OPTIMISING LIGHT EXPOSURE TO IMPROVE HEALTH AND WELLBEING

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Abbreviations and glossary:

Circadian rhythm: the physical, mental and behavioral changes occurring over a roughly 24-hour cycle that enable organisms to anticipate and prepare for regular events in their environments. Circadian rhythms are internally generated by cells, but can be modulated by external cues, such as light.

Suprachiasmatic nucleus (SCN): A cluster of cells in the brain's hypothalamus, which acts as the body's master clock, enabling all the other clocks of the body to keep time with each other, and with the external time of day. Its timing is altered by light information coming through the eye.

Intrinsically photoreceptive retinal ganglion cells (ipRGCs): Light-responsive cells in the back of the eye's retina which feed into the SCN and other areas of the brain, providing information about the external time of day.

Melatonin: a hormone released by the pineal gland at night, in response to a signal from the SCN. Melatonin acts as a biological signal of darkness telling the other clocks around the body that its night. Its secretion is suppressed by light exposure.

Chronotype: A person's propensity to sleep at a particular time of day. Some people are early-types (larks) who wake-up and go to bed relatively early; some are late-types (night-owls) whose body clocks are shifted later; most us are intermediate types.

Circadian misalignment: When the circadian rhythms in different organs or tissues fall out of synchrony with one another.

Social jetlag: Circadian misalignment caused by going to bed and waking up later on weekends compared to weekdays.

About the author:

Linda Geddes is a Bristol-based freelance journalist writing about biology, medicine and technology. Born in Cambridge, she graduated from Liverpool University with a first-class degree in Cell Biology. She spent nine years at *New Scientist* magazine working as a news editor, features editor and reporter, and remains a consultant to the magazine. Linda has received numerous awards for her journalism, including the Association of British Science Writers' award for Best Investigative Journalism. She is married with two young children, Matilda and Max.

Introduction to the project

We evolved on a rotating planet with regular periods of light and darkness, and throughout human history this relationship with sunlight has dictated our biology. It's estimated that up to half of our genes - including those involved in metabolism, mood and alertness - are under the control of circadian clocks, which regulate the timing of biological processes over a roughly 24-hour period and enable organisms to anticipate and prepare for regular events in their environment. These rhythms exist in every organ and tissue of our bodies and they are kept in synchrony with each other - and with the external day - through exposure to light and darkness. Electric lighting, shiftwork, and increased amounts of time spent indoors are disrupting these rhythms, with potential consequences for our health.

Exposure to artificial light in the evening is pushing our body clocks later and suppressing the natural cues that tell us it's time to sleep. At the same time, alarm clocks and 9-5 office hours mean many of us are waking up before our bodies are necessarily ready. Because we're more active in the evenings, we're also often eating large meals when are bodies are least physiologically prepared to deal with it. These problems are compounded by reduced light exposure during the daytime because of indoor working. The result is a weakened or disrupted circadian rhythm, which may interfere with our sleep and ultimately raise our risk of developing chronic diseases such as type 2 diabetes or cancer.

It's not all negative though: a better understanding of how both sun- and artificial light affects our biology could improve many aspects of our health and well-being. Delivered at the right time and intensity, light could help us to stay sharper and more focused at work or school, improve our sleep, reduce the risk of industrial accidents, and possibly even boost recovery from illness or slow the progression of degenerative brain disease like dementia or Parkinson's.

Over the past few decades, scientists have been waking up to the importance of these biological rhythms and the role that light plays in keeping them synchronized. In recognition of these efforts, in late 2017, the Nobel Prize for Medicine was awarded to those scientists who unpicked the molecular mechanisms of the circadian clock. We are now at a turning point where this basic research is finding practical applications in healthcare and industry. Scientists in the USA, Germany, Denmark, and Sweden are at the forefront of this revolution.

Having been commissioned to write a book on this subject for Profile/Wellcome Collection, I approached the Winston Churchill Memorial Trust for funding that would enable me to travel overseas to see some of these innovative projects for myself and to bring back ideas that could be applied in homes and public spaces within the UK.

During the Spring and Summer of 2017, I travelled to the USA, Germany, Sweden, Denmark and Italy to meet some of the scientists involved in these projects and ordinary people who are affected by their work. I have written about their stories in my book, *Chasing The Sun: The new science of sunlight and how it shapes our bodies and minds* (published in January 2019), and through a series of magazine and newspaper articles.

In this Fellowship report, I will describe the background to these projects and the science underpinning them, as well as exploring the impact they are having on people's lives. I will begin by explaining how the circadian clock works, and how electric lighting may be interfering with these rhythms with potential consequences for our health. I will then show how an application of this knowledge could be used to benefit healthcare, industry, and society more generally. Finally, I will summarize the lessons to be drawn from these projects by individuals and organisations within the UK.

Findings

OUR INTERNAL CLOCKWORK

Circadian rhythms are found in most life forms, including humans. They enable us to anticipate and adapt our biology to regular events in our environment, the most profound of which is the rising and setting of the sun each day.

The most obvious example of a circadian rhythms in humans is sleep: we tend to feel tired at night and more awake in the daytime. However, there are circadian rhythms in all our organs and tissues: Our core body temperature is at its lowest in the early morning and peaks in the early evening; logical reasoning peaks in the late morning; while physical co-ordination peaks in the early afternoon.

The oldest written observation of a circadian rhythm stems from the observations of a ship's captain under the command of Alexander the Great. Whilst travelling throughout North Africa and India, he recorded how the leaves of the tamarind tree move up during the day, and fold down again at night. Then in 1792, the French astronomer Jean Jaques d'Ortous de Marian noticed that mimosa plants similarly open their leaves during the day and close them at night - even when placed in a dark cupboard.

This observation, together with more recent studies in animals and humans, suggests that these rhythms are internally generated: Divorced from all external time cues, our biology and behaviour cycles over a roughly 24-hour period. So how are these rhythms generated?

Much of what we know about the molecular mechanisms of how circadian clocks work comes from studies of the fruit fly *Drosophila*. It was these studies that led three American circadian biologists to receive the Nobel Prize for Medicine in late 2017. One of them was Michael Young at the Rockefeller University in New York, whose lab I had visited during my fellowship to gain a greater appreciation of the mechanics of the circadian clock.

Usually, fruit flies are creatures of routine: They lay their eggs in the morning, sleep during the early afternoon, eat throughout the day, and are most active immediately before sunrise and sunset. Their larvae hatch at dawn.

However, the *Timeless* mutants I observed during my visit to New York, are different: Looking at a flask of them shortly after lunch, I saw that some were sleeping, others were flying around, while several maggots were also emerging from eggs.

Timeless is one of several strains of Drosophila, which lack the usual circadian rhythms, due to mutations in their genes.

During the 1980s, Young, together with his fellow Nobel Prize-winners, Jeffrey Hall and Michael Rosbash at Brandeis University in Boston, pieced together how the protein products of these genes drive the circadian clock.

Each day, inside every cell, they showed that a precisely-timed and self-sustaining dance takes place: It involves several proteins accumulating, coming together, and then switching off their own production, before degrading and allowing the whole process to start over again. This molecular dance takes close to, though, not exactly 24 hours - the precise timing varies between individuals.

A similar system has since been found to operate in mammalian cells, including our own - and many of the genes involved bear remarkable similarities to those that drive the clock in fruit flies.

