Lux and Vision

- Do humans differentiate between light-levels when unable to compare them directly?

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Abstract

The aim of the study is to evaluate how humans experience two different light levels. The aim is also to evaluate their visual performance in those light levels. This is done in conditions where participants are not able to directly compare the lighting scenarios.

The hypothesis is that lower light levels may be found more comfortable when no direct comparison can be made with other lighting. At a lighting conference in 2001, architect Kristin Bredal talked about that if we were able to lower all urban lighting by 30% no one would notice, as the contrasts would stay constant. In this study an experiment with two different light levels was performed in an office environment, to see if a similar effect could be achieved.

One aim of the study is investigating whether people can tell the difference between two different light levels where photopic vision is fully active, when their eyes are adapted to darkness in between the scenes.

A further aim is to evaluate how human visual performance and comfort level is affected by the change in light level. And if higher light levels are really preferred by most people, as claimed in many current lighting experiments.

During the study an experiment with 28 participants was performed. The participants completed visual acuity tests and evaluated their experience of the scenes in two different light levels with a period of adaptation to darkness before each test in order to reset the visual system.

The results showed support for the initial hypothesis, with a light level that is normally seen as far too low today being accepted as more comfortable than the average possible answer.

It was further seen that the period of adaptation to darkness used during the experiments was not enough to make participants completely unaware of the difference in light level. It was however seen that many participants seemed to not have consciously detected the difference in light level until they were specifically asked about it.

No difference in visual acuity was found between the two light levels tested. The brighter lighting scene was rated higher on visual comfort parameters by slightly more participants than the one with a lower lighting level. It is unknown whether those results may have been affected by the fact that most participants became aware of the difference in light level once asked about it.

Differences were seen between the type of results obtained in this study and previous studies where participants were able to directly compare different light levels. It is therefore suggested that efforts should be made to separate effects of light level from the effects of participants expectations on how they will be affected by the light level in further studies.

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1 Introduction

In Sweden, the standard SS-EN 12464-1 describes minimum requirements for indoor lighting. The norm for general work areas in offices is 500 lux[1]. This level has been constant since 1962[2], before which lighting recommendations suggested 60 - 150 lux[3].

Today we know that contrasts have a bigger impact on our visual abilities than the actual light level, as our eyes adapt to the highest light level in our visual field. However, the adaptation is considerably slower moving from a higher light level to a lower, than the opposite.

Many previous lighting experiments investigating preferred light levels have allowed participants to vary the light level themselves until settling for the level considered most comfortable. This procedure may affect people to choose the highest light level possible before disturbing glare occurs, partly because of our eyes inability to instantly adapt to a lowered levels of light as to a higher ones, and partly due to the widespread belief today that we always see better the more light we have.

This paper investigates how visual acuity and subjective evaluation of a scene varies with different light levels, when the participants eyes are allowed to adapt to a very low level of light in between tests.
The work has been performed as a Master Thesis on Lighting Design and Health, covering 30 hp, at the Royal Institute of Technology in Stockholm, Sweden.

1 Svensson, 2010, pg. 149
2 Ljuskultur, 1965, pg. 129
3 Ljuskulturs månadsblad, 1929 ; Ljuskulturs månadsblad, 1940

1.1 Aim of the Thesis

The aim of the thesis is to investigate whether people can tell the difference between two different light levels where photopic vision is fully active, when unable to compare them directly.

Further, it aims at evaluating how human visual performance and comfort level is affected by the change in light level. And if higher light levels are really preferred by most people, when their eyes are properly adapted and they are unaware of the difference in light level. The hypothesis is that lower light levels may be found more comfortable when no direct comparison can be made with other lighting, than otherwise.

1.2 Research Questions

- Can humans tell the difference between two distinctly different light levels when no direct comparison between the scenes can be made?

- Is the performance of human vision enhanced by a higher light level than 150 lux, all other factors being constant, when the eyes are properly adapted?

- Is a light level of 500 lux generally preferred over one of 150 lux by humans, once their eyes have been properly adapted to each light level and no direct comparison between the two light levels can be made?

1.3 Disposition

The thesis begins with a chapter on its background conditions, describing how light has been used historically in Sweden, the physiological properties of our vision, and how those relate to the light levels we have today.

Next, the methodology chapter describes how the experiment was designed and carried out.

The results chapter presents results found from the experiments, those are later discussed and commented on in the discussion and conclusion chapters.

1.4 Boundaries

The thesis focuses on investigating the difference of human perception and performance in two specific light levels, no guidelines of appropriate light levels for different tasks will be given.

The thesis focuses solely on the impact of the light level, color temperature and light distribution are kept constant in order to avoid unwanted influence from those factors. It is not investigated in this experiment whether the light distribution or/and color temperature are the most appropriate for the task.

1.5 Explanation of terms

Cones

One of two types of visual receptors in the human eye. There are three types of cones that register red, green and blue light respectively.

Fovea

A part of the eye located in the centre of the retina in the human eye, which contains densely placed cone receptors and is responsible for detail vision.

Illuminance

The amount of light that hits a specified surface, measured in lux.

Landholt Ring

The Landholt ring is a standardized optotype used in visual acuity and visual speed tests. It is also the reference optotype to which other visual acuity tests are calibrated.

Lumen (lm)

Measurement unit for the total amount of light emitted from a light source.

Lux

The measurement unit for illuminance, measuring lumen / m^2.

Lux meter / Light meter

A device that is used to measure the amount of light which falls on a specific spot of a surface.

Mesopic Vision

Mesopic vision is a combination of photopic vision and scotopic vision in light levels between 0,1 and 3 lux.

Optotype

An optotype is a standardized symbol for testing vision.

Photopic Vision

The vision of the eye in light levels above 3 lux. In photopic vision the cone cells of the eye are used. They allow color perception as well as a significantly higher visual acuity than that available in scotopic vision.

Retina

A layer of tissue lining the inner surface of the human eye, which contains our visual receptors.

Rods

One of two types of visual receptors in the human eye, that are active in low light levels and registers information in black and white.

