems were developed. The research conducted by Hall, Rosbash and Young are the basis of the scientific demonstration of the functioning of the circadian system in humans, not to be confused with biorhythms, which are rather an urban legend, very popular in the USA in the 70s, without any medical or scientific basis, as demonstrated by a hundred scientific researches [3].

Importance of the circadian cycle for human health

A timed system acts in our organism, managed by the suprachiasmatic nucleus of the brain, which lasts about 24 hours, called circadian from the Latin circa-diem, through which all physiological processes such as sleep, nutrition, hormone production, blood pressure, body temperature, digestion, psychological alertness, coordination and muscle strength are managed [4]. It is important to emphasise that all of these factors have a daily cycle of action and also act on the effectiveness of our immune system. To know the actual timing state of our circadian cycle, the most effective method is based on the measurement of the amount of melatonin present in the blood [5-6]. Melatonin is a hormone produced by the pineal gland under the control of the suprachiasmatic nucleus. In an individual with a correct timing of the circadian rhythm, melatonin increases in the evening hours immediately after sunset and begins to decrease before sunrise, remaining low during the day. For years now, melatonin can also be purchased as a drug or dietary supplement and is taken by people who have sleep problems and want to resynchronise their circadian cycle [7].

However, this internal clock needs to be synchronised for the needs of life on Earth and the exogenous element that generates this synchronism is light. Indeed, in the absence of the rhythms of natural light, due to the Earth's rotation, the clock can go out of phase with multiple implications for our health and well-being [8]. Many individuals suffer, often unknowingly, from more or less serious discrepancies in the circadian cycle; these can also be caused by exposure to inadequate artificial lighting. The disturbance in the circadian rhythm can occur late, called owl disorder, or early, called lark disorder [9]. In the course of an individual's life it is quite common that when young one is like an owl, extremely active in the evening but with awakenings in the late morning, while in old age one becomes more like a lark, with tiredness immediately after sunset but with early morning awakenings. However, beyond certain limits, these lags become pathological. Disturbing the normal circadian cycle can cause migraines [10], headache [11], irritability [8], seasonal depression [12], deficiencies of the immune system [13], chronic fatigue [14], obesity and diabetes mellitus [15]. An increase in the probability of developing some cancers has also been hypothesised, as a consequence of the alteration of the circadian cycle that affects the production of various hormones and the efficiency of the immune system [16-18].

Interior for circadian system

The largest and most accredited artificial lighting research centre in the world is the Lighting Research Center (LRC) of the Rensselaer Polytechnic Institute in Troy (NY, USA). I was lucky enough to visit it for a full day in 2014. It is a 4-storey building that hosts classrooms, offices and measurement laboratories. Much space is dedicated to setting up real environments of daily life, such as offices and homes, in which people work and reside to experience the effects of artificial lighting from a neurophysiological standpoint: by analysing blood, body temperature, electrical activity of the brain and other tests of a psychological nature. The LRC was headed for many years by Mark Rea, an architecture and cognitive sciences professor. His well-known statement is "... the circadian system can be considered a blue sky detector..." which "... appears to be the ideal source of circadian light, given our evolutionary past as upright hunters and gatherers, active during the diurnal phase" [19]. Since 2017, the new director of the LRC is architect Mariana Figueiro, who for years has been studying the effects of lighting on health in the design of human spaces [20].