If you shut a flask of fruit flies in a dark cupboard for several days or weeks, they will continue to generate these internal rhythms. But, because the internal clock is usually a little shorter or longer than 24 hours, these rhythms will gradually drift out of synchrony with the external time of day. This phenomenon, called free-running, has also been observed when humans live under constant dim light, in e.g. a sleep lab or cave.

Even so, in the real world, we manage to stay synchronised with day and night. This is because, buried deep in the retinal layer of our eyes are a group of light-sensitive cells called intrinsically photoreceptive retinal ganglion cells (ipRGCs), which connect to a tiny area of the brain called the suprachiasmatic nucleus (SCN), or the body's master clock, from which all the other cells of the body take their time cues.

Exposure to bright light triggers a chemical change in the ipRGCs, which tells the SCN to adjust its timing, and this message is then conveyed to all the other clocks in our various organs and tissues: In this way, they keep in time with one another, and with the rising and setting of the sun outside. Doing so is important, because processes such as the metabolism of food require the co-ordinated activity of many different organs and tissues; if they become desynchronised, reactions may become less efficient, or even proceed in the wrong order, eventually leading to diseases such as diabetes or cancer.

IpRGCs are particularly sensitive to light in the blue part of the spectrum, which includes daylight, but also many sources of artificial light. If we are exposed to bright light during the evening, or at night, this tricks the brain's master clock into thinking it's the daytime and it will adjust its timing accordingly. This can be useful, because it enables our clock to reset to a new time zone if we travel abroad, say.

However, it also causes problems:

- Artificial light at night shifts our overall internal timing later - making us more "owlish" - yet we still must get up to go to work or school in the morning, so it may curtail our sleep. Sleep deprivation has been linked to mood changes, memory lapses, problems concentrating, weakened immunity, weight gain and high blood pressure.
- Exposure to bright light at night suppresses the release of melatonin, a hormone which is released during the evening and overnight, and signals to the rest of the body that it's time to shift into night-mode – including those areas of the brain that promote sleep.
- Light also has a direct alerting effect on the brain, so exposure to bright light in the middle of the night can make it harder to sleep. Bright light during the daytime, on the other hand, is usually a positive thing because it boosts alertness. Those light-sensitive ipRGCs also project to brain areas controlling mood; studies have suggested that altered timing of light exposure may contribute to depression.
- Irregular light exposure – as you might get if you work occasional night shifts, or even if you stay up later at weekends to socialise - can cause the timing of the various clocks in our organs and tissues to become desynchronised, because these clocks don't adapt to changes in the timing of light exposure at the same rate. Such circadian desynchrony is associated with worse health outcomes (see below).

All of this is of concern because the proportion of the Earth's surface that is artificially lit is growing by around two percent each year. Research also suggests that people living in areas with elevated levels of light pollution tend to go to bed and wake up later than those living in darker areas; they also sleep less, are more tired during the daytime, and are less satisfied with their sleep.

HOW WE USED TO SLEEP

To gain a better appreciation of how artificial light and 24/7 living might be affecting our biology, I visited an Old Order Amish family in Lancaster County, Pennsylvania. The Amish live off-grid, not because they are opposed to the use of electricity per-se, but because it is an effective way of keeping the modern world out. This means that there is no electric lighting in their homes.

Amish families don't spend their evenings in total darkness; usually, there will be a large gas-powered light in the kitchen, which can be wheeled into the living area, enabling them to cook, socialise, and read in the evenings. Some households have even started using powerful, battery-powered lanterns to provide additional light. Even so, most Amish homes are significantly darker in the evenings than typical American or British dwellings. Amish people also spend considerably more of their time outdoors during the daytime than most people in the West. If we want to understand how modern light exposure might be interfering with our sleep and other aspects of our biology, such as mood, the Amish are a good place to look.

Teodore Postolache at the University of Maryland has been studying light exposure patterns among the Old Order Amish: One of his most interesting findings so far is that they have far lower rates of seasonal affective disorder (SAD) than other populations living at similar latitudes[i]. A leading theory is that this is because their sleep and wake times are more closely aligned with the rising and setting of the sun each day. It could also be that, because they spend so much more time outdoors, they are exposed to bright light in the early morning, which acts as a natural antidepressant. We know, for instance, that exposure to bright light for at least 30 minutes shortly after waking is an effective treatment for both seasonal affective disorder and general depression.

Postolache and his colleagues have also examined how the lack of electric lighting in Amish homes might affect their sleep. Although they stay up for some time after dark, Amish families do tend to go to bed earlier - typically, between 9-9.30pm in summer, and 8.30-9pm during winter. Most Amish people start work at around 5.30am, so they're often up by 4.45am. On average, they sleep for around 8.12 hours during winter, and 7.30 hours in summer[ii].

This supports the idea that exposure to artificial lighting during the evening may be pushing our circadian clocks later.

My Fellowship also brought me into contact with Kenneth Wright, a circadian biologist at the University of Boulder in Colorado. He has been investigating the impact of artificial light on the timing of our sleep by sending groups of ordinary Americans camping in the Rocky Mountains, where the only source of light at night is firelight, and where they are exposed to far more daylight during the day. Within just a couple of days, even those participants who claim to be night owls shift to an earlier sleep pattern more closely aligned with the rising and setting of the sun each day[iii].

Such findings have implications for British households: if we were to similarly dim the lights in the evenings, and spend more of our daytime outdoors, we might feel sleepier earlier and potentially get more sleep as a result.

SHIFT WORK

Of course, not everyone has the freedom to go to bed when they choose. Some 12% of the British workforce – around 3.2 million people – regularly work night shifts, an increase of 260,000 in the past five years[iv].

Although our bodies can adapt to working nights to some degree, full adaptation is rare, and more than two thirds of people who work nights, don't adapt at all. Instead, they are active and exposed to bright light when their bodies are ready to sleep; eating when their digestive system is usually resting and trying to sleep when the internal clock is firing off alertness signals because it is daytime.

Night shift workers are more likely to be overweight and suffer from type 2 diabetes than those who keep more normal hours. They also have a higher risk of heart disease, stomach ulcers and depression, while long-term shift-work has also been associated with the development of some cancers, particularly breast cancer. Part of this could be due to sleep deprivation: the overall sleep of night shift workers is curtailed by 1-4 hours each day, on average. However, circadian misalignment is another likely culprit.

During my fellowship, I met Captain Seth Burton, a submarine commander in the US Navy, stationed at Newport, Rhode Island. During the early part of Burton's career, US submariners operated on an 18-hour "day": they would stand watch for six hours; spend a further six hours "off-watch"; then have six hours to sleep, meaning that a new day came, not every 24 hours, but every 18 hours. It is impossible for the body clock to adapt to this schedule, and so it begins to "free run" on its own internal time of close to 24 hours. However, the Navy's schedule meant that submariners like Burton were trying to sleep and eat their meals six hours earlier each day – inducing an extreme and continuous form of jetlag.

18-hour days are rare, but there is increasing evidence that irregularity in our sleep and meal-times – of the sort induced by more conventional shiftwork, or even going to bed and waking up later at weekends compared to weekdays – may be harming our health. Our body clocks will try to adapt to the new routine by shifting their timing, but the clocks in our various organs and tissues don't all move at the same rate, so they fall out of synchrony with one another.

Researchers at Brigham and Women's Hospital in Boston, US, have been investigating the impact of this 'circadian desynchrony' on our health. During my Fellowship, I was given a tour of their sleep lab, which is widely regarded as one of the top sleep research facilities in the world. One of the first things you notice upon entering it is that you're walking uphill: this is because the entire floor of the research area is thicker than the other hospital floors, and it floats separate from the rest of the building so that vibrations from everyday life don't reach the research participants and provide clues as to what time of day it is. Neither do their rooms have external windows, and to enter them you must pass through a double set of doors, to ensure no daylight gets in.