Scotopic Vision

The vision of the eye in light levels below 0,1 lux. In scotopic vision only rod cells are used to perceive light, everything is thus perceived in black and white.

2 Theoretical Background

Ever since we learnt to control fire, we have vitalized lighting in order to enhance our ability to perform visual tasks in different environments. With artificial light the working day could be extended into the evening, and tasks requiring precise detail vision could be performed where natural light was insufficient. Increased lighting became seen as the equivalent of increased visual performance, and this notion has seldom been questioned.

In 1929 a study that was published in Ljuskulturs månadsblad, the precursor of the magazine Ljuskultur, showed that human visual performance increases as the light level is raised until 150 lux, and becomes constant after that[4].

In the 1960ies, it was considered that visual performance was increased at least until the light reaches a level of 2000 lux[5]. Those findings were published in a separate handbook on good lighting, by the by then established magazine Ljuskultur. The standard of 500 lux for office work environments was set in 1962[6]. According to Magnus Frantzell, current publisher at Ljuskultur, it was likely decided on as a compromise between preferred light levels in studies on vision and the light levels that could economically be achieved at the time. This fact is also supported by researcher Lars Starby in his book on lighting, where he writes that humans tend to choose light levels between 1000 and 3000 lux in experiments but that lighting is usually kept at not quite that high levels due to economical reasons[7].

During the last few decades, increasing attention has been given to the effects lighting has on our circadian, and other biological systems. We have also become more aware of that contrasts play a more important role for our visual performance than the actual light level, as our eyes adapt to the brightest point in view[8]. Simultaneously new LED light sources that can provide more light while using less energy than previous technologies, have been developed. We are approaching a point where we will be able to economically provide the 2000 lux suggested as superior for vision[9], as well as easily vary the light level around us. So the question becomes whether generally increased lighting is a development we want to see, or if lower and possibly more varied light levels can provide solutions that enhance as well our visual performance as our biological functions.

2.1 A short History of Lighting in Sweden

In the beginning on the 18th century, there were no street lights in Stockholm[10], and lighting inside consisted of candles and simple oil lamps until the 1860ies[11]. The first street lighting consisted of gas lanterns, 97 of which were put in public places around Stockholm in the autumn of 1749[12].

4 Ljuskulturs måndasblad, 1929
5 Ljuskultur, 1964a
6 Ljuskultur, 1965
7 Starby, 2006a, pg. 264
8 Ejhed, 2011
9 Ljuskultur, 1964a; Ljuskultur, 1964b
10 Garnert, 1997, pg. 10
11 ibid., pg. 11
12 Garnert, 1998, pg. 12

Electrical lighting indoor became common around the 1910s, as by then several power plants which sold electricity had been established[13]. In the 1920ies electric lighting became common also around the streets[14].

Incandescent bulbs of many different types were common in the 1930ies, but started being replaced by less energy consuming discharge lamps during the 1940ies. Fluorescent tubes became common around the 1950ies and became more energy efficient as development continued into the 1960ies. A new table of recommended light levels was adopted in 1962. Among other it described 500 lux as the minimum level for office environments, and caused a lively debate as researcher Lars Starby describes in his book on the history of lighting.[15] Many claimed that the suggested lux levels were uncomfortably high, but those complaints were dismissed as depending on glare rather than light level as humans are able to read in bright sunlight with light levels of above 100 000 lux[16].

Further lighting recommendations were issued in the 1970ies, those differentiated between general lighting and task lighting and introduced the 1 - 3 -10 rule for office work environments[17]. It was states that the light level in the task area (x) should be surrounded by lighting with a third of its strength (x/3) in the immediate vicinity of the task area and that the surrounding light should be at the strength of ten percent (x/10) of that in the task area. The recommended light level of 500 lux was however kept constant.

13 Garnert, 1997, pg. 38
14 Garnert, 1998, pg. 52
15 Starby, 2006b, pg. 8 - 33
16 Ljuskultur, 1964a
17 Straby, 2006b, pg. 37

Compact fluorescent lamps were introduced in the 1980ies and LEDs started to enter the lamp market in the 1990ies. During the beginning of the 21st century we have seen a fast development in lighting technology that is continuing towards more energy efficient lighting.

2.2 Human Perception of Light

“[V]ision is the most developed sense in man and much of our knowledge of the external world comes through it”[18] can be read on the first page of neurobiologist Semir Zekis book on the architecture of our cerebral cortex.

We get information about the world around us through visual receptors in the retina, a light-sensitive layer of tissue lining the inner surface of our eyes. The receptors register radiation and send signals on to the brain that enables us to understand what it is we are seeing. The visible spectrum consists of radiation with wavelengths between 400 and 700 nanometers[19], as can be seen in figure 2.1.

The eye contains two types of visual receptors, rods and cones. There are three different types of cones, that perceive red, green and blue respectively. The eye is most sensitive to green light in the middle wavelengths of the visible spectrum. For this reason, lights with a lot of green and yellow wavelengths produce a stronger sensory response than red or blue. Whether there is any advantage to visual response being dependent on wavelength is a question that still remains

18 Zeki, 1993, pg. 1
19 Svensson, 2010, pg. 10

unanswered, as the Harvard professor of neurobiology Margaret Livingstone wrote in her book on the biology of seeing in 2002[20].

