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Context

To start off, I'll remind ourselves that, by some estimates, we spend an awful amount of time sitting indoors, up to 90%of our days spent indoors.

And that typically means that we are also in an illuminated area, typically not by natural sunlight but by artificial or electrical lighting. Primarily, those lighting standards and conditions are set with vision as the main priority in mind, but we know that light exposure visible light exposure has a wide range of physiological responses.

Typically, when we think of lighting, even in practice, we think about light as visual. Something more or less related to mood lighting is that it makes us happy, sad, calm, excited, etc. But there's so much more that happens with lighting or in response to light exposure. It really starts off at the very minute level with changes in gene expression, going to protein changes, hormonal changes, and endocrine changes, which then all circle back to affecting our mood, alertness, neurobehavioral performance, and cognition. And so the scope of lighting really goes well beyond just changes in mood. And we need to start considering its impacts on the various different health outcomes that are affected by lighting.

And I'll again remind ourselves that we can design interventions and try new things, but for them to be effective and efficacious, they need to be grounded in science. And so over the last few decades, we and others have carefully characterised how the different properties of light affect human physiology, ranging from spectral conditions, intensity duration, pattern, timing, history, et cetera.

And then, taking that basic physiology, you can design interventions that are efficacious and effective. So, the simple guidelines that we follow when we are designing our interventions is a dichotomous split between where the individuals are going to be: are we designing the intervention for a space where individuals will be sleeping or not?

Because if they're not sleeping, they're presumably there to be doing some work and to be active and alert. So, the priority there is maximising alertness, which demands a slightly different approach to when the individuals will be sleeping in that environment or space.

If they're working and sleeping in the same environment, then for some portion of the time when they're active, you want them to have maximal alertness. But then, when it gets closer to bedtime, and certainly during bedtime, you want to tune down the lighting so that it maximally promotes sleepiness.

And so what we essentially do for environments where individuals are not sleeping is use high melanopic intensity lighting, which is high intensity, blue-enriched throughout the work hours. Based on basic physiology in the lab and field trials, we know that maximises alertness and productivity.

If it's an environment where individuals will be sleeping as well, then, as I mentioned, during the wake hours when they'll be working, they'll again have the same blue-enriched or short wavelength enriched bright light and then close to bedtime, we'll make it dimmer and make it more blue depleted or short wavelength depleted.

So, with that basic principle and science in mind, let's look at some application work we've been doing. Now, the application of cycled lighting, specifically making the days brighter and the nights dimmer, increasing the contrast between night and day, is nothing new; it's been going on for a long time.

These are just a handful of examples of similar work in the field. This approach has been tried in various healthcare settings, from care homes to the NICU, in the PICU, etc. Most trials have had positive results, where the outcomes they were measuring were improved by light exposure.

And this goes back; these examples are from the early 2000s. And then obviously, we know phototherapy itself for depression, for example, has been used clinically since the 70s and 80s. So there's a long history, rich history of using light to improve health outcomes. When we take

an intervention into a new space, there are certain key things to identify, starting with who your stakeholders are.

And in the healthcare setting at least, there are at least three key stakeholders that we need to identify. The care recipients, the patients, or the residents. Then there are the care providers, the clinical staff, the support staff, etc. And then there's the institution itself.

What benefit does the institution get from implementing such lighting interventions? Then, we need to identify the key performance indicators, the KPIs, because the different stakeholders will have different performance indicators that are meaningful and impactful for them to judge whether the lighting intervention has been efficacious and essentially worth it. The one key thing that we have realised is that there is no one-size-fits-all solution. Yes, we have general guiding principles, but every environment has its unique challenges that need to be addressed.

And you have to tailor your intervention to the needs of your client. Especially now, with all the electronic data that's available, there are multiple sources from which you can extract data to look at the impact of your intervention.

Application 1- Medical Errors in ICU[1]

So, I'll start off with an application where people do not sleep. We and others have done extensive work to show that if you don't get enough sleep, Your cognition, neurobehavioral performance and productivity are affected. And this translates to the medical field as well. For example, when physicians have limited or restricted sleep because of their work shifts, it leads to increased medical errors.

In the U. S. and globally, medical errors are an immense burden to the patient, the care recipient, the institution, and the care provider, and they are very costly. Given the premise that light exposure can improve light exposure can improve alertness, we wanted to test an outcome such as medical errors, which would be a major KPI in the healthcare industry. Essentially, can you do something with lighting to improve or reduce the number of medical errors?

And so, in this particular trial, we leveraged an opportunity where this university hospital ICU was getting an upgrade from fluorescent lighting to LEDs. The primary driver for them to make the switch was energy efficiency. But we used that opportunity to put in some of what I call sleep and circadian-informed lighting intervention principles.

