Entrainment and Disruption: Lessons Learned from Implementing Circadian Rhythm Lighting

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Introduction

The application of artificial lighting to adjust or entrain circadian rhythm, by maintaining biological processes and behaviors relative to the 24-hour day/night cycle, has well-documented effects on health [1, 2]. Circadian rhythm lighting (CRL) has also shown promise to be effective as an integrated part of care and treatment of dementia patients [3], seasonal affective disorders, psychiatric and long-term hospitalized patients [4–6]. As most of the work investigating the impact of light on health and well-being has been performed in the laboratory [1], the authors' current work prioritizes research in natural settings [7], with the objective of optimizing light's impacts on health and well-being outside laboratory conditions. However, research in natural environments presents a larger degree of complexity when dealing with patients in sensitive situations. For example, previous research has indicated that, in order to have a maximum effect of circadian lighting on the sleep-wake-cycle, high levels of illuminance are needed, where 5000 photometric lux have been used in light therapy in the treatment of 'sundown syndrome' among elderly with dementia [8]. As also stressed by Sander et al. and Boyce [3, 9], and as highlighted in this study, such levels of illuminance are unrealistic to implement as general lighting in care facilities, except in carefully controlled treatment circumstances.

This paper focuses on how the implementation of CRL influences the everyday life and well-being of patients and staff in two specific healthcare contexts. The intention of these field studies was, within the overall aims of the research projects described below, to investigate the well-being of residents from a holistic point of view, considering the context and cultures of the residents. Both case studies presented here are therefore sub-studies within two larger intervention trials and aim at understanding the essences of the perceived reality and experiences with the phenomenon of light from the resident's point of view. This is explored through their everyday practice of light sources, and predominantly their use of electrical lighting, since the methods used in the studies attempt to identify effects of circadian adjusted lighting effects, where changes in daily routines and rhythms can serve as indicators for their wellbeing.

Case 1: LIGHTEL (Albertshøj) care facility for elderly dementia patients in Albertslund, Denmark

This case is a sub-study derived from a larger transdisciplinary intervention trial investigating the effect of the introduction of CRL on care facility residents with varying degrees of dementia. The large intervention trial collected both medical, anthropological and sensor-based data [7] in a concurrent research design, where CRL (Figure 1.) was installed on a single floor in residents' private rooms, common spaces, living rooms and dining room. Previous research [8] shows that patients with dementia often have an abrupt circadian rhythm, making them an interesting target group for light exposure treatments.

As care for dementia patients encourages secure and homely environments, the sub-study examines the influence of the CRL intervention on the residents' "practice of home" [10–12] and their perceived reality and experiences of light, from an anthropological viewpoint. Residents were interviewed about their daily lives and routines before the installation, during the control trial and the intervention. This was carried out in order to uncover how the implementation of CRL affected

the residents' acceptance of the new lighting technology and the effect on their everyday lives and well-being.

During the study, the residents and staff were encouraged to have the pre-programmed CRL lighting on at all times, and only to turn it off (by a switch on the wall) in case of emergencies. The care facility had large window sections illuminating rooms with daylight, and besides the CRL the residents were allowed to use their own lamps brought from home.

Baseline	Control Period: Static lighting setting	Intervention: CRL (Dec.11th 2017 – Feb 4. 2018)	Control Period: Static lighting setting
1 week	8 weeks	8 weeks	8 weeks
Group A			
	Group B		

Table 1: Research design for case-study 1. Oct. 2017- Marts 2018.

Case 2: Ballerup Psychiatric Centre, Eating Disorder Unit

Eating Disorder (ED) patients pose an interesting case, as Anorexia Nervosa (AN) and Bulimia Nervosa (BN) can be linked to comorbidity in disorders including depression and sleep deprivation, insomnia, obesity, diabetes, bipolar disorder and seasonal affective disorder, all of which have previously been shown to be affected by 24-hour pattern of light and dark [8, 13][14]. The objective of this particular study was to introduce two different CRL programs, to be able to compare and investigate if exposure to the two schedules (Figure 2.) would show effects on the activity and wellbeing of the hospitalized patients, through entrainment of their circadian rhythms.

These two schedules were implemented in a newly built psychiatric treatment facility for ED patients. The facility offered CRL in private patient rooms, dining room, treatment rooms, and an open office, whereas corridors, courtyards and a lounge area, had access to dynamic lighting and high levels of daylight.

