Hospital lighting and patient's health

The influence of daylight and artificial light on the circadian rhythm, length of stay and pain levels of hospital patients

BSc Thesis Health and Society

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Abstract
Aim The aim of this study is to provide an overview regarding the effects of daylight and artificial light on the circadian rhythm, length of stay and pain levels of hospital patients. **Method** The search engine Scopus is used to gather literature to conduct the literature review. **Results** Lighting is a complex concept which can be measured using light intensity, light colour, and brightness. The circadian rhythm is related to the hormones cortisol and melatonin which regulate the sleep-wake rhythm. This may be disturbed in hospital patients because of improper lighting environments. Length of stay is especially related to daylight and is an indicator for hospital quality and costs. Lastly, pain levels are related to the hormone serotonin and to vitamin D which are both produced by daylight. **Conclusion** This study concludes that mainly daylight should be taken into account when adapting hospital rooms to the lighting environment because daylight is positively associated with circadian stimulus, reduced length of stay and reduced pain levels. Artificial light should be used complementary to daylight but must be adapted to certain criteria before implementation. When the hospital building is properly adapted to both daylight and artificial light, this will provide benefits for hospital patient's health and ultimately for the hospital's bottom line.

Table of contents

1 Introduction

Over the last years the academic attention on healing environments has increased. A healing environment produces positive health outcomes for patients within the physical environment (Huisman, Morales, Van Hoof & Kort, 2012). Several advantages relating to the healing environment can be described, for example a reduced length of hospital stay, and a reduction in anxiety (Dijkstra, Pieterse & Pruyn, 2006). The scientific base for the healing environment started to develop in the second half of the Twentieth-century with research of Ulrich (1984), who studied the impact of the difference between a patient's view on a brick wall and nature on the length of stay and the amount of pain medication of patients. From this moment on, more research on the subject was conducted and, in these studies, it was concluded that the physical environment could have several positive effects, such as on the emotional well-being and on stress-reduction of both patients and healthcare personnel (Van Hoof, Rutten, Struck, Huisman & Kort, 2015). A relatively new concept related to healing environments is Evidence-Based Design (EBD).

Evidence-Based Design can be defined as an approach for the design of healthcare facilities, basing design choices on scientific data (Van Hoof et al., 2015). The purpose of Evidence-Based Design is to describe how the physical environment, especially the built environment, improves the health of patients or healthcare personnel, based on scientific evidence (Clancy, 2008). With the knowledge on how the physical environment can improve the health outcomes of patients, healthcare buildings can be adapted to provide optimal healing effects for patients and a pleasant working environment for healthcare personnel. Implementing the knowledge from Evidence-Based Design in a hospital may result in safer hospital environments and improved quality of care, resulting in lower stress-levels of healthcare personnel and improved safety and well-being of the patient (Ulrich, 1984; Van Hoof et al., 2015). Regarding Evidence-Based Design, various aspects of the physical environment can be taken into account, of which examples are windows, lighting, seating arrangements, and nature (Huisman et al., 2012). In many articles about Evidence-Based Design, lighting is mentioned as one of the factors with the greatest influence on patients' health (Joseph, 2006; Dalke et al., 2006; Dijkstra et al., 2006). However, lighting is a complex concept, including several aspects which should be taken into account. For example sunlight, which comes from the sun and might provide positive effects, but also negative effects such as heat or glare (Veitch, 2005). Furthermore, there are several types of artificial light available, which all may have a different influence on patients (Alzubaidi & Soori, 2012). In this paper the focus will be on lighting, because it can be considered as one of the main factors of Evidence-Based Design influencing patients' health, and it is a very complex concept which needs more elaboration.

The first person to emphasize the importance of lighting on the health of patients was Florence Nightingale. In her 'Notes on Nursing' (1860) she mentioned that after the need of fresh air, the need of light is most important. According to her, not just daylight would improve the health status of the patient, but especially sunlight was important. Since this time, many articles have been written about the importance of light in a hospital. Lighting in a hospital can have major influences on patients. Hospital patients may be very emotional and under a great amount of stress when entering a hospital (Dalke et al., 2006). At such a moment, lighting could increase the confidence of the patient by improving navigation through the hospital, which promotes faster access, and therefore reduces frustration (Dalke et al., 2006). Other studies concluded that specifically sunlight might have a positive influence on patients recovering from surgery or other medical interventions. Dijkstra et al. (2006) concluded that sunlight had several beneficial effects on the patients' experience, among which a reduction in the length of stay in the hospital, decreasing mortality rates, and lower pain levels. Lastly, proper lighting in a hospital is needed so the staff is able to function optimal, for example daily routines can be better executed with sufficient lighting. A proper lighting system with absence of glare is of great importance when examining a patient, so mistakes in the examination can be avoided (Leccese, Montagnani, Iaia, Rocca & Salvadori, 2016).

With lighting a distinction can be made between daylight and artificial light. Daylight is natural light which occurs during daytime. Sunlight, as part of daylight, is the light coming directly from the sun (Webb, 2006). Artificial light is light from non-natural sources that can be turned on and off (Webb, 2006). These types of lighting may have different influences on the health of a patient. Several health outcomes can be measured regarding the influence of lighting. Three categories can be differentiated as important health outcomes related to lighting, which are the circadian rhythm of a patient, length of stay in the hospital of a patient, and pain levels of a hospitalized patient (Dunn, Anderson & Hill, 2010; Choi, Beltran & Kim, 2012; Walch et al., 2005). Studies have shown the importance of lighting on these three categories, but in current literature there is no overview available of the influence of daylight and artificial light on these three categories. Therefore, the aim of this paper is to provide an overview of the influence of daylight and artificial light on the circadian rhythm, length of stay and pain levels of a hospitalized patient. The research question is formulated as follows: *What are the differences in effects between daylight and artificial light on the circadian rhythm, length of stay and pain levels of patients in a hospital?*

To be able to answer the research question, three sub questions are formulated:

1. *What is lighting (daylight and artificial light) and how can lighting be measured?*
2. *What are circadian rhythm, length of stay and pain levels and in what ways can these concepts be measured?*
3. *What are the effects of lighting on the circadian rhythm, length of stay and pain levels on patients in a hospital?*

2 Methods

To provide an answer on the research question, a literature study has been conducted. Articles were gathered using the search engine Scopus. To gather articles to answer the research question, the following search string was used: TITLE-ABS- KEY ((lighting OR sunlight* OR sunshine OR daylight* OR “natural light” OR "artificial light*" OR "electronic light*" OR “LED-light” OR “fluorescent light” OR “incandescent light”) AND (“length of stay” OR “hospitalization” OR “time in hospital” OR “circadian rhythm” OR “pain level” OR “pain medication”) AND (hospital) AND (patient OR "sick person")). Conducting this search string in Scopus resulted in 164 results. Furthermore, for each concept separate strings were searched in Scopus, to gather all possible relevant articles. For daylight and artificial light also separate strings were formulated, to make a clear distinction between both concepts.

The second method that has been used to gather articles was snowballing, thus using reference lists and citations of articles. Both backward and forward snowballing were used, meaning that first the reference lists of useful articles were analysed for other relevant articles. Secondly, the articles which referred to the first article were analysed. Using the snowballing technique, there is a high possibility of finding all relevant articles on this subject.

The first selection of the articles was based on the title and the abstract. An article was included when it was written in Dutch or English, when it studied the effects of light on patients and when it was related to the hospital environment. The effects of light on patients must regard the circadian rhythm, the length of stay of the patient in the hospital, or pain levels of the patient. An article was excluded when it was written in another language than Dutch or English, and when it was not related to the hospital environment. An article was also excluded when it focused on the influence of lighting on hospital staff instead of patients, and when it did not take into account the circadian rhythm, length of stay, or pain levels.

After the first selection based on the title and abstract, articles have been included or excluded. The second selection was based on a quick scan of the article, in which the article was read roughly. Based on this, the decision could be made whether to include or exclude the article in the final selection. The articles included in the final selection were the articles which were used to write this literature review. To be able to work systematically, the articles have been divided into three categories: circadian rhythm, length of stay, and pain levels. The articles have been analysed per category, which was an organized way of working. Articles which included two or more of the concepts were placed in all relevant categories, to make sure the information per category was complete.

3 Lighting and concepts of lighting

3.1 Introduction

Lighting is a very broad concept which needs more elaboration to provide a good understanding. In this chapter, lighting and related concepts are elaborated. Both daylight and artificial light are included in this chapter. First, an explanation is given of the biological effects of lighting on the human body. Furthermore, several concepts are elaborated, among which light intensity, duration and colour. In the paragraph on artificial lighting, three types of artificial lighting are explained, which are incandescent light, fluorescent light and LED light. Thereafter, a paragraph that elaborates on measurement methods of lighting is included. This chapter ends with an elaboration on lighting in hospitals, to provide an overview of the current situation of lighting in the hospital environment.