Studies at this facility have provided important insights about the impact of circadian desynchrony on our health. They suggest it can result in disturbed sleep, decreased vigilance and poorer cognitive performance, and that circadian misalignment can also disrupt our metabolism. In 2009, Frank Scheer and colleagues published research suggesting that circadian misalignment interferes with the secretion of several hormones involved in the regulation of appetite. Volunteers whose body clocks were deliberately misaligned, also became less sensitive to the effects of the hormone, insulin, and their blood sugar levels rose, causing some of them to enter a pre-diabetic state after just ten days. Their blood pressure increased by 3mm Hg, on average - enough to be clinically significant in people with high blood pressure[v].

However, it isn't only shift-workers who need to worry about circadian misalignment. My Fellowship also took me to Munich in Germany, where I met Till Roenneberg, a professor of chronobiology at Ludwig-Maximilian University. He is responsible for coining the term “social jetlag” to describe the circadian disruption caused by getting up early on weekdays for work or school, and then staying up later and sleeping in at the weekends. According to Roenneberg, just 13 percent of the population are social jetlag-free; 69 percent of people experience at least one hour of social jetlag per week, and the remainder suffers from two or more hours[vi].

During my Fellowship, I also attended the Sleep 2017 meeting in Boston, US. Here, a study was presented which found that for every hour of social jetlag people experience each week, their chances of suffering from cardiovascular disease increases by 11 percent. They also experience worse mood and greater levels of tiredness; and for every hour of social jetlag, they are 22 percent more likely to say that they have good health instead of excellent health, and 28 percent more likely to say their have fair or poor health. Separate studies have linked social jetlag to obesity, smoking and alcohol consumption.

This has implications for all of us. As far as possible, we should aspire to greater regularity in when we eat and sleep - getting to bed early enough to get adequate sleep every night.

Finding a solution to the problem of shift work is less easy. One strategy that Scheer is currently investigating is whether imposing regular meal times during the daytime and avoiding eating at night can reduce the impact of night shifts on people's health.

Roenneberg has also investigated the effect of matching people's natural sleep preferences to their shift schedules, so early-types never work the night shift and late-types never work the morning shift. When he implemented this at a factory owned by ThyssenKrupp Steel in Germany, people reported getting an average 30 minutes extra sleep on workdays, as well as better quality sleep. As a result, they also needed less catch-up sleep on their days off, reducing social jetlag by approximately one hour per week[vii].

HOW ARTIFICIAL LIGHT COULD HELP

Forsmark Nuclear Power station in central Sweden also employs nightshift workers in its control room. The work is highly skilled, but monotonous - each day there is a list of checks and safety tests to work through: there are 3,000 rooms in Forsmark 3 alone. Once you get to the end of that list, it's time to start again. "It would be easy to slip into auto-pilot, but you need to stay alert," says Jan Hallkvist, operations manager at Forsmark 3.

If a problem is detected, you need to be able to think on your feet. The control room operators have instructions on what to do in the event of an earthquake, a flood, or an aircraft crash, but they can't plan for every possible scenario. The 2011 accident at the Fukushima Daiichi plant in Japan – the result of a 15-metre tsunami disabling the power supply and therefore the cooling of the three nuclear reactors – is testament to that. "People need to be alert, and able to solve complex problems quickly," Hallkvist says.

Running a nuclear power station is a 24-hour operation, and so the control room operators work in rotating shifts, including two night-shifts per week. Maintaining alertness within the control room is made even more difficult by the fact that it's buried deep in the heart of the power station, with metres of metal and concrete separating it from the outside world – which means there are no windows.

The problem is particularly severe during the winter months. Located at roughly the same latitude as the Shetland Islands, from November to February, Forsmark’s control room operators see barely any daylight, regardless of which shift they're working.

Hallkvist originally approached a circadian biologist at the University of Stockholm called Arne Lowden, for advice on how to help his staff adjust to their shift schedules and to remain awake during the night shift. He mentioned the poor lighting in the control room, and Lowden told him: "If you’re going to change the lighting, you should think about circadian lighting".

Almost 140 years since electric lighting began transforming the face of the planet, and making 24/7 work routine, the invention of LED lighting is ushering in a new era: one where at least some of the effects of daylight can be realistically recreated indoors.

Unlike incandescent lamps, which generate light by sending an electric current through a conductive metal filament, heating it up, LEDs use a solid piece of material called a semi-conductor. Semi-conductors are elements like silicon, which wouldn't normally conduct electricity, but have been chemically treated so that they can – at least to a limited degree. As a result, they produce light, but very little heat, making LEDs more efficient and durable than incandescent light bulbs.

The other beauty of LEDs is that they are tiny, which means that many different-coloured LEDs can be joined together to vary the shade of the light they produce. Until recently, the consequences of LED lighting on our biology have been largely negative: white-blue street lighting, which – although very useful in terms of enabling us to see - suppresses melatonin and disrupts sleep. But increasingly, LEDs are being used to make dynamic, or circadian lights: the colour and intensity of which can be adjusted according to the time of day.

For an extra couple of thousand Euros, Lowden explained, it would be possible to install a lighting system that could supply a shot of intense white-blue light to boost workers' alertness at key times, such as the start of a night shift, but also fade to a dimmer, warmer white in the run-up to the shift's end, to prepare them for sleep - in this way, the night shift would be more like an afternoon/evening shift, and the daytime, their night.

Similarly, the intense, blue-white lighting could provide a substitute for sunlight for those working day-shifts in the dim control room, keeping them rooted in the 24-hour world.

Hallkvist was intrigued enough to allow Lowden to test whether such lighting could really boost alertness and sleep in a subset of his workers, as well as helping them better adapt to rotating shift work.

Illuminance is measured in Lux: a typical office is around 200 Lux, while outside on an overcast day in winter it is around 3000 Lux, and in summer it can reach as high as 100,000 Lux.

Before the installation of the new lighting system at Forsmark, the illuminance in the control room was a weak yellow light of 200 lux. The new lights were hung above the reactor operators' desk, and at their peak, yielded 745 lux of intense blueish-white (the circadian system is more sensitive to blue wavelengths of light). The rest of the operators worked at desks turned away from the new lights, so they could function as controls.

The experiment was performed during winter, and the results were positive enough to persuade Hallkvist to install the lighting system throughout the control room. The most convincing result was a reduction in the reactor operators' sleepiness during both night and day shifts – but particularly during the second night shift, which is often the hardest. This was despite the reactor operators only being exposed to the intense white-blue light for 1-2 hours at the start of the night shifts[viii]. During day shifts the bright lights were on between 8am and 4pm – replicating what was occurring in the outside world.

Even so, not everyone is convinced about the wisdom of exposing night shift workers to intense white-blue light. It boosts their alertness, but it's also suppressing their release of melatonin and delaying the timing of their clocks.

"There's a risk of making things worse by interfering with light exposure during or after the night shift," says Frank Scheer, who points to the example of blue-blocking glasses, which some people recommend as a means of shielding oneself from daylight on the journey home: it's true that this may make it easier to sleep, but if you're driving, it also increases the risk of accidents.