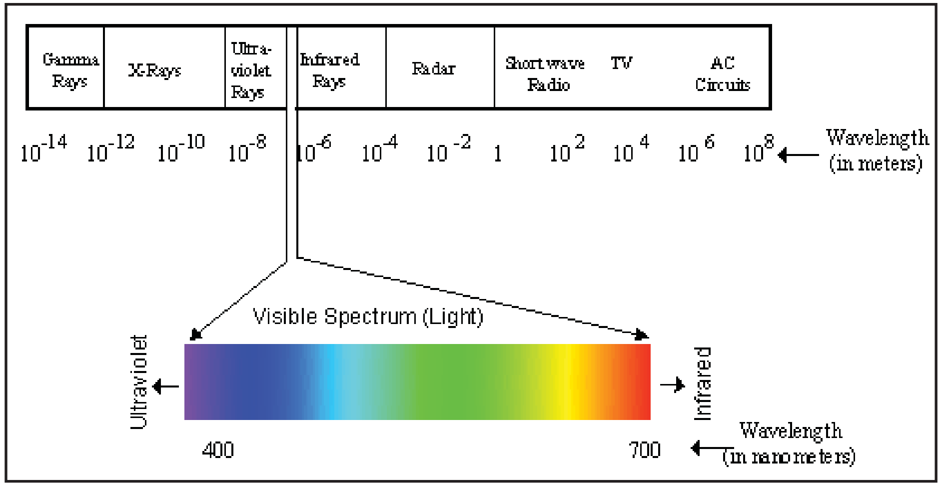

fig. 2.1, The Visible Spectrum of Radiation.

The cones are also responsible for our detail vision with which we can decipher small details and are concentrated around the fovea, also called the yellow spot, a small part of the retina of each eye. Our detail vision stretches over a visual angle of only 2º in the middle of our visual field while the surround vision lets us see in an angle of 170º[21]. The surround vision is provided by cones that are spaced all around the retina, but at a much lower concentration than within the fovea. While we can not see details with our surround vision, it is vital for our understanding of space.

The rods perceive only differences in brightness and are able to provide information in far lower illuminances than the cones, for this reason we see in black and white at night. The rods sensitivity curve is different from that of the cones, and they are most sensitive to blue light.

Our photopic vision is fully active from levels of above about 3 lux[22], below that our ability to see colors and details decreases as the cones become less active. Scotopic vision occurs at levels below 0.1 lux, then only rod receptors receive visual signals and we see completely in black and white without the ability to notice detail. Between 0.1 and 3 lux we use the so called mesopic vision, which is a state when the cones are still receiving signals but too weakly to be considered photopic vision.

2.3 Seeing Contrasts

Our eyes adapt to the brightest point currently in view, and contrasts are therefore more important for our vision than the actual light level[23], as lighting theory professor Jan Ejhed described in lecture series at KTH during the autumn of 2011. Neurology professor Colin Blakemore develops this notion in his book on Vision from 1996. He writes that while the ability to function in a wide variety of visual conditions is an important purpose of light adaptation, a probably

20 Livingstone, 2002. pg. 40
21 Liljefors, 1996, pg. 10
22 Ejhed, 2011
23 ibid.

equally important one is:

> to provide a signal in the visual pathway which is more-or-less independent of the ambient lighting level, which represents the *contrast* in the visual image. Most of the visual scenes which we normally encounter involve *reflecting* objects, and in a reflected scene the contrast is independent of the mean level of illumination. Extraction of contrast information means that, for scenes comprising reflective objects, the signals sent from the retina to the brain are invariant with the ambient level of illumination. In this way the brain is presented primarily with information about the scene, rather than with information about the light level.[24]

With this knowledge, and that of photopic versus scotopic vision described in the last sub-chapter, one could believe that human vision would work equally well in any light level between 3 lux and the maximum level of light that our eyes are able to adapt to. As most people can tell from experience, this is not completely true, suggesting that there are also other, more complex factors in play. Blakemore writes that the reason to that our ability of seeing textures and details increases in high light levels could be due to any number of factors. One factor that he goes on to examine further is “that the improvement in vision occurs because light adaptation changes the spatial organization of the retina”, and regarding to the effect he states that “That some such change occurs is well documented physiologically”[25].

24 Blakemore, 1991, pg. 161
25 Blakemore, 1991, pg. 169

While some processes affecting our visual performance during different lighting conditions are know, like the change in spatial organisation of the retina mentioned above, there are more than likely others which are currently not. What is more, even when it comes to the well documented processes, what is referred to as “high light levels” is not specified in exact numbers.

In the absence of distinct values for light levels in between which our vision is at its best, current lighting recommendations are based on experimental data of human performance during and preference for such. As the aim of the lighting recommendations is to create lighting suitable for humans, basing them on studies of human perception of light seems to me as well logical as desirable. What does not make sense to me is how such studies, made under scientifically validated conditions, can obtain very distant results only 30 years apart.

When discussing negative effects of light today it is commonly mentioned that our brains have not changed significantly since we lived in caves, and therefore are not perfectly suited for the environment we expose them to today. Following this logic, it would be safe to claim that no changes major enough to tenfold our visions need of light occurred between 1929 and the 1960ies. Those just happen to be years when major studies on human performance in different light levels were published.

Returning to the norm of 500 lux established in the 60ies, it was based on what was seen to be acceptably much light in offices evenly illuminated by general lighting created by fluorescent tubes in the ceiling.

It was however long before that well known to lighting designers that an even illumination throughout the room is far from well suited for office work. Back in 1907 electrical engineer Charles P. Steinmetz did not only talk about how and why our eyes adapt when lighting is changed, but also how this effects what lighting is suitable in different conditions. He talked about that an even, general illumination should be aimed at when it comes to street lighting while rooms in a home benefit more from concentrated light, and also wrote that:

> Most cases, however, require a general illumination of moderate intensity, and a far more intense local illumination, as over desks in an office, or the reading tables in a library. In such cases merely a general illumination would be sufficient if very intense, but this is uneconomical and to some extent objectionable on account of the blinding glare, which is disagreeable. Therefore a combined general and local illumination is more efficient and more satisfactory.[26]

So in order to provide comfortable lighting for office environments a lower general illumination with stronger task lighting should be used, as per Steinmetz statement. As the 500 lux required in offices today is normally calculated as the average illuminance within the room, this would require the illuminance in the working area to be substantially higher than 500 lux when following the 1-3-10 rule. What is more, task lighting is today most often excluded from lighting calculations in offices. If an even, general, illumination of 500 lux is used, the task lighting would need to raise the light level at the task area to 5000 lux in order to follow the 1-3-10 rule. In practice task lighting is offices is still rare, and while it is seen as unacceptable to design an office that does not reach the requirements of 500 lux as the mean level of light, the provenly more important issue of contrast rendition is often ignored by the use of only general illumination.

