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Preface

Humans are diurnal organisms whose biological clock and temporal organization depend on natural light/dark cycles. Throughout evolution, changes in the photoperiod were a signal for seasonal acclimatization of physiological and immune systems as well as of behavioral patterns. The invention of electrical light bulbs created more opportunities for work and leisure. However, exposure to artificial light at night (LAN) affects our biological clock, and suppresses pineal melatonin (MLT) production.

Knowledge accumulated in the past decades and our better understanding of eye photoreceptors and the discovery of melanopsin in the bipolar ganglions gave us a better perspective on light intensity and light spectrum in relation to the entrainment of our biological clock and the importance of events with timing.

In many electrical light bulbs used today and considered "environmentally friendly," electrical energy is converted into short wavelength illumination thus increasing the light intensity to the levels we have not been used to in the past. Such illumination effectively becomes "light pollution" which disrupts pineal melatonin (MLT) production. Among its other properties, MLT is an antioncogenic agent, and therefore, its suppression increases the risks of developing breast and prostate cancers (BC&PC).

To the best of our knowledge, this book is the first authored book which attempts to address the linkage between light pollution and BC&PC in humans. It explains several state-of-the-art theories, linking light pollution with BC&PC. It also illustrates research hypotheses about health effects of light pollution using the results of animal models and population-based studies.

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Boris A. Portnov

Contents

Chapter 1
Introduction

Some people will never learn anything, for this reason, because they understand everything too soon.
Alexander Pope

The levels of health care and living conditions in many regions of the world have improved considerably in the past decades, especially in urban areas. Yet, modern urbanized and industrialized ecosystems are not necessarily the healthiest places to live in. In addition to many "traditional" health hazards, such as air pollution, and general stress associated with living in urban areas, yet, many new health hazards constantly emerge or are being recognized as such.

Relatively recently, for instance, exposure to low frequency electromagnetic radiation, such as radio and microwave frequencies (RF/MF) was recognized as a health risk to humans, along with exposure to various chemicals often found in urban areas, such as benzenes, detergents, endocrine disrupting chemicals (EDCs), heavy metals, and many others that are found in soils, drinking water and building materials of which our homes are built. Even more recently, shift-working, which is quite common in urban areas, has been added to the list of risk factors potentially carcinogenic to humans (ACS 2007).

In this book, which is, to the best of our knowledge, the very first authored book published on the topic, we discuss yet another potential risk factor for human breast and prostate cancers (BC&PC)—Light-at-Night (LAN), which can be termed "light pollution" or even "light toxicity."

One may ask: *How can light become a risk factor? What can be more natural to humans, as diurnal organisms, than light?*

These questions are intuitively correct, indeed. Therefore, one clarification is required: It is *not* regular daytime sunlight, to which humans have been accustomed over the years of human evolution, we are talking about. The matter is that the light we are exposed today in our homes, work places and in public spaces often differs from regular sunlight by two important properties—*timing* and *wavelength*.

Let us elaborate. Throughout the years of evolution, our human ancestors, as other mammals, were diurnal. They (normally) were active during daytime and rested at night under (normally) dark conditions. Bearing in mind that the human evolution, for a long period of time, took place close to the Equator, our ancestors followed close to 12 h of light–12 h of darkness (12L–12D) cycles.

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Although humans have always been attempting to prolong the light part of the day, by whatever means locally available—burning wood, animal fat, organic and mineral oils, etc. (especially after they moved from the equatorial areas to places with short days and long nights), —possibilities for nighttime activities under such limited lighting sources, were rather limited.

The situation has changed dramatically in the past 120–130 years with the invention of an electrical light bulb, demonstrated to the public nearly simultaneously by Joseph Swan in the UK and Thomas Alva Edison in the USA in 1879.

Since then, electrical light bulbs and electricity, as an energy source for illumination, have become more reliable and affordable. Following these technological developments, electric lights proliferated widely across the globe, reaching even the most remote peripheral regions and rural areas of developing countries.

As a result of this proliferation, which has started, as we should emphasize, only 120–130 years ago, humans across the globe are no longer "tied" today to the traditional 12L–12D cycles, but can be active around the clock, if they chose so. Supported by artificial illumination, we can be active at night and rest during the day, quite contrary to our diurnal nature, "programmed" by the years of evolution.

In addition to these *changes in the temporal activity patterns*, which artificial illumination enables, our eyes are often exposed to *high light intensity when they are supposed to have been exposed to very low light intensity* (if at all), that is, after sunset and even at night.