NASA is also using “dynamic lighting” to help its astronauts adjust to shiftwork and the unusual light conditions of space. Circadian desynchrony is a major problem for astronauts working on the International Space Station (ISS). For one thing, the light-dark-cycle they’re exposed to is very unusual: the ISS completes a full orbit of the Earth every 90 minutes, meaning its astronauts experience a sunrise or sunset every 45 minutes. Also, the nature of their work means that astronauts often work long hours under high stress to complete their tasks or must abruptly change their sleep schedule to accommodate e.g. a shuttle docking.

During my Fellowship, I met Smith L. Johnston, a medical officer and flight surgeon based at the Johnson Space Center in Houston, who has been spearheading efforts to combat this circadian desynchrony.

ISS astronauts sleep inside small, padded cabins, which have recently been fitted with adjustable, colour-changing lights: Before bed, US astronauts use the “pre-sleep” mode, which has had the blue part of the light spectrum removed; when they wake up in the morning, they can get an alertness boost and strengthen their circadian rhythm by switching to a brighter, blue-enhanced light. This setting is also deployed to help shift the clock forwards or backwards if an astronaut needs to change their sleep schedule because of their work demands.

Similar principles are also being applied in mission control back down on Earth, to help staff adjust to night shifts. For instance, during their breaks, staff can walk on a treadmill under a bright blue-white light, because both exercise and bright light provide them with an alertness boost.

Such strategies could be considered by businesses employing shift-workers in the UK – although they must be weighed against the potential health costs of exposure to bright light at night. Although it boosts alertness, exposure to bright light also shifts the internal clock, which may be undesirable if someone is only working one or two night-shifts before moving back to day shifts.

Meanwhile, Mariana Figueiro at the Lighting Research Center in Troy, New York, has some preliminary evidence suggesting that bright red light could provide an alternative to blue light – it seems to boost alertness without affecting the timing of the internal clock. Further research is needed to confirm this.

Strategies such as those being employed at Forsmark and on the ISS could be applied to non-shift-workers as well. Most of the circadian biologists I met during my fellowship advocated trying to avoid bright light after sunset – particularly light in the blue part of the spectrum - which can be achieved by installing dimmable and/or colour changing light bulbs. They also advise avoiding electronic gadgets such as tablet computers and smartphones, in the hour or two before bed, and installing “night” features or apps such as F:lux, which reduce the amount of blue light emitted from electronic screens.

MAXIMIZING DAYLIGHT

Many of the researchers I interviewed also advocated maximising exposure to bright daylight, both to strengthen the circadian clock and keep it synchronised to the light-dark cycle outside. This is particularly important during the morning, when the brain’s master clock is most responsive to light. Strategies for doing so could include eating breakfast in a sunny area of the house, walking/cycling to work or school, and taking a walk outside at lunchtime.

Architects and businesses should also consider prioritizing daylight in building design. Recent research by Marianna Figueiro suggests that doing so could boost people's sleep, which could have knock-on consequences for their work or school performance as well.

Meanwhile, emerging evidence indicates that daylight exposure could help to negate the effects of light exposure at night. During my fellowship I attended the annual conference of the Society for Light Therapy and Biological Rhythms in Berlin, where I met Dieter Kunz from St. Hedwig Hospital in Berlin. He and his colleagues recently invited 18 volunteers into their sleep lab for three days. The first 15-20 minutes of each morning was spent in dim light, after which some of the volunteers continued to sit in gloom, whereas others were exposed to bright, blue-enriched light for the next three hours. Then, during the run-up to bedtime, volunteers were either exposed to dim white light, bright blue-enriched light, or moderate orange light for 30 minutes.

Kunz and colleagues found that exposure to bright light during the morning boosted reaction speeds throughout the day, suggesting they were more alert. What's more, if they were subsequently exposed to a burst of blue light before bed, which would usually shift the internal clock later, it remained stable[ix].

In other words, if you spend your mornings in bright light, it may not matter if you use electronic devices or keep the lights switched on during the evening. "The effects of light in the evening highly depend on the light you were exposed to in the morning," Kunz says.

RECOVERY FROM JET LAG

During the US-leg of my Fellowship, I spent a morning with Steven Lockley, a sleep expert at Brigham and Women's Hospital and Harvard Medical School, who is employed by NASA and professional sports teams to draw up sleep and light exposure schedules to combat jetlag. Lockley has recently launched an app, called Timeshifter, which enables subscribers to achieve a similar feat, however, he talked me through the basic principles.

Usually, it takes approximately one day to adjust to each time zone you cross, but Lockley claims that, with appropriate light timing and melatonin administration, it is possible to shift people by 2-3 hours a day, which would mean getting over the jetlag from a London to New York flight in two days, rather than four or five days.

The body clock is most susceptible to being shifted forwards or backward, at either side of dawn: If you're exposed to bright light before dawn, this will send a strong message to *delay* the clock's timing, which is what you want to achieve if you're travelling west. However, if you're exposed to bright light after 6am, this will send a powerful message to *advance* the clock, which is what you want to achieve if you're travelling east.

When travelling overseas, people firstly need to ask themselves what time their body clock thinks it is, and secondly whether they wish to advance or delay their clock?

Taking a London to New York flight as an example: US Eastern Time is five hours behind Greenwich Mean time, which means travellers need to delay their clock by five hours. To facilitate this, they should actively seek out bright light during the evening and early night (UK time) and avoid it from 6am onwards (UK time). So, if their flight departed London at 5pm, say, they should spend their entire journey trying to access bright light, and particularly blue light, e.g. by using a tablet or laptop. Once they arrive, they should continue accessing light until an hour or so before their desired bedtime in the new time zone.

Coming back the other way, travellers want to advance their body clock, which means avoiding bright light at night (Eastern Time – assuming their bodies have adjusted to the new time zone) and seeking it out from 6am onwards (Eastern Time). Say their flight departed at 8pm – they should put on an eye-mask and simply try and sleep for the entire 8-hour flight. However, when they arrive in London at 9am it would still only be 4am according to their internal clock. So, they should continue avoiding daylight for another two hours, e.g. by wearing dark, wrap-around sunglasses.

ARTIFICIAL LIGHT AND HEALTHCARE

So far, I have reported on measures that might be taken by healthy individuals to boost their circadian rhythms and reduce the detrimental effects of exposure to light or night or crossing multiple time zones. However, hospital patients and elderly people living in care homes often have less access to daylight and less control over the type of light they're exposed to during the evening/at night. Also, our circadian rhythms tend to flatten as we get older, which means we need more exposure to bright light during the daytime to keep them robust and entrained to the external time of day.

At Glostrup Hospital in Copenhagen, researchers have been trialling a "dynamic lighting system" on the stroke rehabilitation ward, to investigate if stabilizing and strengthening patients' circadian rhythms can enhance their recovery. During daylight hours, both the colour and intensity of the lights is tuned to mimic daylight, but as the afternoon progresses, the light grows progressively dimmer and redder, as wavelengths from the blue part of the spectrum (which activate the circadian system) are removed. At night, the lighting in the corridors and shared spaces is dim orange, and patients' rooms are kept dark – although they can switch on an orange reading light - and if staff need to perform medical procedures the overhead lights are also orange.

Preliminary data suggests that stroke patients exhibit more robust circadian rhythms in response to the circadian lighting system and show reduced depression and fatigue, compared to those housed in a section of the ward with conventional hospital lighting.

Staff on the ward have also noticed a difference. Julie Marie Schwarz-Nielsen is a nurse who often works the evening shift between 3pm-11pm. Since the lighting changed, she says she's noticed herself feeling more tired towards the end of her shift. This highlights a potential downside of such lighting systems: medical staff need to be alert and awake during shifts. Installing brighter lighting in the staffroom could be one solution.