For someone who spends his or her life in nature and mainly outdoors, the circadian cycle is synchronised by the rhythm of natural light, which is the circadian light par excellence. But what is a circadian light, exactly? A circadian light (CL_A) is natural or artificial light that, for its quantity, duration and spectral content, is able to synchronise the circadian system by inhibiting the production of melatonin, with a degree of effectiveness that is called circadian factor (CS). It has been shown that effective stimulation of the human circadian system with a CS value greater than 0.3 is achieved with at least one hour of light exposure. Many researchers, such as Mark Rea, have long argued that the circadian aspects of natural and artificial light should also be considered in interior design. However, today there is no world standard capable of defining a circadian photometry. The world body that deals with light, vision and colour, i.e. the Commission Internationale de l'Eclairage (CIE), has presented a document that takes stock of the research in this area [21] and another proposing a roadmap for future research [22] and a standard to define the spectral sensitivity functions of cones, rods and ipRGCs (intrinsically photosensitive Retinal Ganglion Cells), as well as the quantities and units of measurement that can be used in experiments [23]. Since the circadian system is a multidisciplinary topic that concerns design, light, colour and the human being, there are many entities that are dealing with it in various capacities. A report published by the SCHEER (Scientific Committee on Health, Environmental and Emerging Risks) of the European Commission has recognised, on the one hand, that there are no problems for human health related to the use of LEDs in lighting, and on the other the scientific existence of the relationship between illumination and the human circadian cycle [24]. Artificial circadian lighting today can be achieved thanks to LED technologies.

In recent years, proposals have been made to quantify the CL_A and the CS [25-26] which have also found application in principle in national regulations in Germany [27] and the USA [28]. Furthermore, in terms of building certification, the Well Building Standard has been proposed for some years [29], which focuses heavily on the health and psycho-physical well-being of people in buildings. Based on scientific research in various sectors, this certification takes into consideration the characteristics of the building that have a direct impact on human health and well-being, including lighting. The guidelines provided by the WELL aim at minimising the negative interference that the lack of natural light or inadequate artificial light can produce on the normal human circadian rhythm.

The environment colour and circadian light

One might wonder why the issue of the circadian cycle arises, given that electric artificial lighting has been present in interiors for over a century. However, it is important to remember that in the last 200 years human activities undergone a radical transformation and concentrated in cities, with the consequent mass migration from the countryside to urban centres and the development of industrialised societies. We have gone from a working life conducted for the most part outdoors, in the countryside, to one conducted mainly indoors, with a limited supply of natural light and exposed instead to artificial light, which has different characteristics from natural light. To understand the dimension of this socio-economic change, following the transition from an agricultural economy to an economy characterised by the use of machines and technology, we should consider that in Europe, for example in 1800, only 2% of the population lived in cities. In the early 1900s the share of the city population had risen to 15%. In this century, the majority of the European population lives in cities [30] and works in closed spaces; even the majority of those who live outside urban centres do not work outdoors anyway. It is estimated that today in industrialised societies, people spend between 80% and 90% of their time indoors [31-32]. Based on this radical change in lifestyles, we must however observe that 200 years are nothing compared to the evolution of the human being and, from this perspective, our exposure to artificial lighting must be considered a very recent introduction [33]. Indeed, our body is made to function and synchronise itself according to the rhythm of the continuous variations of natural light. Our physiology would require being exposed to natural light during the day and complete darkness at night, in order to promote sleep, with its regenerative cycles that have a fundamental role for health, happiness and physical wellness [34].

There are many situations that can negatively affect the circadian cycle. A known factor disturbing the circadian cycle is, for example, flights between multiple time zones. The jet lag occurs due to the phase shift between the sleep cycle, internal organs and the new circadian rhythm induced on the body by the different timing of the received lighting [35]. The social context can also lead people to excessive evening light exposure, consciously or otherwise, contributing to a delayed phase shift in the circadian rhythm, defined as social jet lag. As a consequence of prolonged exposure to a CL_A in the evening, the person is in fact systematically found with a circadian rhythm that is out of phase compared with that required by the activities that generally involve a morning work and/or study commitment [36]. The social desynchronisation of the circadian rhythm has been associated with possible problems, like as excess consumption of stimulants such as caffeine, alcohol and nicotine [37]. Furthermore, social desynchronisation has also been linked to an increased risk of heart diseases and metabolic dysfunctions, such as obesity and diabetes [38]. Evidence was also offered in a scientific review that exposure to inappropriate evening light could have a direct negative effect on the relationship between food consumption and body weight [39]. Indeed, exposure to CL_A in the evening could facilitate the consumption of food in the least favourable moments from the metabolic standpoint, when the body is not predisposed to digestion and the correct metabolisation of nutrients.