LAN often penetrates our bedrooms from outdoor sources through fenestrations in our walls. Outdoor LAN sources include streetlights, as well as lights from billboards, stadiums, shopping centers and other brightly illuminated public buildings and monuments, neighboring buildings, moving vehicles, etc. (Fig. 1.1).

In addition, LAN is often present in our bedrooms when we sleep. It comes from nightlights, working TV sets, computers and other indoor equipment and devices we do not bother (or do not want) to turn off. Moreover, light indicators, including digital clocks, are often switched on, as well as "standby" lights on other electronic devices, such as computers, cellular phones, air conditioners, routers, TVs, DVD players, etc.

In addition, we are also exposed to LAN in our workplaces (especially people who work night shifts), as well as in places of nighttime entertainment—sport and cultural facilities, movie theaters, etc. The *timing of our light exposure* today is thus quite different from what we were evolutionary "programmed."

An additional difference between natural daylight and artificial lights that we commonly use today should also be mentioned. This is the *difference in the wavelength* emitted by these light sources from that of natural sunlight.

The matter is that visible *sunlight* is characterized by a daily changing wavelength in a wide range. In contrast, many artificial light sources, we use today, emit short wavelengths of visible light with a constant predominant wavelength between 450 and 500 nm.

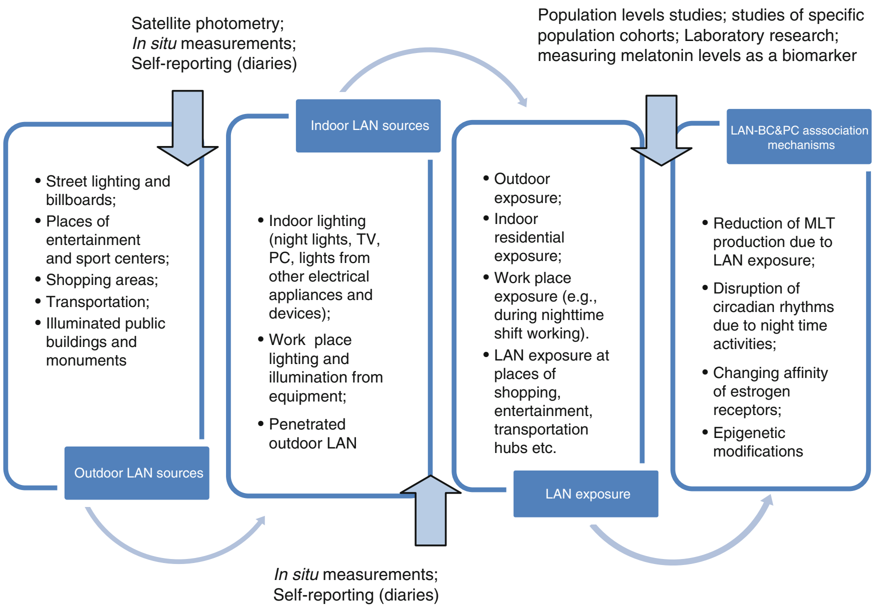

Fig. 1.1 Links between LAN and breast-prostate cancers (BC&PC) —research hypothesis (after Haim and Portnov 2011)

> Do these nightlight-enabled alterations in our life styles and newly introduced light sources interfere with our "preprogrammed" daily cycles? Can these changes and newly introduced LAN sources potentially suppress MLT production, weaken our immune system, and thus expose us to additional health risks, such as BC&PC?

In the rest of this book we shall attempt to answer these questions.

We start first with a brief discussion of visual light and its physicochemical properties. We shall also review selected characteristics of light bulbs used today for indoor and outdoor lighting and spectra of different light sources. These concepts and notions will be discussed in the next chapter (Chap. 2 written by Dr. Fabio Falchi).

In Chap. 3, we discuss the light and dark cycles (photoperiodicity) on Earth as the underlying basis of our temporal organization. As we shall emphasize, most living terrestrial organisms anticipate the time of activity due to the existence of the endogenous biological clock entrained to exogenous environmental photic changes. As we shall argue, our daily rhythms can be described as an orchestra in which the harmony of all instruments is maintained by the single conductor, with the biological clock (the master oscillator) carrying out this function. The biological clock also works as a calendar helping living organisms to anticipate seasonal changes and to acclimatize their physiological and immune systems, as well as their behavioral patterns to the approaching season. For its temporal organization, the biological clock uses the signals of light intensity and wave length detected by the retina in our eyes, but not only as in the case of vitamin D when the light signal is picked by the skin.