However, even if it leaves her feeling sleepy, Nielsen says she has noticed an improvement in her patients – particularly those suffering from delirium or dementia: "They seem to have a better idea about what time of day it is, and I sense that they're calmer," she says.

This trend has been noticed elsewhere as well. People with dementia often have disturbed circadian rhythms and tend to wake frequently at night; this can be dangerous if they get out of bed and walk around, particularly as the night-waking is often accompanied by delirium or confusion.

During my Fellowship I also visited the Ceres Centre, a care home in the Danish town of Horsens, which provides residential nursing care for 32 elderly people, 16 of whom have dementia. Dynamic lighting, like that at Glostrup Hospital, has been installed throughout the dementia wing to boost exposure to bright light during the daytime and minimise it at night. Movement-sensors in residents' bedrooms also trigger a dim orange light to switch on in the bathroom if they get out of bed during the night.

University of Oxford researchers are currently monitoring the impact of the new system on their health, but nurses have already noticed is that the residents seem to be more sociable: "They look more alert in the daytime and they eat a little more," says Jane Troense, one of the nurses on the dementia ward. They are also taking fewer sleeping tablets and drugs to ease their agitation.

Related research is taking place elsewhere. People with Parkinson's disease are another group who frequently wake at night and struggle with daytime sleepiness, and here too the circadian clock has been implicated. During my trip to Boston I met Aleksander Videnovic at Massachusetts General Hospital, who recently published a trial investigating the use of light boxes – of the sort used to treat seasonal affective disorder – in people in the early stages of Parkinson's Disease. The idea wasn't to shift the timing of the clock, but to strengthen the amplitude of their circadian rhythms. Videnovic found those patients who sat next to a bright white light box twice a day experienced improved nighttime sleep, and greater daytime alertness, compared to controls who used a light box that emitted dim red light. They also experienced some improvement in physical symptoms of the disease, e.g. tremors and muscle rigidity[x].

Such research has implications for elderly people in the UK. Even without dynamic lighting, efforts could be made to improve access to daylight, by encouraging people outdoors or situating them close to windows and/or light boxes during the day. They may also benefit from dimmed, or warmer-coloured lighting during the evening and (where possible) darkness during sleeping hours.

USING LIGHT TO TREAT DEPRESSION

During my Fellowship I also met an Italian psychiatrist called Francesco Benedetti, who has been trialing an unusual therapy for severe bipolar depression: He combines short-term sleep deprivation, with light therapy and the drug, lithium (which is a mainstay of treatment for bipolar disorder and appears to work via the circadian clock). The idea is to kick-start sluggish circadian rhythms in the brain.
I later flew out to Milan to see this so-called 'triple-chronotherapy' for myself. Benedetti's primary focus is on bipolar disorder, a condition that causes dramatic shifts in mood, from mania (where people they become high, over-excited, and irritable) to severe depression.

Antidepressants tend to be ineffective in people with bipolar depression, so Benedetti and his colleagues were looking for an alternative. Sleep deprivation had previously been tested as a treatment for depression and was known to work: the problem was maintaining the effect, because as soon as people went to sleep, their low mood usually returned. So, Benedetti began looking for other interventions that might extend the effect, and eventually discovered that bright light (which at that time was showing promise for seasonal affective disorder) and lithium were an effective combination.

So far, they have treated close to a thousand patients with such 'triple chronotherapy': According to the most recent data, 70 percent of people with drug-resistant bipolar depression responded to it within the first week, and 55 percent had a sustained improvement in their depression one month later.
The sleep deprivations occur every other night for a week, and patients are exposed to bright light for 30 minutes each morning – this light therapy continues for a further two weeks after the sleep deprivations end. They also continue taking lithium. "We can think of it not as sleep-depriving people, but as modifying or enlarging the period of the sleep–wake cycle from 24 to 48 hours," says Benedetti. "People go to bed every two nights, but when they go to bed, they can sleep for as long as they want."

Benedetti arranged for me to spend a night on the hospital's psychiatric ward with "Angelina"[1], a woman in her late 60s, who had been suffering with bipolar depression for the past two years. It was the second night in three that that she had been deliberately deprived of sleep. If I'd met her three days ago, she

[1] Her name has been changed to protect her privacy.

says, it’s unlikely I would have recognised her. She didn’t want to do anything, she’d stopped washing her hair or wearing make-up, and she stank. She also felt very pessimistic about the future. After her first night of sleep deprivation, she had felt more energetic, but this largely subsided after her recovery sleep. Even so, she had felt motivated enough to visit a hairdresser in anticipation of my visit.

The hospital staff employ various methods to keep their patients awake: at around 1am, they often cook a meal together in the small kitchen, where they also play cards. Sometimes they also ask the patients to help them with some of their duties, such as folding and putting away bedsheets. But the patients must also entertain themselves for some of the night: Angelina had brought a stack of books with her, and spent several hours watching television.

Not everyone finds it so easy to stay awake overnight. Mirka Kropop is a psychiatric nurse who has worked at San Raffaele Hospital for the past 17 years. Besides her usual duties, on the nights when patients are undergoing sleep deprivation, she and the other nurses are tasked with helping to keep them awake, as well as monitoring them for any signs of emotional breakdown. "Geriatric patients in particular struggle to stay awake," she says. "They may show signs of emotional instability; weeping, feeling agitated or confused. There are also patients who refuse to continue the therapy and go to bed."

If patients do stick it out, however, the change in their mood can be startling and abrupt: "I remember one patient who started to sing and dance, because they were so happy," Kropop says. More often, however, the transition is subtler: "They begin to feel more energy; they may start smiling and speaking a lot - being sociable with the other people who are awake."

I also noticed this transition in Angelina: At around 3am, we moved into the light room: a small room containing five armchairs lined up against the wall, with several large “skylights” overhead. Although it was dark outside, the light coming from these artificial windows was extremely bright: sitting there was like being in a sun-lounge at midday.

When I’d interviewed her seven hours earlier, with the help of an interpreter, Angelina’s face had remained expressionless as she’d replied. Now, at 3.20am, she was smiling, and even beginning to initiate a conversation with me in English, which she’d claimed not to speak. By dawn, Angelina was telling me about the family history she's started writing, which she'd like to pick up again, and inviting me to stay with her in Sicily.

Interest in chronotherapy for depression is beginning to spread. On the day I visited Benedetti's clinic in Milan, I was accompanied by a delegation of Norwegian psychiatrists from Trondheim, who are constructing an entire psychiatric ward with chronotherapy in mind. The buildings have been designed to maximise access to natural light, as studies have suggested that depressed patients who are housed in sunny rooms are discharged more quickly; rooms will also be fitted with dynamic lighting to augment daylight on dark winter mornings, and cut out blue light, which interferes with the biological clock, at night. They had come to Milan to learn how they might incorporate wake therapy into their treatment regimes.

In the UK, the USA, Denmark and Sweden, psychiatrists are also starting to investigate sleep deprivation and light therapy as a treatment for general depression. David Veale is a psychiatrist at the Maudsley Hospital in London and is currently planning a feasibility study there: "We need to demonstrate that it is feasible, and that people can adhere to it," he says.