From the design perspective, however, the most important aspect is that even today artificial lighting in interior spaces is designed to meet the needs of vision and energy saving, but unfortunately it systematically ignores the needs of our circadian system. The actual contribution of natural light to interior spaces should also be considered at the design stage. Some recent studies carried out in real environments have evaluated whether the natural daylight that flows indoors is in sufficient quantity to be considered circadian, as it always is in open spaces. Indeed, it must be pointed out that only the light that reaches the eyes has an effect on the circadian system, that this has a slow response and that when they are in indoor spaces people do not fix their gaze on openings or artificial light sources for very long.

The key point is that in fact, the eyes mostly receive natural light reflected by architectural surfaces and furnishings or transmitted by curtains and other filtering systems, which decrease its quantity and modify its spectrum [40]. To avoid glare, people never look directly towards the light sources, but look towards the surfaces of the interiors which are characterised by spectral reflectances and colours that have a decisive influence on the real spectral distribution of light reaching the eyes. Therefore, the colour of wall coverings and furnishings in interior spaces has a decisive influence on the spectral composition of the light actually received by humans during their daily life indoors.

Some studies carried out at the latitudes of Milan and Naples have observed that in a condominium apartment, with good sun exposure [41], in a library [42] and in two schools [43-44], from the points of view preferentially used by the occupants, the CLA that reaches the eyes of people is almost never able to correctly stimulate the circadian system during the year, as it happens outside. Only in the analysis of some offices on the seventh floor of a building located in Naples and without other surrounding buildings was it possible to obtain natural internal lighting capable of correctly stimulating the circadian system [45]. In all these researches, the walls of the rooms were white. The question we must ask ourselves is therefore what added value could different coloured walls have given to the physiological effects on our health? This is a research topic that could be explored in the future.

Ultimately, in many situations, the spectrum of natural light present indoors during the day may not be able to adequately stimulate the circadian system as would be required by our body. The task of making up for this CLA deficiency occurring in interior spaces should therefore be entrusted to adequate artificial lighting and the enhancement of the spectral characteristics of the circadian light, which can be done with adequate colour design.

Conclusions

As demonstrated by many years of medical research, the subject of circadian stimulation in the interior is important for our health. From the perspective of the design approach, extreme simplifications must be avoided, but neither should this topic be considered an excessively complex element to be included in the future culture of design. The claim that a luminaire has circadian performance is false in itself. This is because the CLA must always be evaluated at eye level, in the typical positions of human beings in an internal environment. This depends on natural light, on artificial light and also on the way in which all the elements of the project, such as indoor colours, affect the light actually present in the environment that really reach our eyes. The CLA therefore depends on the design of the building as a whole, on the colours present in the interior spaces and on the time factor. Therefore, it cannot be just a pre-packaged product or a palette of circadian colours.

From the time standpoint, however, the model to be applied is actually simple: the CLA must not be static but dynamically change during the day like natural light, in terms of quantity, spectral content and possibly direction. During the day we need CLA, while after sunset we can use artificial lighting that has no circadian performance. That is, the day light must facilitate the natural breakdown of melatonin in the blood, while the evening light must not counteract the normal production of melatonin.

A final point concerns the possibility of quantifying the CLA and also the CS factor. Online are available a calculation table [46] and web pages [47-48], thanks to which these two elements can be determined for some light sources on the market or, more accurately, by entering the spectral data measured for the ambient light and as function so the colours of the surfaces. The latter is obviously the most correct methodology and this data can be acquired today with a common portable spectrophotometer. For these measurements, the most significant investigation that can be performed

concerns the variation of light in an environment during a winter day with an overcast sky, since it is typically the worst condition for the contribution of natural light to CLA during the year. The spectral measurement of light must be done by measuring the radiance, at eye level, in the typical positions of human beings in an interior space, considering the typical visual directions towards commonly observed surfaces and according to their chromatic characteristics.

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