2.4 Light and Darkness Adaptation

Although we are able to tell the difference between extremely different lighting conditions like day and night, people are usually unaware of their eyes constant adaptation. As one example, it is a tedious task to convince most people that the average light level outside is actually higher on a overcast day with thin clouds than on a sunny one.

Light /Darkness adaptation consist of three distinct functions, pupil size, switchover between rods and cones and bleaching/reconstitution of the photopigment rhodopsin, also called "visual purple", in the rods. Visual purple is a chemical that gets bleached when exposed to strong light. While bleaching happens almost instantly it can take up to 40 minutes for the chemical to regenerate once back in darkness[27], leaving our vision temporary impaired.

So why do our eyes adapt quicker to light than to darkness? An answer to this question has been sought without much success. An endless amount of sources that describe the processes which control our eye adaptation can be found, and the procedure has been described shortly in the last paragraph. However, no explanation to why our eyes developed in this way is given.

A reason for this discrepancy might be that our eyes adaptation

26 Steinmetz, 1907, pg. 20

27 Blakemore, 1991, pg. 161

was not actually developed for the best possible vision. Already back in 1907 the electrical engineer Charles Steinmetz wrote about that eyes reduce their sensitivity in order to protect themselves against radiation rather than the physiological effect of impaired vision. As the energy of radiation is strongest in short waves, the effect is stronger when exposed to light with a big portion of blue wavelengths.[28]

Once the eyes have had time to adapt properly to a lower light level, the scene is experienced significantly different from what it did at first sight. In a paper on Assessment of brightness, based on his presentation at the 50th anniversary of the Illuminating Engineering Society in 1956, R. G Hopkinson described his first experiences with a photometer as follows;

> The brightness of a road sign on a lighted street at night, might measure ten foot-lamberts, and yet seem to me to be “as bright as day” ; even though I knew that the daylight sky was at least one hundred times as bright.[29]

28 Steinmetz, 1907, pg. 22
29 Hopkinson, 1957, pg. 211

2.5 Lighting for Vision

We need lighting that enables us to perform the task at hand, to feel comfortable while doing so, and to be able to continue on with the task for a desired amount of time without excessive tiering. When we get tired by visual tasks, this depends on tiering of our eye muscles and the parts of the brain that interpret the visual stimuli. Our visual organs themselves, the rods and cones, are believed to be tireless.[30]

The ability to detect the details needed, the feeling of being comfortable in a space and the rate of tiering of the brains and eye muscles are all connected, and partly dependant on the lighting conditions. Dependant on the research method used, the different aspects can be studied independently or as a combined evaluation.

In 1979, John Flynn was the first author of a paper on measurement of subjective light impressions. In the introduction of the study, aspects of human behaviour that might be influenced by spatial illumination are divided into two types: “(1) the effect of light on subject impression and attitude; and (2) the effect of light on performance and overt behaviour.”[31] While the effect on performance and behaviour may be studied without the subjects direct understanding of what is being tested, the results of studies on impression and attitude will always be influenced by the questions asked, a possible problem that I will return to in sub-chapter 2.8.

The state of the art in lighting research today suggests that contrasts play the biggest part in enhancing our vision. Also considered is that

30 Ljuskultur, 1964b
31 Flynn, 1979, pg. 95

generally preferred light levels for office work are between 1000 and 3000 lux, and that the reason for the use of lower light levels (minimum 500 lux) is that higher ones would not be practical for economic reasons[32].

There are however a few recent studies that have obtained results which point toward humans not always preferring the highest illuminance possible. A good example of such a study was published in 2010 by Annika Kronqvist, a PhD student in the field of Lighting Science. In the study she compared performance, well-being and alertness in three different experiment rooms. Two of the rooms were illuminated only by electric light in different configurations and had a table top illuminance of 670 lux and 433 lux respectively. The third room was illuminated solely by daylight with a table top illuminance of 151 lux. In the study it was concluded that spectral composition of light was the most alerting factor, and suggested that complex lighting scenarios should be used in order to:

> create an environment which will sustain performance as well as improve well-being and comfort, suggesting a turn in strategy in office lighting, where the illuminance is down-played by variety and spectral composition of the lighting.[33]

32 Starby, 2006a, pg. 264
33 Kronqvist, 2010, pg. 215

2.6 Non-visual effects of Lighting

It is well known that we need light to feel well, even to function at all as human beings. Most researchers today agree on that we need a certain amount of daylight every day in order to stay healthy, but there is no universally accepted multitude of that amount.

In an article on lighting and color in office environments architect and associate professor at Lunds University Jan Janssens writes that many gaps exist in the knowledge we have on the overall psychological effects of lighting and color. He further mentions that even less is known about the interaction between how light and color affect us and claims that many myths and misconceptions abound among as well the general public as light and color professionals.[34]

This could be part of the explanation to a contradiction that has been puzzling me since I first heard of the effects of blue light on human alertness and the circadian system.

The discussion of blue light started back in 2002 when researchers found a new type of receptor in the human eye. This non-visual receptor is normally refereed to as “the third receptor” and reacts only to blue light. More specifically it is sensitive to wavelengths around 460 nm, as Dieter Lang, speaker at the Professional Lighting Design Convention 2011, wrote in the convention proceedings[35]. Those third receptors have been found to affect our circadian system, and light with a high content of blue wavelengths has been shown to be more efficient at suppressing melatonin than other lighting. It thus has a

34 Janssens, 2006, pg. 197
35 Lang, 2011, pg. 192

stronger alerting effect on humans. Lang discusses the positive and negative effects of using blue enhanced lighting in his text. By adding blue wavelengths it is possible to "double the biologically effective proportions of light" in lamps without significantly increasing energy consumption. This effect can be used to enhance our alertness, but may cause problems if used inconsistently with the needs of our circadian system. The first thought that came to my mind after having learnt this information was that it should be possible to implement in computer screens, to provide an alerting effect during the day and reduce the negative effects of the light exposure in the late evenings.