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[1] Chen, Y., Broman, A. T., Priest, G., Landrigan, C. P., Rahman, S. A., & Lockley, S. W. (2021). The Effect of Blue-Enriched Lighting on Medical Error Rate in a University Hospital ICU. *Jt Comm J Qual Patient Saf*, *47*(3), 165-175. https://doi.org/10.1016/j.jcjq.2020.11.007

This is an environment where individuals are not sleeping, and we wanted to look at the impact on nurses and medical errors. And we're trying to maximise their alertness over 24 hours during the day because it's a 24-hour operation. We made the lights brighter and more blue-enriched.

So we went from 61 melanopic EDI in the pre, in the fluorescent state, to about 208 melanopic EDI 24 7 with the LEDs. We looked at about 1,000 ICU admissions and identified 302 errors. And this was objectively identified by two independent physicians and adjudicated for errors. We found that overall, there was a % reduction in medical errors, a 10% reduction in potential errors, a 13 % reduction in harmful errors and a 33% reduction in high-severity harmful errors. So this is the first proof of the principle that applying the basic physiology we know about light on human sleep and circadian rhythms can translate to actual KPI changes in an applied setting.

Application 2 - Falls in Residential Care[2]

So then, I'll move on to an application in an environment where individuals live and sleep. So, for this, we again leveraged a group of care homes that were going to be changing their lights over from fluorescent to LEDs. And in this case, the primary outcome of interest fell because, as we all know, falls are highly prevalent, especially in the ageing population.

Just like medical errors, falls are tremendously burdensome for the care of the individual; they reduce the quality of life, increase care costs, etc. And then, obviously, the overall economic burden is extremely high just from falls as well.

Many interventions have been tried to reduce falls with varying degrees of efficacy. But why we thought that falls would be affected by lighting in the first place is because the underlying physiological traits that impact fall risk are things like sleep, mood, activity, cognition, etc.

These have all been shown to have benefited from the judicious use of lighting. So, in the study design, we studied four care homes, a pair of care homes under each parent company. Then we collected data pre-upgrade for 12 months, collected falls data, and then one care home from each company got the LED lighting while the other stayed on their standard fluorescent lighting. And then, we collected falls data for another 12 months after the intervention.

This is an ageing population. The average age is around 83. And around 30 to 40 % of the individuals have dementia. So, what did we do with the lighting?

In the control condition, we have the photopic lux and the melanopic lux. In the control setting it's static throughout the day, both in the common areas as well as in the bedrooms.

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[2] Grant, L. K., St Hilaire, M. A., Heller, J. P., Heller, R. A., Lockley, S. W., & Rahman, S. A. (2022). Impact of Upgraded Lighting on Falls in Care Home Residents. *J Am Med Dir Assoc*, *23*(10), 1698-1704.e1692. https://doi.org/10.1016/j.jamda.2022.06.013

In the experimental settings, we made it more dynamic. So during the night time, from midnight to six in the morning, it's dim lighting. Then, the intensity increases, and in the process, the melanopic strength of the light source also increases and then dims back down in the evening. It was a multi-step process in the common areas.

And more dichotomous changes in the bedroom areas. By and large, what ended up happening was that we increased the light intensity during the day between 65 to 73%, and we decreased the light intensity during the night, ranging between 80 to 33%. When we started off, in both the experimental and control sites, the fall rates were similar to, or very close to, the U. S. average. Following the lighting intervention, there was a reduction in the number of falls per patient day in the experimental but not in the control. This resulted in about a 43 % overall reduction in fall rate in the experimental sites with the lighting intervention compared to the control sites.

And this remains significant even after we adjusted for age, sex, and the presence of dementia.

We had PNNL come in and do their own independent evaluation of energy efficiency and energy savings. There were significant energy savings from the conversion to LEDs, and a smaller portion of the savings came from the dimming of the lights at night. Their independent report is available online here.[3]

Application 3 - Behavioural Health Unit

But this is another trial we've done more recently in collaboration with PNNL. This was in a behavioural health unit.

And in this particular trial, it wasn't just a change in lighting but the whole environment. They went from an old building to a new building. The old BHU was, again, fluorescent-based lighting, static throughout the day. The new BHU is not only a new building; there is also dynamic lighting that changes throughout the day using the same principles.

This is a very complex program - chosen by the architectural firm in consultation with the institution itself. We evaluated the impact of a dynamic schedule against the same principle: dimmer lights at night, less blue-enriched, and lower melanopic strength.

And then, during the day, you're increasing the light intensity to increase melanopic strength overall. It was about a 15-month trial. We collected lighting data, both using wearables and static sensors. And then we had staff surveys. The nurses participated in the study, and we collected data on them.

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https://www.energy.gov/sites/default/files/2022-06/ssl-2022-wisconsin-care-centers-report-2.pdf

Then, we collected patient data at three different times. So, the nursing data or the staff data were collected under the old condition and the tunable condition. Patient data was collected under old static and tunable. Static here refers to a couple of months where they had moved over to the tunable lighting, but the tunable system was maintained static throughout the day.