During the study data was gathered through structured ethnographic observations, interviews, questionnaires, mappings, acoustical sensors, CO2 sensors, occupancy sensors, daylight sensors, thermal sensor imaging, flow data, and clinical measurements, including regular blood and urine analysis. This paper focuses on the results gained through observations carried out during the introduction of the CRL programs during March 2018 to July 2018.

Methods

In both cases, the newly installed technology was intended to implement new standards and practices for circadian light exposure in healthcare facilities.

Case 1: Lighting Intervention

The circadian rhythm lighting (LED-based lamps specially designed by Chromaviso, Denmark) was implemented in both the residents' home, their bathrooms, and all common areas on the single floor of Albertshøj. The lighting system installed followed planned lighting schedules throughout the intervention (see Figure 1. showing changes in Kelvin), designed to follow the day/night cycle. During

the morning hours, the lighting was dim but slowly increased in illuminance and color temperatures (Kelvin) with more of the blue light spectrum. The lighting peaked and reached its maximum illuminance between noon and 2pm, after which it slowly decreased in illuminance and changed to warmer components of the light spectrum during the afternoon. At night, the lighting contained less of the blue light spectrum to minimize impact on patients' non-visual systems. The lighting schedule was carefully designed to entrain the circadian rhythms of the residents', but also support the daily activities in the facility.

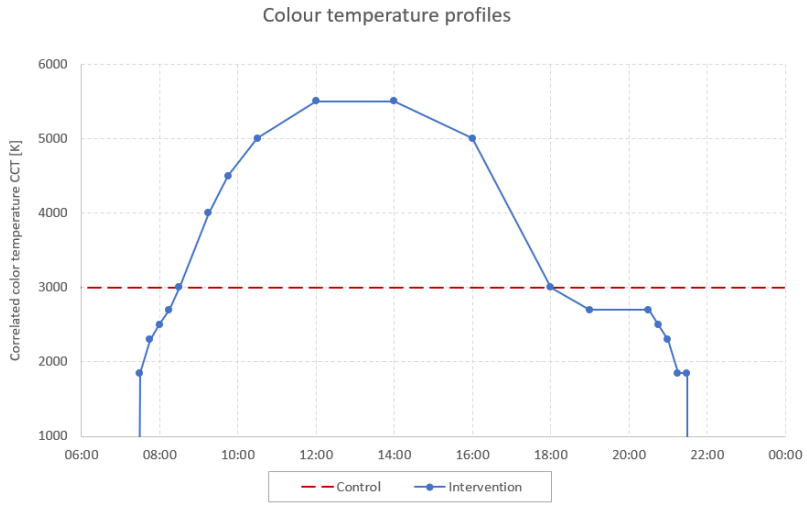

Figure 1, Illustrates how the CRL changes in Correlated Colour Temperatures (Kelvin) over the course of a day installed in the residents' apartments. The light turned on/ off once per day during the intervention as depicted. Whereas the light (intensity and CCT) during the intervention were dynamic, the light in the control period were static.

Case 1: Research design and measurements

Eleven elderly residents participated in interviews during the intervention study, of whom seven participants were frail elderly residents with varying degrees of dementia. The participants were divided into two groups; Group A and Group B, and were exposed to the control light either before or after the intervention (see table 1). Ethnographic interviews [15], mappings [16] were used to gather in-depth information about the individual's life story, perceived reality and experiences. Because the residents were sensitive and frail study-subjects, the sample size depended on the staff's expertise of the resident's cognitive abilities and their physiological state. The caregivers were asked to give an account of each participant if they were able to: be interviewed for 15 minutes or more, provide a detailed account on their daily activities and experience of the lighting. These recommendations from staff reduced the participants appropriate for interviewing from 18 to 7 informants. By the end of the study only 7 participants were interviewed, due to participants having more severe cognitive disabilities and health-related issues than expected and incidence of death. The residents who were unable to be interviewed, were then observed and surveyed through proxy interviews with staff. Mappings of the lamps supplemented the verbal descriptions and was used as method to retrace how the residents used the light sources in their daily routines, as a part of practicing home and their perception of the luminous intensity emitting from the light sources. The participants were interviewed 7 times over the course of 17 weeks from October 2017 to beginning of February 2018. Semi-structured interview-guides [18] were used to survey the residents from group A, who were cognitively as well as physiologically capable of participating in the interviews.