The second thought that came to my mind was that my bedroom had just been painted blue. Color psychology was already well known to me at the time, the most mentioned colors in which are red and blue. Among many others, artist and color researcher KG Nilson has written about the effects of those colors on humans in his book on color theory. Red is the most emotionally intense color, and has been shown to by psychologically activating as it stimulates increased breathing and blood pressure. Blue is the direct opposite of red, having been found to be as well physiologically calming as psychologically passivating[36]. Red makes us alert and ready to act, but also stressed and unfocused if experienced at the wrong time or to intensely. Blue on the other hand lowers stress and makes us relax, but can also be over sedating.

So how could this make sense? How can the color of blue be alerting and sedating all of the same time? One theory that came to my mind was that there might be a difference between color of light and color on a surface. But this did not make any more sense as a blue colored surface reflects mainly blue wavelengths back into the room, thus increasing the relative amount of blue in the light present. Further, memories of scattered information reminded me that several ancient color psychology experiments were made in white rooms with colored glass. The validity of this memory was confirmed when reading Nilsons book, as he specifically states that the physiological effects of blue and red described in the paragraph above were obtained in experiments with colored lighting[37].

The question remains unanswered so far, despite numerous inquires to different professionals during the past two years. What we do know today is that "The impact of separate wavelengths on the brain is unmapped at large.", as Kronqvist discussed in her study[38]. Research is constantly developing, and as we learn more about how lighting affects us new possibilities to use light to enhance human health will be developed.

In a study on assessment methods for lighting quality published in 2005, architect Merete Madsen wrote that humans need to be exposed to bright, cool, daylight during daytime as well as total darkness during nighttime in order to maintain and reset the biological clock. She also wrote that

> The question of luminance ratios, and lighting in general, might even become more complex in the future, as lighting design might have to support health issues beyond what is considered in current lighting design practice. (...) [As] interdisciplinary studies are leading to a better

36 Nilson, 2004, pg. 80ff

37 Nilson, 2004, pg. 80

38 Kronqvist, 2010, pg. 215

understanding of complex relationships between the non-visual effects of lighting and building occupant health.[39].

2.7 Aspects of Lighting Experience

We commonly divide the effects light has on humans into physiological, and psychological. Both aspect categories contain as well visual as non visual effects. As humans tend to have strong relations to and expectations on how light affects them, those aspects can however be hard to measure in subjective evaluations. While measuring cortisol levels or making routine observations of how an unknowing subject moves in a room provides objective information that can be expected to be reliable throughout different scenarios, subjective evaluations will always be affected by what the subject believes and expects will happen.

The phenomenon is called “Confirmation Bias”, an unwanted effect that might arise in scientific experiments due to either the behaviour of the subject under study or/and the interpretations of the observer being influenced by the outcome which they expect. Philosophy professor Sven Ove Hansson discusses a classical case of confirmation bias in his book “The Art of Doing Science”, an experiment where psychology students performed learning experiments on two groups of rats. The students were told that one of the groups had higher learning capacities, and as expected reported better results from those rats. What the students did not now was that they were themselves actually the subjects under study, the rats were from the same strain and had been randomly distributed into two groups[40].

This kind of effect can easily arise when subjects are asked to evaluate consecutive lighting scenarios. If the subject believes that he or she sees better or feels more comfortable in a brighter/dimmer/warmer/cooler lighting, his or hers evaluation will undoubtedly not only depend on the situation experienced but also be colored by this belief.

2.8 Do we need more Light?

In a research agenda from 2012 for the “Education at work” conference in Canada researchers Veitch and Galasiu stated that “Healthy light is inextricably linked to healthy darkness” and that “Human well-being relies on a regular exposure to light and dark each day.”[41]. This interest for not only light but also darkness has mainly developed in the last few decades, likely due to the overexposure of stimuli we experience in the modern world.

There are currently many silent retreats around the world, where people come for days or even weeks at a time to be completely silent. Stephen Treffinger wrote in The Wall Street Journal that “Going quiet is said to soothe frazzled nerves and lower blood pressure, not to mention give you some time for reflection in a very noisy world.”[42] A similar wish to rest from over lighting can be expected to exist today. Rumours of “Darkness Centres” where people come to spend weeks in

39 Madsen, 2005, pg. 2

40 Hansson, 2007, pg. 42

41 Veitch, 2012, pg. 2

42 Treffinger, 2012

complete darkness in order to reset their system can be found online, claiming that there has at least been one somewhere in Mexico and another called the "Sierra Obscura Darkness Centre" in Nevada City. Several participants have detailed their experiences at the later one, showing that it was in operation back in 2009, today it is however confirmed to have been discontinued. The subject was researched by me back when I first started to consider a topic for my thesis, with the interest of finding out whether health aspects could be linked to such a break from light exposure.

With further research my belief today is that a suitable environment to rest from over lighting would consist of a place with no artificial light rather than one which is completely dark all the time. In such an environment the circadian system would have the possibility to reset itself to a natural rhythm. For optimal effect placing of such a facility should be close to the equator in order to provide a suitable length of both day and night, and obviously be placed far away from any source of artificial light.

In the long run it would of course be desirable to design the environments we normally live in such a way that a specific retreat to rest from over lighting would not be needed. But in order for that to be possible we will need to reconsider the belief that "more lighting is always better", which is common today.

At the PLDC lighting conference in 2001, architect Kristin Bredal talked about that if we were able to lower all urban lighting by 30% at once in an instant, no one would notice. As the contrasts would stay constant our eyes would adapt and hence perceive the environment in the same way as we did before[43]. This statement gives an idea of how much excessive light we already have today.

LEDs allow us to produce more energy efficient lighting than ever before, and it is common to hear energy experts talk about how important it is to continue development of LED technology as we would otherwise soon not have enough power to run all lights "since we all want more light than we have today". This particular quote was said by Peter Bennich during a lecture at the Street Lighting Forum 2011 in Stockholm. The quote is most likely true, judging from views on lighting heard from the general public. The belief that more light always means that humans as well see as feel better, is deeply rooted.