Staff demographics. Very small sample sizes here, 20 individuals or so in the two different conditions and then the patient demographics again, fairly small sample sizes, 30, 20 to 30 individuals. And this is. Relatively short-term stay, about a week or so, as opposed to the care home study, which was all long-term stay.

However, this particular trial allowed us to see how care providers are also impacted by lighting. The first thing that we found was how they rated the lighting environment. And by and large, we saw an obvious improvement between the old and the tunable and going to tunable. All the environments were rated as excellent to good, whereas in the old fluorescent environment, ratings from the nurses for lighting in different areas were mainly fair and poor.

When we looked at their mood itself, the positive affect and negative affect of the staff working there, we found there was a trend for improvement in positive affect with this tunable lighting in place. And there was actually a significant reduction in the negative affect, indicating that the mood is improved in the staff as well, working in this environment.

Then focusing on the patients themselves; remember, this is a behavioral health unit. It's a mixed environment with individuals with different medical conditions.

One of the clinical outcomes that is followed is the suicidal ideation score. And so when we compare that on average across the three different conditions, we find that there's a significant reduction in suicidal ideation score with the tunable lighting compared to the old or even the static condition.

When you split this by sex, and you look at it relative to the length of stay, we see the suicidal ideation score in the tunable lighting has a faster recovery than in the other two conditions.

This is my conclusion slide.

By and large, in various settings, we see that implementing sleep and circadian-informed lighting interventions does have a positive effect on health outcomes, and we and others have examined this application in clinical settings, commercial settings, and residential settings.

So, I'll just quickly end by acknowledging all the fantastic collaborators I've worked with, the different institutions, the research, and the funding agencies. And thank you very much for your time.

John Bullock:

Thank you very much for that. That's wonderful stuff. You made the comment that people are either sleeping or they're active, and I wonder to what extent that is taken as an absolute and what you're counting as being active because if I'm sitting down reading a book, or if I'm running around, they're both activities, but they are very different.

How varied were you in terms of activity, bearing in mind the people that you were working with?

[00:18:01] **Shadab Rahman:** Yeah, that's a fantastic question. The first thing is that there isn't a one-size-fits-all solution. So, there is tailoring involved. Having said that, we took a very simplistic approach in the interventions I showed you.

You're either awake, or you're asleep. And when you're awake, you're "active." Other studies, which I haven't presented here, have been published, for example, in the NASA research, where crew members went through a 45-day mission, and there, you have this range in activity.

During the day they're really active doing their work. They even have exercise bouts, and then towards the evening, they're awake, but they calm down. They're reading books, watching movies, etc. So there, we took a more graduated change in the lighting scheme, right?

So when they were really awake, active, and working, the lights were maximally blue-enriched and bright. And then, closer to bedtime, there was one step three hours before bedtime; we dimmed the lights but to a normal room intensity level. And then, two hours before bedtime, we brought it down even more to about 18 or so melanopic EDI.

So again, based on your needs, you may need to implement a more systematic, graduated, tailored intervention.

John Bullock:

One of the situations that Shelley and I have found in the care home environment is whether you work astronomically, you work with the seasons, or whether you go with the daily routine of the house, which tends to be equal from 6 am to 6 pm. We spoke to Russell Foster about defining

what we mean by the circadian rhythm of an environment. It still seems to be a little bit up for grabs. But how did you approach that?

Shadab Rahman:

So we took the latter approach, where we went by the institutional needs. There are obviously pros and cons to taking both approaches. So, I don't want to come up with a hard and fast rule. Again, I think it depends on our objective, what's pragmatic, and what will work. So if the objective is to mimic nature as closely as possible and follow the seasonality in the photoperiod, etc. Fantastic, that can be done.

But if the objective is operations and you know you have to follow a certain schedule, then pragmatically, it's better to follow that schedule so that, on average, things are moving in the right direction instead of implementing a lighting schedule, which now creates a conflict with your work schedule. And then, you're always struggling. Ultimately, that just leads to poor effectiveness of the intervention, at least in our opinion.

John Bullock:

On that basis, then, what did you find that daylight was a help or a hindrance in terms of whatever daylight contribution you were getting into the various rooms?

Shadab Rahman:

In the care homes, it was really sad. At least we did the studies in Wisconsin, where it can be pretty long nights.

The amount of daylight that comes in is almost negligible. If you take a meter and you read it next to the window, sure, you're going to get a daylight exposure. By the time you're halfway into the room, there's barely any daylight that's going to have a measurable impact.

It still works as a cue. It primes the system to experience the contrast between day and night. I'm not taking any of that psychobiology away. However, in terms of the actual alerting impacts of lighting, there's barely any daylight that's reaching the eye. Even in the care, in the common areas, they have large, big windows with light coming in. But by the time you're halfway into the room, that light's not reaching the eyes.

John Bullock:

Okay. It looks like daylight contribution is the same regardless of which side of the Atlantic you're on!