Participants were given a verbal explanation of the project on the first encounter. When the next interview was conducted, the purpose of the study was briefly summarized. The interviews lasted between 30-50 minutes depending on the resident's current physical and cognitive state and willingness to answer our questions. The dialogue with the participants focused on the residents'

everyday life, relating to their routines, activities in their apartment, socially and outside the nursing home, their experience of the facility and their sleeping patterns. The main topics during the interviews were the residents' understanding, evaluation and practice of the installed light sources, both their own light fittings as well as the new CRL light sources. As more interviews were held, participants were asked about whether anything had changed in their routines: for example, relating to sleeping patterns, activities, physical health or mood. The results presented in this paper is a part of a larger analysis-process where the interviews were transcribed in summary, then thoroughly read through rapidity and lastly coded into themes. The results are based on both the interviews and observations gathered. In this paper, citations are provided by three of the residents out of seven interviewed, and the quotes used were selected to exemplify or highlight the analyzed themes and issues.

Case 2: Lighting Intervention

In the newly developed building in Ballerup, the dynamic lighting system was designed to allow for the software programming of two CRL schedules, termed 'L1' and 'L2' respectively (see Figure 2). During the test period, patients in the facility were not able to turn off the lights in their private rooms from 7am - 9pm, with the exception of during medical attention where higher light levels would be required; in these cases, staff could override the CRL.

Figure 2, L1 and L2 daily CRL schedules: Light Intensity (in Lux) and Correlated Color Temperature (in Kelvin) installed in common areas.

The first schedule L1 matches the natural course of the day/night cycle, with generally higher color temperatures and intensities during the day than the second schedule. L2 was designed to match

the strictly structured daily program applied by the medical staff in the facility and provided two daily 'light boosts' of cold white light and high intensity lux levels: a very strong peak in illuminance during the morning and another peak in the afternoon.

Natural light coming through the windows, direct sunlight in the courtyard and light from tablets and computers presented disruptions in the influence of the CRL. Moreover, the test period ran from April to July and included, for Denmark, higher than average sunlight hours, affording attractive outdoor conditions for the patients to use the courtyards.

Case 2: Research design and measurements

CRL Scenario	*Test*	*L1a*	*L2a*	*L1b*	*L2b*
Time period	*6 weeks (March-April)*	*3 weeks (April-May)*	*3 weeks (May)*	*3 weeks (June)*	*3 weeks (June-July)*

Table 3, research and test design for case study 2

The experiment was based on a framework of ABAB phased design, where each phase lasted three weeks. This design enabled a comparison of the observations and data collected from the two differing lighting programs. Each schedule was carefully designed to accompany and support the daily activities in the facility.

A baseline was initially proposed prior to the data collection, but due to delays in completion of the new buildings, together with technical changes in the building, the data collected from the baseline has been discarded.

The medical staff carried out interviews and questionnaires to measure and track changes in anxiety levels and wellbeing. Patient observations were focused on the common area in the heart of the building, where data from heat sensors, decibel and humidity were measured during the trial. The observations were only gathered in the common areas to respect of the patients' privacy and because the thermal cameras were situated here.

Figure 3: Thermal camera image of lounge area (observer seated in upper right corner)

The structured observations were carried out in time slots during the period 8.30pm-00.30am, allowing observation of the interaction patterns between patient-to-patient, staff-to-staff and patient-to-staff, at times where the artificial lighting was dominant.

Results

Adaptation and tolerability

The findings from Case 1 illustrate the difficulties for the residents in adapting to the circadian lighting. The discontent with the new lighting was exemplified by resident 1:

"Yes, you know what? When I am seated here by myself, then I let this be turned on, and it is on all the time [table lamp with green glass-shade and brass lamp base] because I like the lighting that it provides, and then no more lighting is needed. Likewise, in the bathroom you know what? I have tons of light in there, where a lamp has also been installed. It is completely insane. It is too much". [All quotes said by participants are translated by the author from Danish]

The time needed for adaptation to the CRL was generally longer than expected; at the end of the intervention, many of the residents who were interviewed still preferred their own lighting and daylight, rather than the circadian lighting. Resident 3 explains her thoughts about the process of adaptation: *"But whether I can get used to it, that I do not know. Whether I will say: 'oh, how pleasant it is', that I am afraid that I will never really do, but you never know"*. The residents' negativity also stemmed from the project itself. The clinical and anthropological studies collected data concurrently on the same participants. Thus the patients were surveyed frequently, which for some was more than to what they were accustomed.