3.2 Daylight

Daylight is the light during daytime, from sunrise until sunset. Daylight causes a natural lighting cycle, which means differences in intensity during the day and differences between seasons, caused by the sun. Therefore, lighting is different at every moment of the day, instead of at a constant level (Joarder & Price, 2013). As mentioned before, sunlight is part of daylight. Sunlight is the light coming from the sun, which is brighter.

Light consists of electromagnetic radiation (EMR) which is the cause for humans to be able to see. EMR differs across the range of wavelengths from 390 to 780 nm and stimulates photoreceptive cells in the retina which create vision. Light falls onto the retina and through photoreceptors in the eye it sets off signals to the visual cortex. When the information from the light falls onto the visual cortex, the brain interprets this information and creates images. The human photo detection also causes humans to see the cyclical pattern of light and dark, which causes the ability for humans to make a difference between day and night and related to this, periods of activity and rest. This is called the image forming pathway (figure 1) (De Kort & Veitch, 2014). The second pathway is called the non-image forming pathway, in which light does not reach the visual cortex and therefore does not create images. In this pathway especially the suprachiasmatic nucleus (SCN) is important. Light falls onto the retina which regulates the operation of the SCN. The main function of the SCN is to control circadian rhythms, which is associated with the sleep-wake rhythm (De Kort & Veitch, 2014).

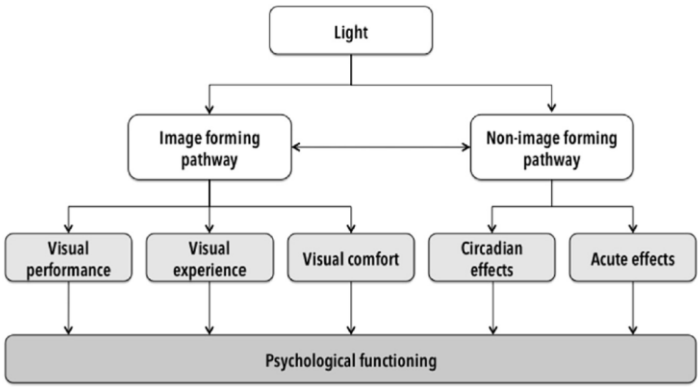

Figure 1: Pathways of light. Reprinted from "From blind spot into spotlight. Introduction to the special issue 'Light, lighting, and human behaviour", by Y.A.W. de Kort, 2014, *Journal of Environmental Psychology, 39*, 1-4.

Several other concepts of daylight need more explanation. Firstly, light intensity is an important factor to take into account. Light intensity is the total amount of incoming light on a specific surface. This is measured in lux. Light intensity rapidly changes during daytime and even between seasons because of changing sun positions and differences in cloud covering in the sky (Joarder & Price, 2013). It also differs within a room, with a different intensity near the window and near the back of the room, opposite from the window (Joarder & Price, 2013). Furthermore, a difference can be made in luminance and illuminance, which are both are measures of the intensity of light. Luminance measures the light directly coming from the light source, and illuminance is the light around the light source. For example, directly looking into the sun may cause temporary blindness because of the luminance, while the illuminance causes an optimal view around the light source. Luminance is related to direct light, while illuminance is related to indirect light (De Molenaar, 2003).

Another important concept is light duration. Light duration is the number of hours per day lighting occurs. This may differ per season because of different weather types within seasons (Begemann, Van den Beld & Tenner, 1996). On a winter day the duration of daylight will be shorter than the light duration on a summer day (Thorne, Jones, Peters, Archers, & Dijk, 2009). Thorne et al. (2009) conducted research on the differences in light spectrum between seasons. They concluded that subjects were exposed to significantly more light in summer compared to the winter. Furthermore, they studied the differences in light colour between summer and winter. Blue light was significantly lower in winter days, while red and green light contributions were higher in winter days.

Light colour is the last important concept to recognize. The colour of lighting is dependent of the wavelength of light. The wavelengths separately cause our ability to see colours (De Molenaar, 2003). During daytime, the colour of natural light differs, from a blue spectrum in the morning and afternoon to a red spectrum in the evening (Santhi et al., 2012). Table 1 shows an overview of wavelengths related to colour. Light colour is related to two hormones: cortisol and melatonin (Frisk, Olsson, Nylén & Hahn, 2004). The blue spectrum causes an increase in cortisol, so the cortisol level is at its highest between morning and afternoon (Frisk et al., 2004). Cortisol increases the energy level of a human being, which results in the ability of executing an activity for a longer term. The melatonin level reacts to the red spectrum, which causes an increase in melatonin in the evenings (Frisk et al., 2004). Melatonin is also called the sleeping hormone, and one of its functions is to regulate the sleep-wake rhythm (De Rui et al., 2015). From this can be concluded that natural light causes an increase in the energy level during daytime, and that natural light causes an increase in the melatonin level in the evening, which is related to a regular sleep-wake rhythm. A third hormone that is influenced by lighting is serotonin. Sansone and Sansone (2013) concluded in their study that sunlight might influence the production of serotonin directly through the skin. Serotonin is known as a hormone that inhibits pain (Walch et al., 2005). However, the relationship between serotonin and lighting needs further research because still some inconsistencies among studies exist (Sansone & Sansone, 2013).

Table 1: Composition of the light spectrum. Adapted from “Lichtbelasting. Overzicht van de effecten op mens en dier,” by J.G. de Molenaar, 2003, *Alterra-rapport 778*.

Light colour	**Wavelength in nanometer**
Violet	390 - 455 nm
Blue	455 - 492 nm
Green	492 - 577 nm
Yellow	577 - 597 nm
Orange	597 - 622 nm
Red	622 - 780 nm

3.3 Artificial light

Artificial light is light made by humans and comes from non-natural sources (Webb, 2006). Several forms of artificial light are available, such incandescent light, fluorescent light and LED light. Incandescent light was the first type of light that was developed, which was relatively safe and was a reliable indoor light source. However, this light source was not energy efficient because of the short life of the lamp, and therefore fluorescent lighting was developed (Whitmore & Schulze, 2011). Fluorescent lighting was developed to produce similar positive health effects as natural light, but it may be the cause of many health problems, among which the most important is skin cancer. The reason for this may be the high spectral power distribution of fluorescent light compared to natural light (McColl & Veitch, 2001). The difference between natural light and artificial light is that natural light has a range of wavelengths from 390 till 780 nm, while the wavelengths of artificial light are mostly more concentrated in limited areas, for example in the red or orange area (Joseph, 2006). Nowadays LED lighting is seen as the most energy efficient artificial light source (Whitmore & Schulze, 2011).

LED is short for light-emitting diodes. Most current research has been done on white LEDs, which have been improved on colour quality and vision performance. LEDs seems to have many advantages, such as a long life, dim ability and variability, unlimited switching, flexible design, high luminous efficacy and compactness (Ryckaert, Smet, Roelandts, Van Gils & Hanselaer, 2012). Nowadays, LED lighting is used to replace fluorescent lighting, because LED lighting seems to be more energy saving and seem to have a longer life (Ryckaert et al., 2012). However, this leads to questions whether LED lighting has similar quality to fluorescent lighting. The study of Ryckaert et al. (2012) showed inferior colours of LED tubes compared to fluorescent lighting, and poor luminous maintenance characteristics. This study also conducted a case-study on the replacement of fluorescent light by LED lighting in a small office room. Several findings of this study are relevant. First, a fluorescent lamp distributes light in all directions, while a LED tube only spreads light downwards. Furthermore, the lighting was tested on luminaire intensity. This resulted in a different luminaire intensity of fluorescent light compared to LED light. However, the luminaire efficiency increased using LED light compared to fluorescent light, from 77 to 85 percent. LED light causes energy savings from up to 70 percent, but the mean illuminance using LED lighting decreased with about 50 percent, which resulted in unacceptable levels of illuminance. Furthermore, visual experiments were conducted to compare the effects of TL light, LED light and fluorescent light. Factors on which the visual experience was tested were general lighting quality, colour quality, and perception of glare. TL resulted to score highest on almost all these investigated factors. LED tubes were perceived to make the room darker compared to fluorescent lighting, and fluorescent lighting was perceived to have the highest visual attractiveness (Ryckaert et al., 2012).

Another study on the differences between types of artificial lighting was conducted by Alzubaidi and Soori (2012). This study was directed at the hospital environment. Alzubaidi and Soori (2012) concluded that only LED lighting had positive effects on eliminating factors such as headaches, eye irritation and fatigue, which are negative factors which may be caused by improper lighting. LED was concluded as the type of lighting with the least visual discomfort. However, within the category of LED lighting several types exist, and, related to the hospital environment, within this category it may differ per hospital or ward which type of lighting should be chosen. Both incandescent lighting and fluorescent lighting appeared to have very high power densities, respectively 120 W/m2 and 66.04 W/m2. The recommended power density in a hospital is 25 W/m2. LED lighting has a power density of 25.2 W/m2, which makes this type of lighting the best suited for energy efficient lighting in hospitals (Alzubaidi & Soori, 2012). Furthermore, as can be seen in table 2, LED lighting has the highest number of average lamp life in hours, which also contributes to the sustainability of the lamp. Lastly, LED lighting appeared to be the type of lighting with the most absence of glare and flickering, which contributed to the result of LED lighting being the most appropriate type of hospital lighting (Alzubaidi & Soori, 2012).