At Copenhagen Mental Health Centre, which I also visited during my Fellowship, a psychiatrist called Klaus Martiny has been investigating the therapeutic effects of light for general depression. In one recent study, he discovered that his depressed inpatients were discharged after 29 days, on average, if their rooms faced south-west, compared with nearly 59 days for those inhabiting north-west-facing rooms. Depending on the month, the intensity of daylight in the south-west rooms was 17 to 20 times brighter[xi]. Martiny has also published two of the only randomized controlled trials to look at wake therapy in general depression. In the first study, 75 patients with general depression were given the antidepressant duloxetine, in combination with a chronotherapy package consisting of sleep deprivation, bright light and regular bedtimes, or exercise. After the first week, 41 per cent of the chronotherapy group had experienced a halving of their symptoms, compared to 13 per cent of the exercise group. And at 29 weeks, 62 per cent of the wake therapy patients were symptom-free, compared to 38 per cent of those in the exercise group[xii].

In Martiny's second study, severely depressed hospital inpatients who had failed to respond to antidepressant drugs were offered the same chronotherapy package as an add-on to the drugs and psychotherapy they were undergoing. After one week, those in the chronotherapy group improved significantly more than the group receiving standard treatment, although in subsequent weeks the control group caught up[xiii].

No one has yet compared wake therapy head-to-head with antidepressants; neither has it been tested against bright light therapy and lithium alone. But even if it's only effective for a minority, many people with depression – and indeed psychiatrists – may find the idea of a drug-free treatment attractive. "I'm a pill pusher for a living, and it still appeals to me to do something that doesn't involve pills," says Jonathan Stewart, a professor of clinical psychiatry at Columbia University in New York, who I interviewed during my Fellowship, and who is currently running a wake therapy trial at New York State Psychiatric Institute.

Unlike Benedetti, Stewart only keeps patients awake for one night: "I couldn't see a lot of people agreeing to stay in hospital for three nights, and it also requires a lot of nursing and resources," he says. Instead, he uses something called sleep phase advance, where on the days after a night of sleep deprivation, the time the patient goes to sleep and wakes up is systematically brought forward. At the time of my visit in June 2017, Stewart had treated around 20 patients with this protocol, and 12 had shown a response – most of them during the first week.

He acknowledges its limitations: "For those for whom it works, it's a miracle cure. But just as Prozac doesn't get everyone better who takes it, neither does this," he says. "My problem is that I have no idea ahead of time who it's going to help."

If disrupted circadian rhythms are a cause of depression, possibly strengthening the circadian clock could be a way of preventing it from occurring in the first place. This is something that Martiny is currently testing in Copenhagen: Often he finds that his depressed inpatients get better during their hospital stay, but relapse once they are discharged. Dubbed 'circadian-reinforcement therapy', the idea is to strengthen their circadian rhythms by encouraging regularity in their sleep, wake, meal and exercise times, and pushing them to spend more time outdoors, exposed to daylight.

Peter is a 45-year-old care assistant from Copenhagen who has battled with depression since his early teens and has been hospitalized for it six times, including for a month in April 2017. Since his discharge that May, he had made several changes to his life, including trying to spend more time outdoors exposed to bright daylight; getting up at 6am every morning to help his wife with the children; always eating breakfast; not napping during the daytime; and trying to be in bed by 10pm each night. He also wore a device that tracked his activity and sleep, completed regular mood questionnaires, and if there was any deviation in his routine, he would receive a phone call to find out what had happened.

Martiny showed me Peter’s data: It confirmed a shift towards earlier sleep and wake times and showed an improvement in the quality of his sleep, which was mirrored by his mood scores. Immediately after his release from hospital, these averaged around 6 out of 10. But after two weeks they’d risen to consistent 8s or 9s, and one day, he even managed a 10. At the beginning of June, he returned to his job at the care home, where he works 35 hours a week. “Having a routine has really helped me,” he says.

So far, Martiny has recruited 20 patients to his trial, but his target is 120; it’s therefore too soon to know how many will respond the same way as Peter, or indeed, if his psychological health will be maintained. Even so, there’s mounting evidence that good sleep routine can help our mental wellbeing. According to a study published in *Lancet Psychiatry* in September 2017 – the largest randomised trial of a psychological intervention to date – insomniacs who underwent a ten-week course of cognitive behavioural therapy to address their sleep problems showed sustained reductions in paranoia and hallucinatory experiences as a result. They also experienced improvements in symptoms of depression and anxiety, fewer nightmares, better psychological wellbeing and day-to-day functioning, and they were less likely to experience a depressive episode or anxiety disorder during the trial.

There may yet be other ways of bringing light into daily lives of those living with depression: Martiny has created window frames with lightboxes incorporated into the side panels, which are shaped to create the illusion of a shaft of light entering the room, even when its dark and grey outside. The brightness of the panels is also dynamic, meaning that its intensity changes throughout the day. These are currently being fitted into the windows of the rooms on the psychiatric ward, as an alternative to asking patients to sit in front of a light box.

LIGHTING IN SCHOOLS

Brainlit is a company based in Lund, Southern Sweden, which I visited during my Fellowship, and which has been installing dynamic lighting systems (also called circadian lighting) at Swedish schools, hotels and farms (as both milk production in dairy cows, and egg laying in hens appears to increase when they live under a light/dark cycle that more closely mimics the natural cycle outside).

In 2015, Brainlit installed its ‘BioCentric’ lighting system in a classroom at Lindeborg School in Malmö which caters for approximately 700 pupils, ranging from preschool through to age 16. Throughout the day, ceiling lights in the classroom change in colour and intensity, to simulate being outside on a bright spring day. When pupils enter the classroom at 8.10am, the lights are a bright blueish white to wake them up, and they grow gradually more intense as the morning progresses. They are dimmed slightly in the run-up to lunch, to calm to students and help them adjust to the gloomier light outside, but after lunch they are cranked back up. Then, as the afternoon progresses, the lights gradually dim and become more yellow.

Malmö is located on roughly the same latitude as Edinburgh, and the school day begins at 8.10am, which means that during mid-winter (when the sun doesn’t rise until around 8.30am) teachers and pupils arrive when it is still dark outside.

One theory is that the later sunrises of winter delay our internal rhythms, so that they’re no longer in tune with when we go to sleep and wake up. Mood follows a strong circadian rhythm: we tend to wake up grumpy, and become more cheerful as the hours pass, then our mood falls again overnight. If this pattern becomes misaligned with the actual time of day, then those night-time lows in mood occur during the daytime instead. Also, if the pattern of melatonin secretion is delayed because of exposure to artificial light in the evenings, this could leave us feeling more sluggish in the mornings.

Bright morning light both advances circadian rhythms and suppresses melatonin, so this could explain why it is an effective treatment for Seasonal Affective Disorder. Most of the children at Lindeborg school aren’t depressed, but the new lighting system appears to affect them nonetheless: In a small, pilot study, fourteen pupils from the classroom with the new lighting system and 14 from a neighbouring class with ordinary lighting were given Jawbone activity trackers and asked to keep sleep diaries for two weeks. During the second week, significant differences started to emerge between the two groups in terms of their sleep, with those in the classroom with dynamic lighting experiencing fewer awakenings and spending a greater proportion of their time in bed asleep[xiv].

No one has yet studied whether the lighting system affects students' exam scores. But another trial at two schools (one primary and secondary) in Hamburg, Germany, found that when the classroom lights were made brighter and more whiteish-blue than normal, the frequency of errors when children took a concentration test dropped by 45%, while the pupils' reading speed increased by 35%[xv].