Lighting recommendations vary considerably in different countries, as can be seen in figure 2.2, further confirming that it is currently impossible to define the perfect light level. Simultaneously research outlining the problems of over lighting and light exposure at the wrong time and/or of the wrong type, is being developed. Although at an early scientific stage, eye opening insights on the subject can by obtained from Ian Chenys documentary "The city dark". The movie explores as well directly physiological aspects of over lighting, as psychological questions like not being able to see the stars at night.

Considering the vast physiological and psychological effects the lighting around us has as well as the tendency of believing that brighter light automatically equals enhanced vision, research methods that separate the actual effects of the lighting from the effects that the subject expects the lighting to have, need to be developed. The lighting technology available today provides numerous methods of controlling

43 Bredal, 2011

lighting and if we are able to accept more varying light levels than we are currently used to, the technology opens up possibilities of using varied light throughout the day in order to enhance well being. As Madsen wrote in her paper, more health issues connected to lighting are likely to be discovered as research continues[44]. In order to address those, further research of in what range of light our visual system works satisfactory for different tasks will be needed.

Table 7.1 Recommended maintained horizontal illuminances (lx) for different activities in offices in different countries (after Mills and Borg, 1999)

Country and year	*General*	*VDT tasks*	*Reading tasks*	*Drafting*
Australia, 1990	160	160	320	600
Austria, 1984	500	500	—	750
Belgium, 1992	300–750	500	500–1,000	1,000
Brazil, 1990	750–1,000	—	200–500	3,000
Canada, 1993	200–300–500	300	200–300–500	1,000–1,500–2,000
China, 1993	100–150–200	—	75–100–150	200–300–500
Czech Republic	200–500	300–500	500	750
Denmark	50–100	200–500	500	1,000
Finland, 1986	150–300	150–300	500–1,000	1,000–2,000
France, 1993	425	250–425	425	850
Germany, 1990	500	500	—	750
Japan, 1989	300–750	300–750	—	750–1,000
Mexico, proposed	200	—	900	1,100
Holland, 1991	100–200	500	400	1,600
Russia, 1995	300	200	300	500
Sweden, 1993	100	300–500	500	1,500
Switzerland, 1997	500	300–500	500	1,000
UK, 1994	500	300–500	300	750
USA, 1993	200–300–500	300	200–300–500	1,000–1,500–2,000

fig. 2.2, Table of lighting recommendations in different countries.

44 Madsen, 2005, pg. 2

3 Methodology

An experiment was designed in order to test how participants would perform during, and evaluate, two lighting scenarios that differed only in light level. The aim has been to investigate whether participants notice the difference and/or react differently to a light level consistent with current recommendations and one that was recommended in the beginning of the 20th century. In order to minimize the effect of confirmation bias, the experiment was performed during single-blind conditions where participants were adapted to a very low light level between tests in order to make impossible direct comparison between the scenes or to a reference light.

During the experiment participants were put in a situation similar to working in an office environment. In this space they performed a task on which their performance was measured. At the same time the task simulated activities normally performed in an office (reading and writing), after having performed the task participants were asked about how they had experienced different aspects of doing so.

The whole experiment was repeated twice, in two different light levels. Before the first test scene, and in between the two scenes, participants spent 5 minutes in darkness (<1 lux) in order let their eyes adjust to scotopic vision. As the cones are not active during scotopic vision, this allowed participants detail vision to adjust to each new light level without having a previous reference to compare with.

In John E. Flynns paper on measurement of subjective light impressions he suggests that a participants commitment of time should be limited to 45 minutes or less as subject fatigue becomes a limiting factor.[45] As the experiment described in this paper was designed it was expected that subject fatigue might occur at an accelerated rate than normal when participants were exposed to darkness in daytime, the aim was therefore to limit each subjects involvement to no more than half of the time limit suggested by Flynn. The final time each participant spent on the experiment was about or just over 20 minutes, including initial instructions and final questionnaires.

Flynn also wrote about the importance of eliminating or keeping constant as many confounding variables as possible, which"may require a counterbalancing and/or randomization of several factors"[46]. In this experiment the layout of the room, the color temperature of light and the direction of light have been kept constant throughout all experimental occasions. The mix of subjects was randomized in the sense that requests to participate in the experiment were sent out to participants of various age and professional background through several different forums, all participants who answered participated in the experiment. Presentation order of lighting scenarios and optotype sheets has been counterbalanced, as described further in section 3.7.

3.1 Layout of Experiment Space

The study was performed in an experiment room with no view to the outside where only minimal light seeped in through covered glass walls, creating a light level of < 0.1 lux and thus putting the visual system into a scotopic state.

45 Flynn, 1979, pg. 98
46 ibid.

The room used measures roughly 3,5 by 4,5 meters and has a ceiling height of 2,75m, see attachments 1 and 2. The walls and ceiling are painted white, and the flooring consists of light colored wooden parquet. Two of the walls consist mostly of glass, that was covered with thick curtains, also in white.

In the space, desks with chairs were set up at two opposite walls, placing the participants 1 meter away from their respective wall (att. 1). In front of the desks clipboards holding charts of Landholts Rings, that were used during the visual acuity test, were fastened at eye height on each of the walls. The answer sheets were placed at the middle of each desk.

3.2 Luminaire choice and placement

The permanent lighting in the room consisted of one ceiling fixture in the middle of the room containing fluorescent tubes, this was used while participants entered the room and the experiment was explained.

For the experiment lighting, two Erco Lightboard Wallwashers were used (att. 5). In order to keep the direction of light constant throughout the experiments, dimmable fixtures were used. The luminaires were controlled by a Dali system with preset scenes.

LEDs with a color temperature of 4000K were used as this is today the most commonly installed one in offices where LEDs are used. It was important to use LEDs in order to keep the color temperature constant while varying the light level. Wallwashers were used in order to create a soft fading of the light from the task area. As only one luminaire was used on each side of the room, providing both task and ambient lighting, the proportional contrasts between task area and the surrounding area were kept constant throughout the experiments.