Table 2: Lamp efficiency, service life and power density. Adapted from "Energy efficient lighting system design for hospitals diagnostic and treatment room - A case study," by S. Alzubaidi, 2012, *Journal of Light & Visual, 36*(1), 23-31.

Type of lamp	Lumens per watt	Average lamp life in hours	Colour rendering	Power density (W/m2)
Incandescent	8-25	1000 - 2000	100	120
Fluorescent	60-600	10000 - 24000	82-95	66.04
LED	28-79	25000 - 100000	40-85	25.2

Lastly, important to mention related to artificial light is the concept of bright light therapy. Bright light therapy is a therapy in which bright light from artificial sources is used, with the aim to positively influence the health of patients. Past studies have mainly focused on the effect of bright light therapy on Seasonal Affective Disorder, together with mood or depressive disorders (Krysta, Krzystanek, Janas-Kozik & Krupka-Matuszczyk, 2012). However, bright light therapy might also positively influence circadian rhythms and pain levels, as has been studied by Leichtfried et al. (2014). Bright light therapy aims to influence the circadian clock of people, by providing a clear day/night cycle when the therapy is provided at the right moment of the day. For example, bright light therapy provided in the morning might reduce melatonin levels, which might result in higher awakening of the patient during daytime (Krysta et al., 2012). Furthermore, bright light therapy may influence serotonin levels, resulting in higher serotonin levels which is associated with lower pain levels. Therefore, bright light therapy may have an influence on both the circadian rhythm and pain levels of patients (Leichtfried et al., 2014).

3.4 Measurements of lighting

Lighting can be measured based on the perception of humans and based on technical components, which will both be explained. Regarding the perception of lighting by humans especially the image-forming pathway is of importance. To measure this, several factors should be taken into account. First, according to Florin, Arsinte and Mastorakis (2010) light colour is important. The colour of lighting determines the beauty of the image people see. Without colour, an image may seem dull, and colour adds more beauty to the image. Next to this, Beute and De Kort (2013) state brightness or luminance to be of great importance regarding people's preferences on light. They state that people prefer bright lighting environments compared to dark light environments. Furthermore, brightness seems to be most important related to executing (work) tasks, as Akashi and Boyce (2006) concluded in their study on lighting perception on the work floor. Furthermore, Stidsen, Bjerrum, Kirkegaard, Thuesen and Fisker (2011) studied light preferences of participants in their own homes. The authors of this study concluded that important factors regarding the perception of lighting are light intensity or illuminance and location of the light source. Beute and De Kort (2013) concluded that people preferred conditions with more intense daylight over less intense daylight. Light intensity or illuminance can contribute to the day/night cycle of human beings (Bernhofer, Higgins, Daly, Burant and Hornick, 2013). However, high light intensity might cause discomfort because of for example glare (Veitch, 2005). Lastly, participants mentioned the location of the light source to be important because this could lead to unwanted reflectance's or trouble seeing in the dark (Stidsen et al., 2011). From this can be concluded that important factors regarding people's perception to light are light colour, brightness or luminance, light intensity or illuminance, and location of the light source.

The before mentioned concepts can be measured using technical measurements. Colour of lighting depends on the wavelengths. To measure colour, often the reflected colour is measured, which can be done using a reflectometer. This instrument takes measurements in the visible region of a given colour sample (Florin et al., 2010). Furthermore, brightness or luminance seemed of great importance.

This can be measured using a luminance meter (Choi et al., 2012). However, per person it differs in what way the eye adapts to the incoming light, which makes brightness a subjective concept (Beute & De Kort, 2013). This should be measured using questionnaires. Furthermore, many illuminance meters are available for measuring illuminance, of which two examples will be given. The first example is the study by Choi et al. (2012). They used two illuminance meters, one for measurements in interior environments, and another for measurements in exterior environments. These meters measured illuminance in lux. Subsequently, Joarder and Price (2013) also used illuminance meters to measure light intensity in a patient room. They used indoor data loggers which were placed on the wall behind the patient's bed. These data loggers provided 24-hour data on the light intensity measured in lux.

Light perception can also be measured using questionnaires. Boyce, Veitch, Newsham, Myer and Hunter (2003) used questionnaires to measure the experience of the patient regarding the influence of light intensity on visual and physical discomfort. The questionnaire on visual discomfort tested the effect of light intensity on eye discomfort. The questionnaire on physical discomfort measured the influence of light intensity on several physical symptoms, such as sore throat, sore back, and excessive mental fatigue. Participants had to rate the light intensity at which they felt discomfort for all factors separately, with the following answer possibilities: not at all, a little, moderately, very much, extremely. The last questionnaire used in this study was about lighting control. This questionnaire included five items about the perceived lighting control of the patient, which had to be rated on a five-point scale. An example of an item is as follows: "the lighting control system allowed me to create the lighting conditions I wanted" (Boyce et al., 2003, page 33). Lastly, Dianat, Sedghi, Bagherzade, Jafarabadi and Stedmon (2013) also used a questionnaire to determine the satisfaction with the lighting environment. The study had the aim to determine the satisfaction regarding the lighting environment of hospital staff. Therefore, the authors used a survey with questions on lighting which has been developed for the work environment but could be implemented in the hospital environment as well. An example of a survey question is as follows: "How satisfied are you with the lighting condition in your work environment?" Participants had to answer on a five-point scale from very low until very high (Dianat et al., 2013). The entire questionnaire is included in appendix 1.

3.5 Lighting in hospitals

Hospital lighting should be adjusted to meet two requirements: the staff should be able to execute their activities and the environment should be visually satisfying for patients (Alzubaidi & Soori, 2012). For every area in the hospital different recommendations are established, because in every area different activities are executed, and the lighting should be adjusted to the activities of the specific area (Alzubaidi & Soori, 2012).

Lighting in hospitals have been found not to be optimal for improving patients' well-being when they are in the hospital. Hospital lighting has been reported as extremely low (50-300 lux). Another factor regarding lighting in hospitals is the ability of nurses to adjust the lighting in patient rooms as to the preferences of the nurses, which may result in disadvantages for the patient. However, the nurse is also able to create a better healing environment for the patient by adjusting the light properly in the advantage of the patient (Bernhofer et al., 2013).

In a hospital it can be beneficial to use artificial lighting because nurses and doctors need proper lighting to be able to execute their activities independently of the natural light of the moment (Leccese et al., 2016). It is important that hospitals use artificial lighting sources with lighting colours as close as possible to natural light (Leccese et al., 2016). However, for patients artificial lighting may have negative consequences, especially when it is used at night. It may disturb patients' sleep pattern, which may have an impact on several health outcomes such as diabetes, heart disease and mood disorders (Cho et al., 2015). Another possible disadvantage of artificial lighting in a hospital room is that the lighting source only comes from one or a few points, which results in inadequate illuminance uniformity (Leccese et al., 2016).

4 Circadian rhythm, length of stay and pain levels

4.1 Introduction

In this chapter the concepts circadian rhythm, length of stay and pain levels are elaborated. Of all concepts a definition is given. Furthermore, the influence of lighting on the concepts is shortly mentioned, and possible consequences for the health of a hospital patient related to this are elaborated. Several hormones have an influence, especially regarding to circadian rhythm and pain levels, which are also elaborated. Lastly, possibilities of measurements of the concepts are given.

4.2 Circadian rhythm

Definition

The circadian rhythm is a biological rhythm of human beings, of which one cycle endures for approximately 24 hours. It is also called the sleep-wake rhythm, because it relates to the naturally occurring daylight-darkness cycle (Bernhofer et al., 2013). The endogenous clock of the human being is the time-keeping system in the body, which produces circadian rhythms even without external time cues. In this endogenous clock molecules are most important, because they repeatedly fluctuate every 24 hours and therefore specify time points. These time points are specified by concentrations of the molecules in the suprachiasmatic nucleus (SCN) in the hypothalamus (Toh, 2008). The main function of the SCN related to circadian rhythms is to adjust the endogenous rhythm to the external time signalling stimuli occurring at a specific point in time. These external time signalling stimuli are also called zeitgebers (Bjorvatn & Pallesen, 2009).

Disruptions in the circadian rhythm occur as a consequence of a misalignment between the endogenous clock and the external environment (Bjorvatn & Pallesen, 2009). The most important external factor influencing the circadian rhythm is light. The SCN is particularly sensitive to light and therefore lighting may cause disruptions in the synchronizing of light in the SCN, which causes disruptions in the circadian rhythm.