The issues of acceptance and tolerability were not only connected to the residents' lighting culture but were also affected by their fear of using modern technology: *"The top switch is the new one. That one you must not touch!"* (Resident 1). Residents' insecurity towards the new CRL systems were especially revealed when it did not work: *"I thought in the beginning that it was my mistake, and I did not want to say anything"*. Likewise, Resident 2 did not know how to use the lighting switches with the intention of turning the lights off in the bathroom. This resulted in distress, and decreased her feeling of autonomy and her ownership of the home:

"It functions differently I think. It seems to work opposite of what I have experienced my entire life where you turn it on by pressing up and you turn it off underneath. This is a mess. To me, it seems a bit inverted and wrong because I cannot simply turn it on and off. […] I have had some issues figuring it out and I am still fumbling with the bathroom light. To turn it on you must press up or down or how? At some point, it succeeds. […] As so many other things here in life, I will find a way to live with it".It was also difficult to become accustomed to living in a modern dwelling. Resident 3 explains how she needed to get accustomed to living at the nursing home: *"Beforehand I lived for five and a half year at Aldbo* (previous care facility) *and now I have to get familiar with using an access card to get in and out and to using the elevator constantly. There is one new thing after the other in this place. Then there is this new lighting installed, I think it is a radical change"*.

The residents referring to their previous homes, such as the quote above, could be caused by the institutionalization and modern technology that makes it difficult to feel truly at home. Jacquelyn Frank argues [22], *"Elderly persons who move into life care facilities do not automatically feel at home in their new living arrangements. Frequently, the cause for this discomfort is the physical environment: it is too institutional and too unlike their former homes"* (in Schwarz & Tofle, 1999, p. 166).

The long acceptance times to the new lighting is thus related to the resident's adaptation to living in a modern care facility. Vacher [11] argues that the notion of home is strongly related to a space that residents are in control of. Thus, the loss of control characterizes a movement away from home. This feeling of home is seen through the residents' affection towards their own lamps and lighting fixtures, as exemplified by resident 3: "*if you take my lamps from me then I will move home*". The residents' own lamps neutralize the perception of institutionalization, even though in some cases the lamps were not even connected to the electrical plug points. Although their own lamps, brought

from their previous homes, are a confounding influence on CRL effects, the findings indicate that excluding them altogether from the study would make the adaptation even more challenging.

Analysis of the ethnographic observations from case 2 indicates that the implementation of CRL had a self-perceived negative effect on patients and staff, particularly for those patients who were in mid-treatment and moved into the new buildings directly from the previous facility. This negativity was especially dominant in the pilot phase of the study, which was later discarded due to technical issues with the CRL software. Patients that entered the facility later in the process were observed to have a better adaptation to the system. This could be interpreted as "not knowing" of how it "used to be".

Technical issues in the initial phase often resulted in negative comments towards the research project. The focus of the negativity was often related to the autonomy of the system, the lack of on/off switches and thus lack of control over their private areas. ED patients are sensitive to losing control [21] and the dynamic lighting that was "prescribed" in the entire building triggered complaints, such as some patients felt that lighting levels should be a matter of personal choice.

However, the patients were overall observed to become more positive towards living in the building and the dynamic lighting system (CRL) during the trial. Although this was empirically observed in social activities, talk and inter-group dynamics, no bio-data or questionnaires showed any positive change in anxiety levels.

The influence of staff on residents' acceptance

In case 1 the interviews and observations showed that the residents' attitude towards the light and thus their process of acceptance, were affected by the staff. The interviews with the staff uncovered that as a part of their work routines they strived to maintain a positive attitude and good atmosphere, because this affected the residents' behavior. This relationship was particularly observed in the residents suffering from severe dementia. These spent most of their day in the common area and were highly dependent on the staff for daily tasks and navigation, compared to the less frail, who spent most of their day in their private spaces. Because of the staff's positive attitude and reactions towards CRL from the very beginning, it was observed that this group of residents was more tolerant of the CRL being implemented. The difference in how the lighting was accepted can thus be prescribed by the degree of autonomy, and independence from staff. In general, the staff attempted to encourage the patients to keep the lighting on as much as possible, with the exception of those patients with special needs.

In spite of the staff's encouragement, the frail elderly, who were interviewed, showed skepticism and negativity towards the lighting. Not all staff members were positive towards the lighting, and reported that the bright light caused headaches. The observations and interviews with the staff indicated that the lighting not only affected the residents but also affected their working routines. For example, the staff found it more difficult to encourage the residents to go to bed because they thought it was still day even though it was evening. Therefore, the sundown was set to start an hour earlier during the intervention in order for staff to get everyone to bed before the end of shift.

In case 2, it was observed that the patients reacted strongly to the attitudes of staff in the facility. The new digital systems and dynamic lighting were on several occasions overridden to meet the wishes of patients, for example of not having dynamic lighting in their personal rooms. When the CRL system was turned back on, this was not always supported by the staff, affecting negatively on patient attitudes towards the CRL.