The luminaires were placed diagonally to the left of each participant, one meter behind the experiment table (att. 1) in order to< avoid glare while making sure participants did not shadow their answer sheet. As this placement is optimal for people writing with their right hand, while left-handed people might shadow the spot where they are writing with their hand and should optimally have light coming from the right instead, a question about whether the participant is right- or left-handed was added to the questionnaire.

The light level was measured in the middle of the Landholts rings charts on the wall (vertically) and in the middle of the table with the answer sheets (horizontally), the luminaires were directed so that those measurements corresponded with each other.

3.3 Light Levels

The higher light level was set to be 500 lux, corresponding to the minimum requirement for office lighting in Sweden today.

The lower light level was set to 150 lux, the maximum light level recommended in office working environments before 1962. 150 lux is also the light level after which visual acuity was believed not to improve further with increased lighting, in the beginning of the 20th century[47].

47 Ljuskulturs måndasblad, 1929

Photographs of the two tables used during the experiment can be seen in attachment 4 for each of the light settings. They have been taken with the same manual camera settings and give an indication of that there was a difference in lighting between the scenes. The camera is however unable to correctly describe how the room was experienced on site.

3.4 Participants

Invitations to participate in the experiment were distributed through several different channels. An email invitation went out to all employees at Tyréns office in Stockholm and to a group of students studying a short course on color and light at the School of Architecture at KTH. A public facebook event was also created, links to which were posted in several discussion forums.

The invitation contained a short description of the aim of the experiment, although it was referred to as a “Atmospheric experiment” and nothing was mentioned of that is was about lighting. Prospective participants were told that the experiment would take about 20 minutes to perform, that it would be performed with 1-2 people at a time, and warned that they would be immersed in darkness for several minutes at the time, no other specifics about the experiment procedure were mentioned.

The invitation also specified the time slots available. The experiments were performed between 11.00 and 20.00 from the 11th to the 14th of March 2013. All participants were volunteers that responded to one of the invitations.

The experiment was also tested with 8 participants who were aware that the experiment would test their experiences of different light levels, their results have been excluded from the thesis as the experiment was designed to be performed in single-blind conditions.

3.5 Visual Acuity task

For the visual acuity task in the two experiments, charts of Landholt Rings (fig. 3.1) were used. The Landholt ring is a standardized optotype used in both visual acuity and visual speed tests. It is also the reference optotype to which other visual acuity tests (that use for example letters) are calibrated[48]. It was chosen for its proven ability to provide reliable result on visual acuity throughout tests with ring openings turned in different directions.

fig. 3.1, Landholt ring optotypes facing the four directions used in the test.

The sizes of the optotypes were chosen for measurement at 1 meter (fig. 3.2). The classification of visual performance in the table is used in general vision tests for optotypes of correlating sizes viewed from a distance of 4 meters.

Landholt ring optotypes for presentation at 1 meter			
Outer Diameter	Gap/Stroke width	M-unit	Classification of visual performance
0,92	0,18	0,64	Range of normal vision
1,16	0,23	0,80	|
1,46	0,29	1,01	|
1,84	0,37	1,27	v
2,32	0,46	1,59	Near-normal vision
2,92	0,58	2,01	|
3,67	0,73	2,53	|
4,62	0,92	3,18	v
5,82	1,16	4,00	Moderate low vision
7,33	1,46	5,04	v

fig. 3.2 Table of Landholt Rings Optotype sizes used in the experiments.

It should be noted that the classifications were used only as guidelines to find appropriate optotype sizes, as visual acuity can not always be correctly determined at shorter distances than 4 meters. This is due to the fact that our near-vision depends not only on a persons visual acuity but also on his or hers ability to strain the ciliary muscle in the eye[49]. This ability of “accommodation” to different viewing distances becomes lower with age. As the aim of the experiment was to compare the performance of each person on two identical tasks during two different light levels, no deeper efforts to correlate the test performance to the correct classification of visual acuity have been made. It should also be noted that visual acuity tests are normally performed either using a luminous screen, or when printed viewed at a light level of about 2000 - 3000 lux[50].

48 Colenbrander, 1988, pg. 17

49 Starby, 2006, pg. 77

50 Sir, 2013

The optotypes on the charts (att. 6, 7, 8) were arranged in the typical cone shape of visual acuity charts, where the spacing between optotypes is to be no smaller than one optotype and no bigger than two optotypes. There were 10 rows of progressively smaller optotypes, each row containing 5 optotypes of the same size. Each row was numbered (1 - 10) a distance away from the optotypes, so that the participants could easily find row they were at. Charts A and B were used alternately in the experiments, while chart C was shown in place before the experiments in order to explain the procedure.

The answer sheet (att. 9) had on square for each optotype, arranged in the same grid (5 x 10) as the optotype charts. Each row was marked with the number corresponding to each row on the optotype chart (1 - 10). Each of the squares contained 4 directional arrows (fig. 3.3), the participant was to mark the arrow in which direction the opening of each Landholts ring was positioned.

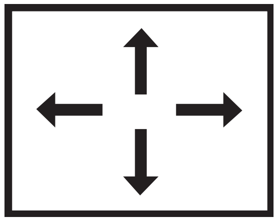

fig. 3.3, Marking box from optotype answer sheet.

3.6 Questionnaires

The questionnaire answered by the participants consisted of three parts. Part 1 (att. 10) contained eight questions were participants evaluated different aspects of performing the task and of the atmosphere in the room. This part was answered twice, once in each of the lighting scenes directly after the participant had performed a visual acuity test.

Part 2 (att. 11) was answered after the whole experiment was finished. It consisted of seven questions where participants where asked to compare their experience of the two scenes. Part 3 (att. 12) was answered directly after part 2 and contained seven background questions about age, sex, education, hand dominance, interest in lighting, whether the participants used glasses and if they often have to increase the lighting around them. A final question also asked participants whether they would accept being contacted after the experiment for follow-up questions.