Importance

For hospital patients, a disruption in the circadian rhythm may have negative consequences. Consequences of disruptions in the circadian rhythm are mainly related to circadian rhythm sleep disorders (CRSD) (Toh, 2008). These sleep disorders are a consequence of a disrupted relationship between the internal clock of a person and the external day-night cycle. Several CRSDs exist, examples are advanced sleep phase disorder (ASPD), delayed sleep phase disorder (DSPD), free running disorder (FRD), and irregular sleep-wake rhythm (ISWR). Two other CRSDs are jet lag disorder and shift work disorder, but these are not included in this thesis because the cause of these disorders is voluntary and these disorders are not reflective of circadian clock dysfunction according to light. Of these CRSDs, the delayed sleep phase disorder is the most common with 83 percent of all CRSDs. After this, the irregular sleep-wake rhythm accounts for twelve percent of the total of CRSDs, and advanced sleep disorder and free running disorder are rarely diagnosed and therefore account for less than two percent of the total of CRSDs. The circadian sleep disorders all affect different population types. ASPD mainly affects elderly, while people with FRD are mostly blind and ISWR people are mostly mentally ill or demented. In healthy individuals circadian rhythm sleep disorders are rare (Toh, 2008).

Several other consequences related to a disruption in the circadian rhythm can be elaborated. The main complaints are related to the disturbed sleep-wake pattern, examples of these complaints are insomnia or excessive sleepiness. This may be related to an impairment in normal functioning and a lower quality of life (Bjorvatn & Pallesen, 2009). Bernhofer et al. (2013) mentions other consequences of a disturbed circadian rhythm, among which mood changes, depression, and pain. Because of these consequences of a disrupted circadian rhythm, it is important for hospital patients to remain their regular circadian rhythm. Disruptions will only lead to worse health outcomes, which may have negative impacts on the healing process of the patient.

Related hormones
Related to the functioning of the circadian rhythm is the hormone melatonin. As mentioned before, melatonin is the 'sleeping-hormone', which increases in the evening and causes sleepiness. In figure 2 the melatonin level during night time can be seen. This figure illustrates that the melatonin level increases after the onset of darkness, peaks around midnight, and the lowest levels of melatonin are at the end of the morning. Sleep normally occurs when the melatonin levels are high, and wakefulness is related to lower melatonin levels (Bjorvatn & Pallesen, 2009). The same figure illustrates the cortisol level, which peaks at wake time around eight o'clock in the morning, is high in the first hours of wakening, and decreases in the afternoon (Boivin & Boudreau, 2014). Cortisol is related to energy levels, which causes the ability of humans to be active during daytime.

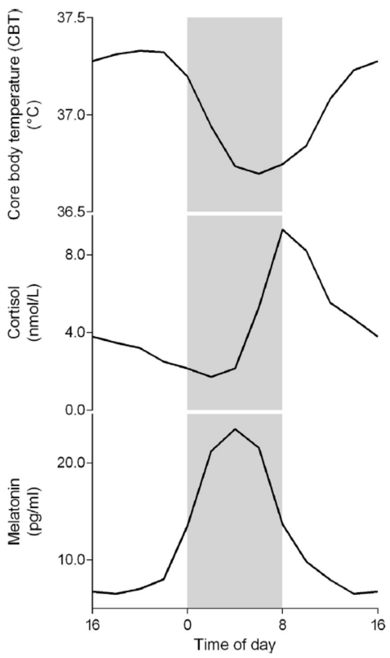

Figure 2: Rhythm of core body temperature, cortisol and melatonin secretion in humans illustrated relative to a nocturnal sleep period. Reprinted from "Impacts of shift work on sleep and circadian rhythms," by D.B. Boivin, 2014, *Pathologie Biologie, 62*, 292-301.

Measurements
Circadian rhythms can be measured in several ways. In the first way, two concepts are important, which are melatonin and core body temperature. Melatonin can be measured in saliva, urine, or blood. However, measurements of the circadian rhythm based on melatonin levels and body temperature are often expensive and difficult to conduct. Therefore, in busy clinical practices this method is not often used (Bjorvatn & Pallesen, 2009).

Another method for measurement is based on the patient history. Using this type of measurement, the sleep pattern of the patient related to their body temperature is examined. An important concept to take into account using this method is the nadir of the core body temperature, which is the lowest point of the body temperature. This normally occurs about two hours before sleep offset. Studies have shown that subjective sleep data from uninterrupted sleep, so without waking up with an alarm clock, are a reasonable good measurement for estimating the circadian phase (Bjorvatn & Pallesen, 2009).

Furthermore, studies have shown that the influence of light on the circadian rhythm follows a phase-response curve (Khalsa, Jewett, Cajochen & Czeisler, 2003; Bjorvatn & Pallesen, 2009). A phase-response curve shows the effect of the timing of lighting on the circadian rhythms. A circadian phase in this example is the nadir of the core body temperature. This theory suggests that there are two ways in which light can influence circadian rhythms: when light exposure occurs before the nadir of the body temperature, a phase delay will take place. This results in later bed- and wake times the following day.

When light exposure occurs after the nadir of the body temperature, a phase advance will take place, which results in earlier bed- and wake times the following day. Another finding of Bjorvatn and Pallesen (2009) was that the further away from the nadir the light exposure takes place, the less effect this has on the circadian rhythm. Furthermore, the higher the light duration and intensity, the greater the magnitude on phase shifts (Bjorvatn & Pallesen, 2009). From this can be concluded that the timing and intensity of lighting are important to recognize regarding circadian rhythms.

The last possibility of measuring the influence of lighting on the circadian rhythm is studying the experience of the patient. When studying the experience of the patient related to the circadian rhythm, mainly the sleep pattern is taken into account, because for patients this is an observable concept. An example is the study of De Rui et al. (2015), who measured the sleep pattern of the patients using the Pittsburg Sleep Quality Index. This is a questionnaire which patients should fill in themselves and measures the quality of sleep, with results ranging from 0 (good sleepers) to 5 (poor sleepers).

4.3 Length of stay

Definition

The length of stay in a hospital is defined as the duration of the stay of the patient in the hospital, from admission until discharge approved by the doctor (Joarder and Price, 2013). Another definition is the difference between admission to discharge, death or other residential institution, as has been given by Li et al. (2012). Length of stay can be differentiated into several types, for example pre-operative length of stay, operative length of stay and post-operative length of stay. In this thesis, the entire length of stay in the hospital will be taken into account, both pre-operative, operative and post-operative length of stay will be included, and also regular admission without surgery. The reason for this is that lighting might have different influences on all differentiations of length of stay.

Importance

The length of stay of a patient in a hospital is an indicator for hospital performance. A first example related to this is the mortality rate. Some studies suggest that the mortality rate is higher when the length of stay is longer (Awad, Bader-El-Den & McNicholas, 2017). However, current studies are divided over these results. Furthermore, hospital length of stay is considered to be a major indicator for the consumption of hospital resources (Awad et al., 2017). Using the information about the time patients are in need of a hospital bed, also called bed management, the allocation of the hospital resources can be improved. The need for personnel and facilities in the hospital can be based upon the average length of stay of patients in the hospital. From this can be concluded that knowing the average length of stay of the patient in the hospital is important for the planning and organization of the hospital. The last factor for which length of stay is an important indicator, is hospital costs. Cortoos et al. (2013) studied the influence of several indicators on the costs of the hospital, among which the length of stay. They concluded that length of stay had the highest influence on the hospital costs. With every extra day a patient had to stay in the hospital, the costs increased with 6.3 percent. From this can be concluded that length of stay is an important indicator regarding hospital costs.

Determinants

Length of stay is a very broad concept, with different determinants for every disease and for every hospital ward. In this paragraph, the main determinants will be assessed using literature about the length of stay in different diseases and hospital wards. Firstly, Wright et al. (2003) conducted a study about the length of stay in hospital patients with heart failure. They elaborated several determinants for length of stay, which are socio-demographic variables, medical comorbidity, disease severity, clinical presentation, in-patient treatment, in-hospital progress and the development of iatrogenic complications. They also mentioned inter-institutional variation and differences in patient insurance status as determinants for length of stay. In figure 3 a model is presented which illustrates factors that influence the length of hospital stay. The second block illustrates the earlier mentioned factors that influence the length of in-hospital stay. In block 1 the healthcare environment is mentioned to have an influence on the pre-admission care, so the factors influencing admission to the hospital. Part of the healthcare environment is lighting. Concluding, in this study the healthcare environment, among which lighting, has mainly an influence on the pre-admission to care (Wright et al., 2003).