LIGHTING IN HOMES

During my fellowship, I also visited an interesting research project taking place on the Danish island of Bornholm, which is seeking to test whether exposing healthy adults to more daylight has any impact on the way they sleep.

On the outskirts of Bornholm's tiny, orange-roofed capital, Ronne, is Green Solutions House, a hotel and conference centre, which harbours a curious, curved, modular glass structure in its grounds. The Photon Space, as it's known, is designed to function as a modern glass home, providing its inhabitants with full exposure to 24-hour light/dark cycle, while protecting them from the elements. Its walls and roof consist of triple-glazed panels bonded to curved glass beams.

I spent three nights in the Photon Space during midsummer to experience how the short nights impacted my sleep: I found that I fell asleep approximately 1 hour earlier when I lived under glass - but my sleep was also more fractured.

Morten Halmø Petersen's experience of sleeping there during autumn was more positive. Having spent the previous six months living in a windowless basement in Copenhagen, the opportunity for unlimited daylight seemed too good to refuse. He is one of twelve volunteers to have participated in a research study investigating the effects of daylight on the body. They spent three nights in the Photon Space and a further three nights in a villa on the island; while Danish and British researchers monitored their sleep, alertness and the timing of their nightly melatonin release. Although the data are still being processed, some of the preliminary findings may shed additional light on why we find exposure to daylight so uplifting.

The researchers recorded significantly higher levels of morning alertness when the volunteers were housed under glass. Also, their morning melatonin offset – marking the end of the biological night – arrived 26 minutes earlier, on average, presumably because they were exposed to the dawn light. One possibility is that this attenuation of melatonin release contributes to feelings of alertness, because melatonin has a mildly soporific effect. However, bright light also activates areas of the brain controlling alertness, so this dawn light may be having a more direct effect as well.

Given that exposure to bright light soon after waking also seems to have an antidepressant effect, people should strive to access daylight from the moment they wake up to boost their mental alertness and mood.

SOCIETY AT LARGE

Bad Kissingen is a spa-town in a sparsely populated region of Lower Franconia in Bavaria, which has recently rebranded itself as the world's first 'Chronocity' - a place where internal time is considered as important as external time, and measures are being taken to improve the population's sleep.

The idea originated with the town's business manager, Michael Wieden, in 2013. He had been following the scientific developments in chronobiology with interest and realised that, not only could this research benefit Bad Kissingen's residents, it could also be a useful marketing tool: Tourists could come here and learn about the importance of internal time, then return home and implement these lessons in their everyday lives.

He contacted a chronobiologist called Thomas Kantermann, and in July 2013, they published a 'letter of intent' which pledged to promote chronobiology research in the town, and to make Bad Kissingen the first in the world to "realize scientific field studies in a wider context." It was signed by several of Kanterman's colleagues, together with Bad Kissingen's mayor and the town council.

One of Bad Kissingen's most enthusiastic early-adopters of the Chronocity idea was the local secondary school, the Jack Steinberger Gymnasium: It caters for around 900 pupils aged 10-18, drawn from the town itself, as well as the surrounding villages.

Some of the older students created a questionnaire and canvassed their fellow-pupils about whether it would be desirable to start school at 9am, rather than 8am: the majority said it would. They also conducted a survey of

the entire school to find out what time pupils went to bed and woke up on weekdays and weekends, which enabled them to calculate the amount of 'social jetlag' they suffer from because of the early morning starts on school days. What they found was that approximately 40 percent of pupils were experiencing 2-4 hours of social jetlag each week, while a further ten percent of them were experiencing 4-6 hours each week - equivalent to flying from Berlin to Bangkok and back.
Teenagers are at greater risk of social jetlag than adults, because people's biological rhythms naturally shift later during adolescence, meaning that teenagers feel tired later. They are also more resistant to the natural sleep pressure that accumulates the longer we stay awake, making it easier for them to stay awake late into the night. Even so, they must get up to go to school the next morning, so their sleep is curtailed. To compensate, they often sleep in at weekends to try and catch up.

Teenagers' later chronotype also means that their natural peaks in logical reasoning and alertness occur during the early afternoon, rather than during the morning as they do in adults.

One strategy is to start school later, as the Jack Steinberger pupils proposed. This tactic has already been adopted by several US states. During my trip to Boston, I met Judith Owens, director of the Center for Pediatric Sleep Disorders, who was commissioned by the American Academy of Pediatrics to draw up a policy statement on school start times, published in 2014. 'Starting school before 8.30am is a key modifiable contributor to insufficient sleep, as well as circadian rhythm disruption, in the adolescent population,' the statement said.

But how late is late enough? Most British schools don't start school until around 8.50am, but one recent study concluded that most 18-year-olds don't feel mentally sharp until much later, and therefore possibly shouldn't start their studies until after 11am. In a separate study, the same researchers tested whether moving the start time of an English comprehensive school from 8.50am to 10am made any difference to its 13-16-year-old pupils. Rates of absence due to illness fell dramatically following the change: Before, absences at the school had been slightly above the national average, but two years after the change they were down to half the national rate. Pupils' school performance also improved: Before the study, just 34 percent of students gained good GCSE passes, compared to 56 percent nationally. But after the introduction of 10am starts, this rose to 53 percent[xvi].

Such late starts would be culturally unacceptable in many countries, including Germany and America, where most adults start work earlier than in the UK. Even switching to a 9am start proved too complicated for the Jack Steinberger Gymnasium in Bad Kissingen because the local bus company has refused to lay on additional services that would enable pupils living outside the town to arrive at school later.

While this is frustrating, the school is taking other steps to try and improve pupils' health and well-being: Some of the classrooms have been fitted with brighter LED lights to try and replicate the effects of daylight on their alertness and sleep. The school also has a policy of sending pupils outdoors to do sports or some other activity if their teacher is absent for any reason.

There has been some other progress: Wieden's current focus is on establishing a Centre for Chronobiology in the town, which would provide an academic hub for chronobiology research across Europe. The Stadtbad **-** the organization that oversees all Bad Kissingen's spa facilities, historic buildings, marketing and tourism - now offers flexible working to its office staff; while the manager of Bad Kissingen's rehabilitation hospital, Thorn Plöger, took the Chronocity idea so seriously, that at one point, he adjusted the hospital's clocks, making some fast and some slow, provoking staff and patients to reflect on their clock-watching tendencies.

Hospital staff could choose their shifts based on their sleep preferences, and Plöger also rearranged the layout of some of the hospital floors to ensure that every therapy room and the dining room had access to daylight and removed the window blinds. Several offices had bright daylight bulbs installed to boost the illuminance. Meanwhile, the inward-facing hospital rooms became repositories for patient notes, and medical equipment.

In February 2017, Plöger left the clinic to become manager of the Bavarian Rhön, the 480 square mile area surrounding Bad Kissingen. But his interest in circadian biology continues, and he is currently developing policies that will promote, and hopefully persuade the Rhön's towns and villages, of the value of turning off their lights - or at least dimming them after a specified curfew - to reduce light pollution.

This is also happening in the UK, where streetlights on major roads and motorways, in town centres and residential streets, are being dimmed during the quietest hours, to save money on energy bills and meet targets for carbon emissions. In America, New York and Montreal have altered their plans to install standard blue-white street lights, adopting warmer shades instead. Meanwhile, in St Paul, Minnesota, tuneable street lights are even being tested that could allow city authorities to adjust their colour or intensity based on the time of day, weather or traffic conditions.