The location and functioning of the biological clock, which is entrained, as previously mentioned, mainly by light/dark (L/D) cycles and acts as our internal calendar, will then be discussed in Chap. 4. The *modus operandi* of our biological clock was considered, for many years, a "black box." Our recent understanding of its functioning came from experiments in which subjects, kept under free running rhythms (FRR), with no external time signal, were entrained to light exposure during the night, which resulted in a phase shift response (PSR), while such a shift was not detected when exposure to light took place during the subjective day. As we also know today, the molecular basis of our biological clock is based on interactions between various clock genes, paired to create hetero-dimmers, and being the templates for proteins production that interact with genes by positive and negative feedback loops.

In two subsequent chapters, Chaps. 5 and 6, we discuss how LAN exposure may affect our daily rhythms (Chap. 5) and what role the pineal melatonin (MLT) hormone, also known as the "hormone of darkness," may play in this process (Chap. 6).

In the next chapter (Chap. 7) we focus on the introduction and spread of artificial illumination. As we shall argue, people knew about electricity for centuries. However, the first successful attempt to use electricity for lighting took place only about two centuries ago and is credited to Sir Humphrey Davy, who discovered in 1801 the incandescence of an energized conductor. Yet, the idea of using electricity for lighting "took off" only after the American inventor Thomas Alva Edison developed his deep vacuum incandescent light bulb with a carbon cotton filament. Since then, both light bulbs and electricity production have become relatively cheap and more reliable. As a result of rapid electricity proliferation, electric lighting has substituted traditional lighting sources, making human populations virtually independent of natural L/D cycles.

In the next three chapters (Chaps. 8–10) we deal, in brief, with the biological definition of light pollution (Chap. 8), the role of light pollution as a general stressor (Chap. 9) and the effects of light pollution on animal rhythms and ecology (Chap. 10). As we shall emphasize, different theories can be used to explain the association between LAN exposure and BC&PC. The direct effect of LAN on the eye retina and resulting infractions of human daily rhythms by disrupting pineal MLT production and secretion, is only one of them. LAN can also act as a general stressor. LAN, through MLT suppression, can also become a cause of changing affinity of estrogen receptors or modify DNA global levels of methylation thus causing DNA changes epigenetically.

Empirical evidence accumulated to date about the links between LAN and BC&PC is discussed and summarized in Chap. 11. As we shall note, a possibility that human body may be affected by ambient light was raised, apparently for the first time, by the Israeli physician Philip Cohen in 1970. As we know today (from clinical experiments, case-control and population levels studies), the link between exposure to artificial light and its potential health risks may be attributed to two interdependent mechanisms—inhibition of MLT secretion from the pineal gland by direct exposure of human vision system to LAN and disruption of daily rhythms by nighttime activities. Empirical evidence for these effects is discussed in Chap. 11, supported by reviewing numerous empirical studies carried out to date.

Worldwide patterns of BC&PC are discussed in Chap. 12. As we shall demonstrate, geographic patterns of these cancers worldwide are surprisingly similar, with higher rates of both BC&PC observed in developed countries and lower rates elsewhere. The incidence rates of these cancers are also higher in more extreme latitudes, suggesting a possibility that such rates are related, among other factors, to LAN, considering that in extreme latitudes artificial light is often used to compensate for a shortage of natural illumination. Our analysis supports such a possibility, especially for PC.

Light pollution and its associations with BC&PC in population-level studies are discussed in Chap. 13, using two specific case studies, which attempted to link digital maps of nighttime illumination captured by satellite sensors with BC&PC incidence rates, thus helping to demonstrate the association potentially existing between them. As we acknowledge, nighttime satellite imagery has been used before, for mapping sky brightness and built surfaces, construction of "global poverty" maps, estimation of ecological footprints of different countries and country specific electrification rates, spectral identification of lights, monitoring forest fires, and for many other development tasks. However, the idea to link the digital satellite images with place-specific incidence rates of BC&PC was originated in two studies spearheaded by the authors of this book.

As we assumed from the outset of the analysis, urban populations residing in highly illuminated areas (such as e.g., central London, Paris, Tel Aviv or NYC) are exposed to LAN not only in their bedrooms but also in many other places, and from a variety of other light sources, which residents of smaller towns and of rural areas do not have, at least, on such a scale. The daily rhythms of the residents of such major populations may also be disrupted by various nighttime activities, such as leisure and entertainment, and employment in businesses working after dusk. In this sense, satellite photometry helps to capture these additional LAN-associated risks. Our underlying research hypothesis was relatively simple: *If there is a significant relationship between population LAN exposure and BC&PC incidence rates, then there should be a significantly strong association between LAN intensities and BC&PC, but not with other cancers, such as colon, larynx, lung, etc*.