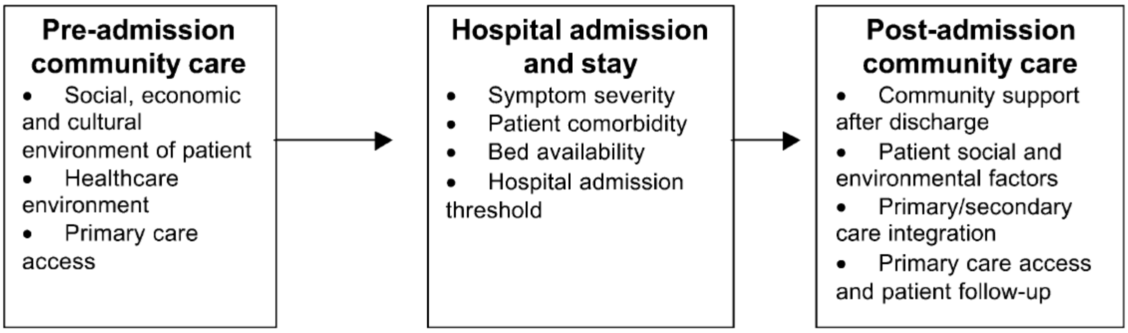

Figure 3: Factors influencing length of hospital stay. Reprinted from "Factors influencing the length of hospital stay of patients with heart failure," by S.P. Wright, *The European Journal of Heart Failure, 5,* 201-209.

Another study conducted by Weiss et al. (2012) studied the determinants of length of stay on patients with psychiatric conditions at the emergency department. The main determinants in this study were completely different from the earlier mentioned study of Wright et al. (2003). The main determinants of length of stay described by Weiss et al. (2012) were the presence of alcohol, use of toxicology screening and the use of restraints. All three determinants caused a longer length of stay on the emergency department. This study is a good example of the differences in determinants for length of stay within a hospital. Because every specific case with a different disease or condition needs different treatment, the determinants for length of stay will be different in every case.

Measurements

To measure length of stay of a patient in a hospital, data from hospital registrations can be used, as has been done by Li et al. (2012). In their study they used the hospitalization summary report (HSR) of the Beijing Municipal Health Bureau. They calculated the length of stay by subtracting admission date of the discharge date in terms of days. If the two dates were the same, the length of stay was set to one day. Further analyses of effects of diseases on length of stay will be different for every single type of disease, and therefore no general measurement can be elaborated on.

4.4 Pain levels of the patient

Definition

According to Bernhofer et al. (2013) pain is still a relevant problem related to hospitalized patients. Pain can be defined as “an unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage” (Merskey, as cited in Anand & Craig, 1996). Pain is an unpleasant experience for patients, and therefore it is necessary to reduce pain levels as much as possible. Studies on pain have been conducted regarding different diseases, which concluded a lack of attention on pain in adult medical inpatients. Mainly pain in post-surgical, cancer, or chronic diseases has been studied (Bernhofer et al., 2013).

When the association of lighting with pain of the patient is studied, often pain medication is taken into account. Pain medication is used to relieve patients from pain. An often-used type of pain medication is analgesic medication. The aim of using analgesic medication is to reduce pain of the patient. However, it also might have unwanted side-effects such as constipation, drowsiness, urinary problems, nausea and vomiting (Walch et al., 2005). Because of these side-effects, it would be beneficial to implement other ways to reduce pain in hospital patients. Furthermore, a reduction in use of medication may lead to lower costs for the hospital, which is beneficial for the hospital. Lastly, decreasing medication use may result in better quality of care and improved health outcomes for the patient (Malenbaum, Keefe, Williams, Ulrich & Somers, 2007).

Related hormones

A hormone related to pain is serotonin. Several studies recognize serotonin as a pain inhibitor, working in the central nerve system (Walch et al., 2005; Sommer, 2004). Serotonin is released from brainstem structures and has an analgesic action. Serotonin is transported both in the periphery of the body and to the central nerve system. Because it is transported by these two ways which are strictly divided by the blood-brain barrier, serotonin can exert various effects on pain signalling mechanisms in both these ways of transport. From this can be concluded that there is a relatively high amount of serotonin in the body, and that serotonin can reduce pain levels (Sommer, 2004).

Measurements

Pain medication use depends per type of disease. The study of Walch et al. (2005) measured the use of analgesic medication as the prescribed and administered use of analgesic medication as needed by the patient. This was measured in the amount of medication needed. Furthermore, the self-administered analgesic medication use of the patient was included, which the patient could control themselves. The amount of pain medication used each day was divided by 24 hours to know the average analgesic medication use per hour. Observed pain of the patient can be measured using questionnaires. Walch et al. (2005) used the McGill Pain Questionnaire, which measures the subjective pain of the patient. In this questionnaire, patients had to rate several aspects on the scale of none – mild – moderate – severe. Examples of the factors they had to rate are throbbing, aching, sickening, and cramping (Melzack, 1987).

Bernhofer et al. (2013) retrieved information on the patients' pain level from the participant's electronic medical record (EMR). The information they retrieved consisted of a self-reported pain intensity level, indicated on the Numerical Rating Scale of 0-10 with 0 being no pain and 10 being worst pain imaginable. Lastly, the medication use of the patient was included.

Hospital staff

Another way to take pain levels into account is the distribution of the pain medication by staff members. One task of hospital staff members, especially nurses, is to distribute the pain medication to patients. It is important that they provide the medication on time, the right medication and the right amount of medication (Booker & Roseman, 1995). The possibility of staff members making errors while distributing the medication exists, which may have several causes of which one is lighting, according to Booker and Roseman (1995). Medication errors include several factors, which are the following: medication given at the wrong time, to the wrong patient, in the wrong dose or the wrong medication given (Booker & Roseman, 1995). For patients the consequences of medication errors are severe, which makes medication errors an important factor to take into account when evaluating the health of the patient. The medication errors of nurses were collected in the nursing quality assurance data, which the study of Booker and Roseman (1995) used to gather their data.

5 Effects of lighting on the circadian rhythm, length of stay and pain levels

5.1 Introduction

In this chapter the third sub question will be taken into account: *What are the effects of lighting on the circadian rhythm, length of stay and pain levels on patients in a hospital?* Literature is used to provide elaboration on the effects of lighting on the three concepts. Every concept is elaborated in a separate paragraph, with sub paragraphs giving explanations on daylight and artificial light separately. Using this information, a conclusion on the effects of lighting on the three concepts is given in the discussion section.

5.2 Circadian rhythm

5.2.1 Introduction

In this paragraph the influence of both daylight and artificial light on the circadian rhythm of hospital patients is elaborated. Bernhofer et al. (2013) and Joseph (2006) state the importance of lighting on the circadian rhythm. According to Acosta, Leslie, and Figueiro (2017) daylight is the ideal light source for optimal working of the circadian rhythm, because daylight provides the right amount, spectrum, distribution, duration, and timing of light. Besides daylight, they also mention artificial light to be able to produce the same positive effects when adapted to these criteria. However, the possibility exists that the use of artificial light may cause a blur in the distinction between daylight and artificial light, which may have negative consequences for the circadian rhythm (Acosta et al., 2017).

5.2.2 Daylight

The influence of lighting on the circadian rhythm is already important at a young age because sunlight may imprint a human's circadian clock early in life. This results in possible vulnerability to disruption of the circadian rhythm later in life (Aguglia et al., 2017). Besides, colour temperature should also be adapted to age, as blue-enriched light might be harmful for children's eyes. Colour temperature should be limited in children's rooms and may be much higher in adult's rooms (Mashkov, Beloev, Gyoch and Pencheva, 2017).

Acosta et al. (2017) studied the characteristics of windows to optimize circadian stimulus in hospital patients. They found that the light intensity was only optimal for circadian stimulus close to the window, and that bigger windows were necessary to provide enough sunlight to optimize the patients' circadian rhythm. However, light intensity could also have negative side-effects when causing visual or thermal discomfort. Highly related to regulation of the circadian rhythm is the hormone melatonin, which has been studied by Zeitzer, Dijk, Kronauer, Brown and Czeisler (2000). In an experimental study on the influence of lighting on melatonin levels they found that high light illuminances almost completely suppressed melatonin levels. This was dependent on the dose, with higher doses resulting in more changes in the circadian phase. Zeitzer et al. (2000) studied the effects in healthy individuals, contrary to Perras, Meier and Dodt (2007) who studied the effects of light and darkness on patients at the ICU. The results of this study were also contrary to the results of the earlier mentioned study, because Perras et al. (2007) concluded that melatonin levels did not inhibit as a result of exposure to light. Besides, they also concluded that the melatonin levels of the patients were already disrupted, which may have been a consequence of an already shifted circadian rhythm as a result of hospital stay.