In spite of several introduction courses, pamphlets and informal meetings, the implementation of the CRL led to misunderstandings in the staff and patient groups, resulting in an overall negative mood in both the patient and staff group. The patients in the facility were observed to have very close relationships with some members of the staff, creating a strong connection with safety and thus trust, which is why the education of staff pre-implementation is to be considered highly

important, so they can support patients during the transition to the CRL. Investing time and resources in informing the residents several times during the study and during changes between intervention and control period should be considered in future projects, in order to potentially reduce the negative experiences related to the implementation of the lighting.

Observations in case 2 showed a significant difference between the patients that moved into the new building as “first movers” and patients that entered later in the process. Where the CRL caused disruption to begin with, a more harmonious adaptation was observed later in the trial. In the first phases, where the dynamic lighting was tested and calibrated, the patients and staff were heavily affected by technical issues, creating a difficult work environment for staff and simultaneously causing impatience and anger from patients.

As seen in both cases, when the lighting affects the residents and patients’ behavior, it also affects staff working routines and consequently their quality of work.

Conclusion

The paper denotes a partial study derived from two longitudinal case studies where circadian rhythm lighting was implemented. Although CRL has well documented health related effects in the laboratory, this paper shows that serious challenges can emerge during implementation, relating to acceptance, adaptation and usability of the technology. These are issues, which needs to be carefully addressed in future projects. The knowledge and recommendations derived from these case studies, are intended for future designers and clients when implementing lighting solutions that stimulates the circadian rhythm.

Both studies showed clear entrainment effects in the initial phases of the implementation of CRL. However, these effects were not all positively perceived by patients and staff. Observations from both cases indicate that the participants had a relatively long adaptation time to the introduced CRL, and displayed difficulties in accepting the change of routines and habits entrained by the CRL. Firstly, the installation of the lighting affected the patients’ everyday routines, as their daily routines adjusted to the automated light and dark programs. Secondly, the implementation of the lighting challenged the everyday work-routines and job-satisfaction of the staff, particularly as the automatic nature of the lighting, without the possibility of personal control, was experienced as a reduction of both staff and residents’ independence. We encourage future studies to test different levels of interaction and user control when implementing CRL. As illustrated in the two cases, the users are not passive, but interacted with the lighting as they please (switching it off or on) and did workarounds if the system did not work as indented. Therefore, it is important that the lighting system is fully functioning from the beginning and is tested thoroughly, and that the user interface is considered to be personalized to the patients’ and staffs’ everyday need, instead of a universal solution.

When implementing CRL in facilities where the patients live permanently or for a longer period, it can therefore be reasonably anticipated that its introduction will influence the everyday routines of patients and staff. While this influence is an intended effect of CRL – namely the entrainment of 24-hour biological rhythms, with ensuing positive benefits for health - it can also be experienced negatively as an unwanted disruption by both patients and staff. This poses the question of whether the design of luminaires and software programs for circadian entrainment should prioritize that of evidence-based practice or focus on the comfort of the occupants, including staff. This is particularly of concern in the implementation phases, where disruption effects are most likely to be experienced. Communication with staff should be prioritized in future projects which implement CRL in order to create better transitions for the patients and to achieve shorter adaptation time to the new systems and lighting conditions. Future projects need to carefully consider this challenge when

implementing circadian lighting in settings such as psychiatric and care facilities, for CRL to become a successful and integrated part in the treatment of patients and the work carried out by the staff.

While differing in many respects from lab experiments, CRL studies in the natural environments offer new perspectives on its implementation in the context of sensitive and frail subjects. However, introducing new 24-hour light–dark patterns is challenging in healthcare facilities where staff encourage patients to 'feel at home' in order to negate effects of translocation, disorientation and lack of control. This is because 'being at home' is a continuous practice built up over a longer period, where a sense of control over one's environment is an important factor. This is especially evident for the elderly, where new technologies are not a commodity, but rather a radical and confusing change, making it difficult for them to feel truly at home. The future challenge is that of moving from a 'one size fits all' approach, toward integrating circadian lighting with personalized systems that allow for individual control and interactions, while maintaining the improvements to human health and wellbeing.

Furthermore, the design of circadian lighting programs and schedules should focus on the perceived comfort of the patients as well as the biological effects of the lighting. It is therefore recommended that a period of transition be introduced in the early stages of implementation, whereby light intensities and correlated color temperatures are gradually adjusted from previous levels to the desired new levels.

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