Conclusion and recommendations

My Fellowship has brought me into contact with many scientists who are trying to understand the impact of sunlight and artificial light on our mental and physical health. Although this field of research is still relatively young, they have demonstrated that there steps we could take - both as individuals and a society - to improve our health and wellbeing.

Individuals

- **Avoid bright light in the evening:** Exposure to bright during the evening and at night will shift your internal clock later, delay release of the night-time hormone melatonin, and have a direct alerting affect. Where possible, use dimmer switches and warmer-coloured lightbulbs, candles and small table-lamps to light your home in the evening, and avoid blue sources of light, such as electronic screens – particularly if they are close to your eyes. Consider installing an app to cut blue light from electronic screens and try not to use them at all in the hour before bed.
- **Maximize exposure to daylight:** The light outdoors during the daytime is 10-500 times brighter than most offices and indoor workplaces. Exposure to bright sources of light in the daytime appears to reduce some of the negative effects of light at night. It also boosts alertness, and strengthens circadian rhythms, potentially resulting in increased daytime productivity and sounder sleep the following night.
- **When getting outdoors is difficult, use bright artificial light instead:** Many circadian biologists keep a light box (the sort used to treat seasonal-affective disorder) on their desk for use during winter, when it may be too cold or wet to comfortably venture outside.
- **Try to keep a regular schedule:** In so far as possible, try to go to bed and wake up at around the same time each day – including weekends, although occasionally lying-in to catch up on missed sleep is unlikely to be harmful. If you are staying up late at night, try to avoid exposure to bright light and/or eating when you would usually be sleeping, to minimize disruption to your internal clocks.

Society

- **We need to take daylight access more seriously:** Architects seeking to improve daylight within buildings need to pay close attention to the amount of light reaching people's eyes – large windows aren't necessarily good enough, as light penetration quickly falls off. Consider augmenting daylight with bright blue/white lighting during daylight hours – although such lighting should be switched off during the mid-late afternoon. Circadian lighting is an interesting development, and early studies are promising, but it too soon to know if it really is an effective counter-measure to dim indoor environments. Employers and Schools should consider raising awareness of the importance of daylight, and encourage staff and pupils to walk/cycle, rather than using public transport, and to get outdoors at regular intervals during the day.
- **Minimize night-time light exposure:** Any organization employing staff or engaging with customers during the evening or night-time should consider reducing their exposure to light in the blue part of the spectrum – and, where safety isn't an issue, dimming the lights. Similarly, local authorities and transport agencies should look to the American Medical Association's guidance on streetlighting. The UK's chief medical officer also recognized that LED streetlighting may be harming people's health in her annual 2017 report.
- **Sleep is a productivity issue:** People who don't get enough sleep are less efficient at their jobs, and more likely to create conflict within a team environment. They are also more likely to get ill. Staff should be encouraged to prioritize sleep and educated about sleep hygiene. For frequent business travelers, education about how to minimize jetlag could also help to reduce sleep deprivation.
- **Acknowledge that different chronotypes exist:** Some people are better at problem-solving and communicating in the morning, while peak in the afternoon. Educating staff and managers about these differences, and taking them into consideration when, e.g. planning meetings, could reduce discrimination against late-types, and enable teams to function better. Allowing some degree of flexible working for extreme early- or late-types is another strategy that could be considered.

- **School start times:** Although most British secondary schools start later than those in the US and other European countries, many teenagers are failing to get the recommended 9 hours of sleep they need per night, which affects their academic performance, as well as their mental and general health. In part, this is because their internal clocks shift later at adolescence, meaning they naturally feel sleepy later, but exposure to bright light at night and electronic screens may be compounding the problem. Schools and local authorities should consider the impact of early start times on their pupils' health, as well as educating them about sleep hygiene and the need to avoid electronic screens and bright lights in the run up to bed.
- **Shift work:** This is an emerging area of research, and it's too early to make specific recommendations, beyond those outlined by UK's Health and Safety Executive[xvii]. However, shift-workers should be aware that working at night disrupts their circadian rhythms and eating a large meal during the night may exacerbate the problem. A burst of bright light near the beginning of the night shift may help to boost alertness, which could be useful in industries where safety is paramount. Avoiding bright light during the journey home could make it easier to sleep, but only if you will not be driving. Night shift workers should also be aware that their mental and physical performance is impaired, making driving generally more dangerous.

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No more snooze button: a complete guide to waking up feeling fantastic. Guardian, 29 Oct, 2018

https://www.theguardian.com/lifeandstyle/2018/oct/29/complete-guide-to-waking-up-feeling-fantastic

Why it's time to see the light on the blight that harms us all, Daily Mail, 2 April 2018

http://www.dailymail.co.uk/health/article-5570611/New-research-light-pollution-reveals-time-LIGHT-blight-harms-all.html

Staying awake: the surprisingly effective way to treat depression. Mosaic, 22 Jan 2018 (republished by The Independent, BBC Future, The Smithsonian Magazine, The Seattle Star).

https://mosaicscience.com/story/staying-awake-surprisingly-effective-way-treat-depression/

Could going to bed at the same time every night ease the pain of arthritis? And other intriguing ways our body clocks govern our health.

Daily Mail, 31 October 2017

http://www.dailymail.co.uk/health/article-5033647/Could-going-bed-time-ease-arthritis-pain.html

Using light to reset the body clock can treat brain disorders

New Scientist, 5 July 2017

https://www.newscientist.com/article/mg23531335-300-using-light-to-reset-the-body-clock-can-treat-brain-disorders/

Late nights and lie-ins at the weekend are bad for your health

New Scientist, 6 June 2017

https://www.newscientist.com/article/2133761-late-nights-and-lie-ins-at-the-weekend-are-bad-for-your-health/

Radio interviews

BBC Radio 4's Start the Week:
https://www.bbc.co.uk/programmes/m0001xp7

Further fellowship-related radio interviews with BBC London, BBC Bristol, RTE Ireland, Midnight In The Desert (USA)

Book reviews:

The Times:

https://www.thetimes.co.uk/article/review-chasing-the-sun-the-new-science-of-sunlight-and-how-it-shapes-our-bodies-and-minds-by-linda-geddes-sps9g2tz9

The Sunday Times:

https://www.thetimes.co.uk/article/review-chasing-the-sun-the-new-science-of-sunlight-and-how-it-shapes-our-bodies-and-minds-by-linda-geddes-sps9g2tz9

The Guardian:

https://www.theguardian.com/books/2019/jan/12/chasing-the-sun-linda-geddes-science-review

Nature:

https://www.nature.com/articles/d41586-019-00025-z

New Scientist:

https://www.newscientist.com/article/mg24132150-600-chasing-the-sun-review-lights-power-over-life-charted/

Talks:

Wellcome Collection, London, 31 Jan 2019

Royal Institution, London, 25 March 2019

Swindon Literature festival, date TBC

Hay Literature Festival, 27 May, 2019

Cheltenham Science Festival, date TBC

Edinburgh Literature Festival, date TBC

Dorchester Literature Festival, date TBC

New Scientist Live, date TBC

Other useful resources:

Changing perspectives on daylight: Science, technology and Culture: http://www.sciencemag.org/collections/changing-perspectives-daylight-science-technology-and-culture

Center for Environmental Therapeutics: http://www.cet.org/

Lighting Research Center: http://www.lrc.rpi.edu/

Society for Light Therapy and Biological Rhythms: http://sltbr.org/

International Dark-Sky Association: http://www.darksky.org/

The Commission for Dark Skies: https://www.britastro.org/dark-skies/