5.2.3 Artificial light

Several studies have been conducted on the influence of artificial lighting systems on the circadian rhythm of hospital patients. Engwall, Fridh, Bergbom and Lindahl (2015) studied the effects of an interventional lighting system, which had light sources around the room and which was automatically controlled by software round the clock. The aim of this system was to simulate natural light regarding localisation, brightness and colour. The authors concluded that this interventional lighting systems was perceived as more advantageous by patients compared to the ordinary lighting system. However, patients mentioned daylight to be still very important in knowing whether it was day or night, and that they got confused when artificial light was turned on at night. However, the patients also mentioned a positive effect of artificial light at night, which was a feeling of safety and comfort when being able to see the staff conducting their tasks. From this study can be concluded that artificial lighting in patient rooms optimally influences the circadian rhythm when patients are able to individually adjust the lighting system in the room, so in every room the lighting environment can meet the patients' individual requirements (Engwall et al., 2015). Artificial lighting may also have an influence on melatonin levels, as has been studied by De Rui et al. (2015). They stated that hospital patients may have delayed sleep-habits as a result of delayed melatonin levels. This may be the result of high exposure to evening- and night-time lighting, which suppresses melatonin levels. Therefore, De Rui et al. (2015) studied the effects of appropriately timed blue-rich light on the circadian rhythm of hospital patients with cirrhosis. They concluded that the interventional blue-enriched lighting system did not show significant results in improving the circadian rhythm, of which a possible reason is that the study population was very small (De Rui et al., 2015). Another hormone influencing the circadian rhythm is cortisol, which has been studied by Giménez et al. (2017). They stated that blue-enriched light in hospitals is limited, which leads to disrupted cortisol levels and therefore a disrupted circadian rhythm. In this study an interventional lighting system was compared to the standard lighting system in the hospital room, in 196 patients staying on the cardiology ward. Patients in the intervention room resulted to be significantly more satisfied with their lighting environment compared to patients in the control room. Furthermore, the total sleep duration of patients in the intervention room increased every day of hospitalization with 5.9 minutes. From this can be concluded that patients in the intervention room were significantly more satisfied and had a longer sleep duration compared to patients in the control room, which may be the result of proper lighting conditions influencing both melatonin and cortisol levels to optimally improve the circadian rhythm of hospital patients (Giménez et al., 2017). Lastly, the study of Mashkov et al. (2017) studied the effects of LED lighting on the circadian rhythm, from which they concluded that the spectral power distribution of LED lighting during the day can simulate the perception of natural daylight, which positively affects the natural circadian rhythm of patients. Furthermore, they stated that night lighting in a hospital should be in the orange – red region, because then no interference with the sleep pattern of the patient would occur (Mashkov et al., 2017).

5.2.4 Conclusion

From this paragraph can be concluded that daylight is important in maintaining the circadian rhythm because of the natural occurring daylight cycle that is associated to the natural occurring circadian rhythm. Blue-enriched light in the morning increases cortisol levels, while red-enriched light in the evening increases melatonin levels. This results in a regular sleep-wake rhythm which positively affects patients' health. Artificial light on the other hand may disturb circadian rhythms, mainly because of light exposure at night which negatively impacts melatonin levels. This may have negative consequences such as sleep disorders, depression or pain. However, properly adjusted artificial lighting systems which can be controlled individually in the patient room may have similar beneficial effects as daylight. Concluding, the advantages of natural daylight are greater compared to artificial light, but artificial lighting systems may be a valuable substitute when no daylight is available.

5.3 Length of stay

5.3.1 Introduction

Several studies have been conducted on the differences in length of stay of patients in rooms with different lighting environments (Choi et al., 2012; Benedetti, Colombo, Barbini, Campori & Smeraldi, 2001). These studies suggest that lighting might have a positive influence on the length of stay of the patient in the hospital. The advantages of lighting on the length of stay may differ between patients with different diseases (Choi et al., 2012).

Furthermore, the length of stay in a hospital can also influence the health outcomes of the patient. Giménez et al. (2017) mentioned that patients with a shorter length of stay in the hospital might have better health characteristics and are better able to respond to the intervention. Therefore, it is important for patients to stay as short as possible in the hospital because this leads to better health outcomes.

In this paragraph, studies are elaborated ranked on the year they were published. The reason for this is that the earlier published studies are the basis for many later conducted studies. Therefore, the studies by Beauchemin and Hays (1996) and Benedetti et al. (2001) are elaborated first, because many studies referred to these studies. At the end of the paragraph a table is shown including the main characteristics and results of the included studies.

5.3.2 Daylight

Beauchemin and Hays (1996) conducted the first study on the influence of sunlight on length of hospital stay, using a naturalistic observational study design. They found a significant shorter length of stay of 2.6 days in patients staying in bright rooms compared to patients staying in dimly lit rooms. Following on this study, Benedetti et al. (2001) replicated the structure of the naturalistic observation with the aim to compare length of stay of patients in eastern rooms and western rooms. Eastern rooms received sunlight in the morning and western rooms in the evening. Participants were patients with a unipolar or bipolar depression. The authors concluded no significant differences in patients with a unipolar depression, but in patients with a bipolar depression a significant shorter length of stay of 3.7 days in patients in eastern rooms was found. This difference was more present in summer and fall compared to winter and spring, because of higher light intensity during summertime (Benedetti et al., 2001). The study of Choi et al. (2012) compared lighting environments in rooms facing northwest and rooms facing southeast, with southeast rooms being brighter in the morning and around noon and northwest rooms being brighter in the afternoon. The authors concluded that the southeast rooms had a higher light intensity and longer light duration, and patients in these rooms had a significant shorter length of stay of 16-31 percent compared to patients in rooms facing northwest (Choi et al., 2012). Next to this study, Joarder and Price (2013) studied the influence of daylight on coronary artery bypass patients and found that the length of stay of the patient would decrease with 7.3 hours per an increase of 100 lux of daylight illuminance. Furthermore, Gbyl et al. (2016) studied the effect of natural light on the length of stay in hospital patients with a depression. Patient rooms were located either on the southeast or northwest side of the hospital, with southeast rooms having a higher sunlight intensity. The authors found a significant difference in length of stay of 29.6 days with patients having a shorter stay in southeast rooms which may be the result of the higher light intensity in these rooms. However, further causes for these significant differences cannot be stated according to the authors (Gbyl et al., 2016).

Contrary to the previous studies, the study of Verceles et al. (2013) did not show a significant difference between patients staying in bright rooms compared to dim rooms. The study included 3344 participants who were randomly assigned to rooms facing north, east, south or west, with the highest levels of light in rooms facing south. This study resulted in the shortest length of stay of patients in rooms facing east, which did not have the highest levels of light. Furthermore, no significant results were stated (Verceles et al., 2013).

5.3.4 Artificial light

Kopp et al. (2016), with an intervention study on the effectiveness of light therapy on characteristics of length of stay in a hospital for patients with cystic fibrosis, found that hospitalized patients had a mean length of stay of 11 days with the light intervention, compared to a mean length of stay of 13.3 days in the historical cohort. The authors concluded that light therapy is related to the length of stay of hospitalized patients, resulting in a significant shorter length of stay when exposed to light therapy (Kopp et al., 2016). The next study that resulted in a significant shorter length of stay using light therapy is the study of Vásquez-Ruiz et al. (2014). They studied the effect of a light/dark cycle intervention compared to traditional continuous lighting in preterm infants. The intervention group was exposed to lower levels of illuminance at night to provide a better light/dark contrast. This resulted in a significant earlier date of discharge of participants in the intervention group compared to the control group (Vásquez-Ruiz et al., 2014).

However, not all studies resulted in a significant shorter length of stay in the intervention group. Giménez et al. (2017) compared a standard lighting system to an interventional lighting system. They concluded that patients staying in standardly lit rooms had an average length of stay of 4.5 days, and patients in rooms with the interventional lighting system had an average length of stay of 5 days. However, the main focus of this study was not on length of stay and therefore this subject is not widely elaborated in this article (Giménez et al., 2017).