Population-based and individual-level studies have their own advantages and disadvantages. Global studies of large populations may provide a high degree of generality and thus help to capture the effects of low exposures by comparing a wide range of differently exposed subjects. However, population studies are generally weak in supporting causality. They also often overlook detailed characteristics, such as hereditary factors, residential history and occupational risks. Other biases may also affect the results of population-level studies of the LAN-BC&PC association, including ecological fallacy, recall bias, and the eyelid effect. These potential bias sources and ways of mitigating them are discussed, in some detail, in Chap. 14.

As we further argue, although individual-level studies may provide rich details about studied subjects, there are obvious limits to the degree of generality and statistical power that a semi-random sample of a few dozens of subjects, for a short period of time (several days), at a certain time in the year, lacking a matched control, can provide. In this setting, population level studies can assist in initial hypothesis testing, assuming that the results of such studies can be followed up by higher resolution studies in humans and by using animal models to understand mechanisms down to the cellular level.

Although most of the studies reviewed in this book relate to BC&PC, there is a rapidly increasing body of evidence, coming from both laboratory research and epidemiological studies, that LAN exposure may also be linked to other health effects, such as e.g., hypertension, obesity, sleep disruption and mental disorders. The mechanism of these potential associations may be similar to those we discuss referring to the LAN-BC&PC links, namely MLT suppression and daily rhythms disruption. Therefore, in the concluding chapter (Chap. 15), we review, in brief, scientific evidence which has become recently available on other, non-BC&PC related, effects of LAN exposure.

As we also point out in Chap. 15, uncontrolled and rapidly increasing exposure to LAN may present a new and serious health challenge for ever increasing human population worldwide. However, the main message we attempt to deliver in this book is not that humans should go back to the "pre-Edison" era of "nighttime darkness." Such calls would be both counter-productive and unrealistic. Instead we should think of adhering, whenever possible, to our "evolutionary-preprogrammed" diurnal life cycles. We should also try to implement sustainable illumination policies, both in our homes and in public places. In particular, we should refrain from using short wavelength light sources, aggressively brought into our private and public domains in the name of "energy saving." Although such illumination sources can save energy, their adverse health effects, in the long run, can greatly outweigh, in our view, any energy saving benefits such light sources can potentially bring today and tomorrow.

Finally we would like to note that not all the aspects of the LAN-BC&PC association are yet clear, and answers to many questions are still pending. Therefore, research on this important topic should, undoubtedly, continue, using various methodologies and comprehensively designed studies.

Part I
Artificial Light and Human Temporal Organization

Chapter 2
Artificial Light and its Physicochemical Properties

Abstract Light is a small part of the electromagnetic spectrum, from violet to red, to which our eyes are responsive. Photometry measures light using several units, including the candela for intensity, the lumen for flux, the lux for illuminance and the candela per square metre for luminance. Vision at relatively high illumination levels is called photopic, when our eyes mainly use cones; in the dark, vision is called scotopic. Recently, a non-visual photoreceptor with peak sensitivity in the blue part of the spectrum has been discovered which regulates our circadian rhythms.

Keywords Light spectrum · Spectral range · Electromagnetic radiation · Photometry · Light flux · Light units · Light intensity · Photopic and scotopic vision · Bulbs · Meltopic efficacy · Photoreceptors · Illuminance · Artificial lighting · Eye sensitivity

Philosophy is written in that great book which ever lies before our eyes—I mean the universe—but we cannot understand it if we do not first learn the language and grasp the symbols, in which it is written.

Galileo Galilei (The Assayer, 1623)

Visible Light

The portion of electromagnetic radiation visible to the human eye we call light. Light can be described as an electromagnetic wave, like radio waves, microwaves, infrared radiation, ultraviolet radiation, X-rays and gamma-rays. All these

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'La filosofia è scritta in questo grandissimo libro che continuamente ci sta aperto innanzi a gli occhi (io dico l'universo)…' Galileo Galilei, 'Il Saggiatore'.

The chapter is contributed by Dr. Fabio Falchi (ISTIL-Light Pollution Science and Technology Institute, Thiene, Italy).

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