Table 3: Included studies regarding length of stay with the main characteristics

Article	**Study design**	**Light type**	**Study population**	**Length of stay (in days)**	**Significance**
Beauchemin & Hays (1996)	Naturalistic observation	Daylight	174 admissions	Dim: 19.5 Bright: 16.9	Significant difference of 2.6 days
Benedetti et al. (2001)	Naturalistic observation	Daylight	602 unipolar and bipolar depressed inpatients	Dim: 23.5 Bright: 19.8	Significant difference of 3.7 days
Choi et al. (2012)	Observational	Daylight	1167 patient data sets	Shorter in bright rooms with 16-31%	Significant shorter stay in bright rooms
Joarder & Price (2013)	Observational experiment	Daylight	263 patients	Increase of 100 lux, reduction of 7.3 hours	Significant reduction by increasing lux
Gbyl et al. (2016)	Preliminary study	Daylight	29 patients	Dim: 58.8 Bright: 29.2	Significant difference of 29.6 days
Verceles et al. (2013)	Observational study	Daylight	3344 patients	Dim: 13.3 Bright: 13.0	No significant difference
Kopp et al. (2016)	Observational study	Artificial light	30 hospitalized cystic fibrosis patients	Dim: 13.3 Bright: 11.0	Significant difference of 2.3 days
Vásquez-Ruiz et al. (2014)	Randomized interventional study	Artificial light	38 preterm infants	Control: 20-98 days till discharge Interventional: 11-63 days till discharge	Significant shorter stay in interventional group
Giménez et al. (2017)	Experimental study	Artificial light	196 cardiology patients	Standard: 4.5 Interventional: 5	No significant difference

5.3.4 Conclusion

From this paragraph can be concluded that especially daylight has a major influence on the length of stay of hospital patients. Almost all elaborated studies show significant results when comparing patient length of stay in a dimly lit room and a bright room. Hospital rooms on the east side of the hospital receive the highest levels of sunlight and patients staying in these bright rooms have a shorter length of stay of at least 2.6 days. A possible explanation for this effect is that natural daylight may positively influence the circadian rhythm, which leads to less side-effects or other health issues, which may result in a shorter length of stay. Regarding artificial lighting, interventional artificial lighting systems seem to reduce length of hospital stay because patients exposed to interventional lighting systems have a significant shorter length of stay in the hospital compared to patients exposed to standard lighting systems. However, the effects of daylight on the length of stay seem to be greater compared to the effects of artificial light.

5.4 Pain levels

5.4.1 Introduction

In this paragraph the influence of both daylight and artificial light on pain levels and pain medication distribution is elaborated. First, the influence of daylight is elaborated together with associated concepts, such as serotonin and vitamin D. Furthermore, the effects of seasonal differences on medication distribution of nurses are elaborated, because medication distribution is important for patients in a hospital. The second part of the paragraph explains the influence of artificial lighting on pain levels of patients, in which several artificial lighting systems are included.

5.4.2 Daylight

An important and much cited study on the influence of sunlight on pain medication is the study of Walch et al. (2005), who studied the influence of sunlight on the use of analgesic medication in 89 patients who had undergone spinal surgery. Patients stayed in either east or west rooms, with west rooms receiving more sunlight. They concluded that patients staying on the dim side of the hospital used 22 percent more analgesic medication compared to patients staying on the bright side. Furthermore, patient’s self-reported pain was measured and from this was concluded that patients staying on the bright side of the hospital reported a significant decrease in pain levels. Lastly, patients on the bright side of the hospital experienced a decrease of 21 percent of analgesic medication costs compared to the dim side, which is beneficial for the hospital (Walch et al., 2005). Thereafter, Bernhofer et al. (2013) studied the effects of daytime light intensity on pain levels in hospital patients. The authors concluded that the self-reported pain levels of the patients decreased during the study, but it was not clear whether this was a result of daylight. Furthermore, pain levels were highest at night time when no daylight was available, but this result was not significant (Bernhofer et al., 2013). Next to this study is the study of Verceles et al. (2013) who focused on the influence of sunlight on pain medication. This study also did not provide significant results between pain medication use in patients staying in either bright or dim rooms.

A hormone related to pain is serotonin, as has also been mentioned by Walch et al. (2005). Serotonin acts as an inhibitor of pain and would therefore lead to lower pain levels. Serotonin seems to mainly influence pain reduction in headaches (Sommer, 2004). Levels of serotonin have been found to increase related to light exposure, which has been studied by Tomaz de Magalhães, Núñez, Kato and Ribeiro (2016), who studied the influence of low-level laser therapy on serotonin levels and concluded that after three days of exposure serotonin levels had increased. Serotonin also has been found to be higher in summer months compared to winter months, because of higher intensity of daylight and a longer duration of daylight per day (Walch et al., 2005).

Furthermore, low levels of vitamin D may be related to high pain levels. Vitamin D is strongly associated with skeletal health, and deficiencies in vitamin D may lead to a reduction in a patient's calcium and phosphate levels. Low calcium levels are especially related to problems with bones such as decreased bone mineralization, which may cause osteoporosis which can be very painful (Lyman, 2005). Vitamin D deficiencies may also lead to other negative health consequences, such as muscle cramps, spasms and seizures (Lyman, 2005). Vitamin D production is highly related to sunshine. Sunlight has a wavelength of 290-315 nm, which can be named as ultraviolet light. This is absorbed by the skin, and in the skin vitamin D is produced (Wacker & Holick, 2013). The human body cannot produce vitamin D by itself, so vitamin D must be retrieved from sunlight or dietary intake. According to Lyman (2005) vitamin D deficiencies can be managed by increased exposure to the sun, but also by exposure to an ultraviolet lamp.

Lastly lighting may have an influence on pain medication distribution by nurses. Booker and Roseman (1995) studied the effect of seasonal variation on pain medication errors by nurses in Alaska, a location with extremes of light and darkness. Several factors were included in the definition of medication errors, of which examples are medication given at the wrong time, to the wrong patient, in the wrong dose or the wrong medication. The main finding of this study is that 58 percent of all medication errors occurred during the first quarter of the year, with the highest percentages in February (22%) and March (29%). Although there appears to be a seasonal pattern to medication errors, the relation between darkness and medication errors was not significant (Booker & Roseman, 1995). Furthermore, Graves, Symes, Cesario and Malecha (2015) studied the decision-making process of nurses related to the lighting environment in patient rooms. They found that nurses did not have a linear decision-making process and thus did not actively consider adapting the lighting environment to improve medication distribution. Some nurses mentioned the well-being of the patient to be important in their lighting decision with the aim to optimize comfort for the patient. However, this may result in lower lighting levels in the patient room at night, which may have negative consequences for the medication administration of the nurse and may result in medication errors (Graves et al., 2015).

5.4.3 Artificial light

Leichtfried et al. (2014) conducted a study on the effectiveness of bright light therapy and pain in 125 patients with chronic nonspecific back pain. The participants were divided over three groups: a control group, an intervention group receiving bright light therapy and a sham group receiving low light interventions. The authors concluded that patients in both intervention groups had lower self-reported pain levels compared to patients in the control group. This result was contradictory to the hypothesis of the authors, because this meant that not only light intensity was an important factor to take into account when reducing pain levels, other factors such as dose, frequency and timing may also contribute (Leichtfried et al., 2014). The study of Taylor et al. (2009) measured the influence of an UV lighting system on 19 patients with fibromyalgia syndrome, a chronic disease which may cause widespread musculoskeletal pain. From this study can be concluded that pain scores measured by the McGill Pain Questionnaire slightly reduced in the UV group compared to the non-UV group. However, these results were not significant. Therefore, it can be concluded that UV light has little effect on pain levels in patients with fibromyalgia syndrome (Taylor et al., 2009). Another method for reducing pain levels regarding artificial lighting is low-level laser therapy (LLLT). The effectiveness of LLLT is dependent on dose and wavelength of the light beam the patient is exposed to. Ruaro, Fréz, Ruaro and Nicolau (2014) studied the effects of LLLT on patients with fibromyalgia by dividing participants in a treatment and a control group. They concluded that the treatment group reported significant lower pain levels compared to the control group after exposure to the laser therapy. From this study can be concluded that LLLT has positive effects on reducing pain levels in fibromyalgia patients (Ruaro et al., 2014). Alghadir, Omar, Al-Askar, and Al-Muteri (2014) also conducted a study on the effectiveness of LLLT, including forty patients with chronic knee osteoarthritis who were divided over a placebo and a treatment group. The authors concluded a significant decrease in pain intensity in patients who were exposed to LLLT (Alghadir et al., 2014). Lastly, Montes-Molina, Martínez-Rodríguez, Rodríguez, Martínez-Ruiz and Prieto-Baquero (2012) conducted a study on the effect of diode light therapy on pain levels in patients with shoulder pain. From this study was concluded that this type of therapy was safe and resulted in lower pain levels in patients in the intervention group (Montes-Molina et al., 2012).

5.4.4 Conclusion

Several conclusions can be made regarding this paragraph on the influence of lighting on pain levels and pain medication. First, daylight seems to have a high impact on reducing pain levels. This may be related to the hormone serotonin, of which levels increase related to lighting and which has an inhibiting effect on pain levels. Furthermore, sunlight seems to be of great importance related to vitamin D. Low exposure to sunlight leads to vitamin D deficiency, which may cause problems with the bones which result in increased pain levels. Next to this, daylight is important related to medication errors made by nurses in the hospital. Most medication errors are made during the winter months in which daylight availability is low. Nurses seem to have poor knowledge on adjusting their lighting environments to improve medication distribution. Lastly, artificial lighting may have positive effects on pain levels of patients, although these effects seem to be smaller compared to the effects of daylight. Several artificial lighting systems can be applied in reducing pain levels, of which examples are bright light therapy, low-level laser therapy and diode light therapy. Pain levels decrease as a result of artificial light therapy, but only with small amounts. From this can be concluded that improving the natural lighting environment in hospital rooms is more efficient compared to the implementation of artificial lighting systems because natural light has more significant effects on the reduction of pain levels and the amount of pain medication.

6 Discussion and conclusion

6.1 Introduction

In this chapter an answer to the research question is provided. The research question is formulated as follows: *What are the differences in effects between daylight and artificial light on the circadian rhythm, length of stay and pain levels of patients in a hospital?* First the main conclusion is given, which is followed by a discussion regarding this conclusion. Furthermore, in the same paragraph the importance of this study is elaborated on. Lastly, limitations of this study are mentioned and recommendations for further research are given.

6.2 Main findings and conclusion

From this study it can be concluded that lighting has a major influence on the health of hospital patients. Daylight seems to be most beneficial compared to artificial light, because the natural daylight cycle is important in maintaining the circadian rhythm of hospital patients. The natural occurring daylight cycle provides blue-enriched light in the morning which is related to an increase of cortisol levels, and red-enriched light in the evening which is related to increased melatonin levels. Cortisol and melatonin are strongly related to the circadian rhythm and mainly regulate the sleep-wake rhythm. In hospital patients, the circadian rhythm may be disturbed because of a poorly adjusted lighting environment, especially when patients are exposed to high levels of artificial light at night. This may disturb the hormone levels which could lead to circadian misalignment. In case of circadian misalignment, side effects such as sleep disorders or depressions may occur. This is also related to the length of stay of a patient in the hospital, because more side-effects are related to a longer length of hospital stay. The length of stay is an important indicator for hospital quality, and therefore it is important for hospitals to reduce the length of stay of patients as much as possible. Studies have shown daylight to be very effective in reducing length of stay. Patients in bright hospital rooms which are mostly located on the east side of the hospital have a shorter length of stay of at least 2.6 days compared to patients staying in dim hospital rooms. Lastly, lighting has positive effects on pain levels and pain medication of hospital patients. Daylight is positively correlated to the hormone serotonin, a pain inhibitor. Sunlight exposure increases serotonin levels which results in decreased pain levels in hospital patients. Artificial lighting systems such as bright light therapy or low-level laser therapy also reduce pain levels, but results were less significant compared to daylight.

6.3 Main discussion

Therefore, to provide an optimal healing environment for patients in a hospital, the main focus should be on daylight when adapting the lighting environment in hospital rooms. Daylight will provide the greatest positive effects, which are circadian stimulus, reduced length of stay and reduced pain levels. However, artificial lighting should not be excluded because the health effects of the patient will be optimal when daylight and artificial light are used complementary, as also has been mentioned by Begemann et al. (1996) who studied lighting in the work environment. However, artificial lighting should be adapted to the environment and must meet certain requirements before implementation, which are the right light illumination, colour rendering, and absence of glare and flickering. This is supported by the study of Mehrotra, Basukala and Devarakonda, 2015. However, not all studies coincide with the results of this study. The study of Arendt (2012) focused on the effectiveness of lighting therapies on people in Polar Regions, in which she concluded artificial lighting therapies to be very important in maintaining people's circadian rhythms because of lack of natural occurring daylight or sunlight. However, this study took place in Polar Regions in which not much daylight was available, which results in artificial lighting therapy to be the best solution (Arendt, 2012). Furthermore, no current studies could be included that contradict to the results of this study, because not many articles are available on the comparison of daylight and artificial light, as has also been mentioned by Pachito et al. (2018).

The results of this study may be of great importance for hospital managers. From this study is concluded that lighting has positive effects on three health related concepts – circadian rhythm, length of stay and pain levels – which seem to be related to the quality of care delivered by the hospital and costs of care for the hospital. Reducing side-effects such as sleep disorders and reducing length of stay of a patient in the hospital may result in better quality of delivered care of the hospital. Besides, a shorter hospital stay of patients will result in lower costs per hospital patient. Therefore, hospital buildings should be adjusted to provide optimal lighting environments for patients. Patient rooms should be located with the windows on the southeast side of the hospital, where sunlight can be received in the morning and early-afternoon. Use of daylight instead of artificial light resulted to be energy efficient, as has been supported by Chen et al. (2014). Therefore, energy efficiency of the lighting systems in the hospital will lower the costs for the hospital. However, interventional artificial lighting systems that are controlled by software round the clock positively influence circadian rhythms by providing the right amount of light and light colour at the right time. Therefore, this system should be considered for implementation in patient rooms. Lastly, patients should be able to individually adjust the artificial lighting in their rooms to avoid negative health effects as a consequence of light exposure at night.

6.4 Limitations and further research

A few limitations can be mentioned regarding this study. First, this study focused on hospital patients, but the illness of the patients differed per consulted study. The literature regarding daylight and length of stay included mainly patients with a depression, which makes it hard to generalize the findings to other patient groups. To be able to generalize to a broader group, the illness of the patients should be taken into account. Second, not many articles studied the effects of artificial lighting on the three concepts included in this study. This resulted in a broader view of artificial lighting including concepts as bright light therapy and interventional lighting systems. The inclusion of different lighting systems made it difficult to compare the effects of these lighting systems to each other. This is also related to the difficulties concluding on the effectiveness of artificial lighting. To overcome this, the focus of further research should be on one lighting system which should be determined in advance. A last limitation is that only lighting regarding patients is considered. Lighting may also have a major influence on hospital staff, for example related to pain medication distribution. Therefore, the influence of lighting on hospital staff may also have an influence on the patient. In further research not only the influence of lighting on the patient should be included, but the influence of lighting on hospital staff should also be taken into account.

Further research should focus on a direct comparison between daylight and artificial light, using the same characteristics for both categories. Therefore, the preferred study population should consist of patients with the same illness or condition. Furthermore, regarding artificial lighting only one system should be determined and included in a single study. When conducting such a study, a direct comparison can be made. Lastly, besides only focussing on patients, the influence of lighting on hospital staff should be taken into account to include all factors that may have an influence on the health of hospital patients.

7 References

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Appendix

Lighting survey questions. Reprinted from "Objective and subjective assessments of lighting in a hospital setting: implications for health, safety and performance," by L. Dianat, *Ergonomics, 56*(10), 1535-1545.

Section 1: Demographic and job details.
1. Your age (years): ———
2. Your gender: ———
3. Your education: ———
4. Your department/job category: ———
5. Your job experience (years): ———
6. Your daily working hours: ———

Section 2: Lighting conditions. Please circle your answer.

Perception of the light level

7. How is the light level in your workstation?
   1. Very low 2. Low 3. Moderate 4. High 5. Very high

Satisfaction with lighting

8. How satisfied are you with the lighting condition in your work environment?
   1. Very low 2. Low 3. Moderate 4. High 5. Very high
9. How satisfied are you with the light level in your workstation?
   1. Very low 2. Low 3. Moderate 4. High 5. Very high

Effects on job performance

10. How the low light level in your workstation affects your job performance?
    1. Very low 2. Low 3. Moderate 4. High 5. Very high
11. How the lighting disturbances (e.g. flickering lights, glare and unwanted shadows) affect your job performance?
    1. Very low 2. Low 3. Moderate 4. High 5. Very high

Effects on safety

12. How the light levels in your working environment can cause falls or slips?
    1. Very low 2. Low 3. Moderate 4. High 5. Very high
13. How the lighting disturbances in your work environment can cause falls or slips?
    1. Very low 2. Low 3. Moderate 4. High 5. Very high

Health effects

14. How the low light level in your workstation can cause eye tiredness?
    1. Very low 2. Low 3. Moderate 4. High 5. Very high
15. How the lighting disturbances in your work environment can cause eye tiredness?
    1. Very low 2. Low 3. Moderate 4. High 5. Very high
16. How do you need to change your posture for better viewing of the objects or working items due to low light levels?
    1. Very low 2. Low 3. Moderate 4. High 5. Very high
17. How do you need to change your posture for better viewing of the objects or working items due to lighting disturbances?
    1. Very low 2. Low 3. Moderate 4. High 5. Very high

Section 3: Improvement of lighting. Please circle your answer.

18. Provision of additional artificial light sources improves lighting in your work environment.
    1. Very low 2. Low 3. Moderate 4. High 5. Very high
19. Provision of additional windows/natural lighting improves lighting in your work environment.
    1. Very low 2. Low 3. Moderate 4. High 5. Very high
20. More appropriate maintenance or installation of lighting fixtures improves lighting in your work environment.
    1. Very low 2. Low 3. Moderate 4. High 5. Very high
21. More appropriate combination of natural and artificial lighting improves lighting in your work environment.
    1. Very low 2. Low 3. Moderate 4. High 5. Very high
22. More appropriate combination of light colours improves lighting in your work environment.
    1. Very low 2. Low 3. Moderate 4. High 5. Very high
23. Do you have any other suggestions for improving lighting in your work environment?