3.7 Experiment procedure

Participants were shown into the room and seated at either side by an experiment table. During two of the experiments there was only one participant, one was seated at desk 1 and the other at desk 2 (att. 1). As participants entered, an answer sheet was already placed on each desk. On the wall, Landholts rings chart C (att. 6) was placed.
Once seated in the experiment room, participants were told the following things:

- That they would be marking what way the opening of each Landholts ring was facing by marking the corresponding arrow on the answer sheet (att. 9).

• That the charts would be changed to ones with the exact same layout, but with rings facing different directions, before the experiment started.

• That they would have three minutes to complete the test and that they would be told when there was 1 minute and when there were 30 seconds left.

• That they were allowed to sit right up to the table, but not lean forward.

• That they were to turn their mobile phones of and put them away so they could not accidently light up during the experiment.

• Finally, they were told that the room would get dark and that they were to sit back and relax as they would be told when the experiment would start once the light was turned back on.

After the information was communicated participants were asked if they had any questions and given a short while to make themselves familiar with the Optotype chart (version C) and the answer sheet. Once everything was clear the light was turned off and the room was left dark (< 1 lux) for 5 minutes.

The light adaptation in the eye happens through several different stages, and it can take up to 40 minutes until the eyes are fully adapted to a very low light level[51]. The break in the curve (fig. 3.5) represents the point after which regeneration of visual pigment in the rods stands for the adaptation that is still to happened. As this experiment focuses on detail photopic vision which the cones are responsible for the aim of the period in darkness was to get the cones fully dark adapted, 5 minutes was therefore used.

A timer, hidden from participants view in a black cloth was used to time the darkness period. Once 5 minutes were up, one of the experiment lighting scenes was turned on. 150 and 500 lux were used alternately every second experiment.

Once the lighting had been turned on participants were asked to look away from the wall in front of them. The optotype charts were then changed while participants got a short while to get used to the light. This period was not timed as the adaptation from <1 lux to levels of 150 or 500 lux happens almost instantly. Optotype charts A and B were used first alternately throughout the experiments, with A first twice, then B first twice and so on. This order was used to get results from both charts, in both light levels, as both first and second scene. In this way the experiment was balanced for potential difference in difficulty between the charts.

Once the charts had been changed, participants were asked if they were prepared to start the test, once a positive answer was obtained they were told to look at the chart in front of them and start marking the optotype openings on their answer sheets as previously instructed. At the same time, a timer held by the test manager was started. Participants were told when they had 1 minute (out of 3 minutes) left,

51 Blakemore, 1991, pg. 161

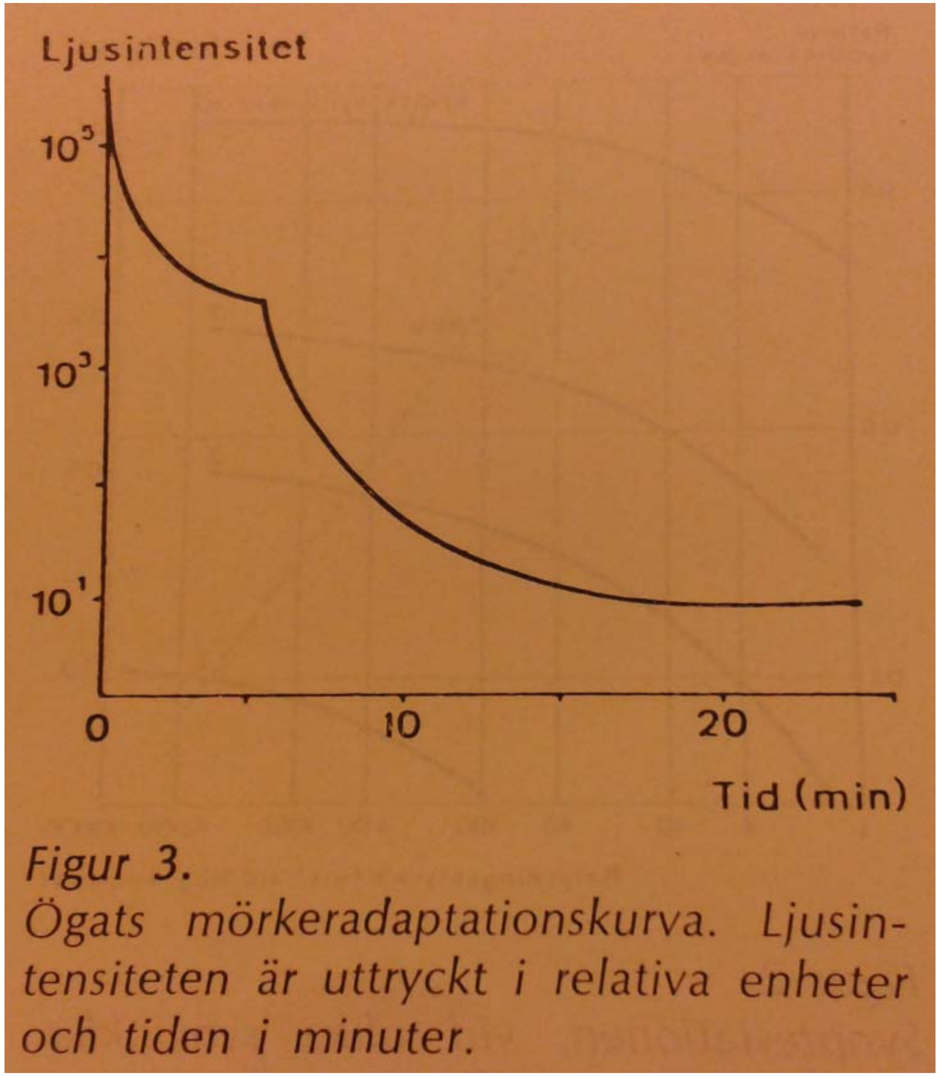

fig. 3.4, "The eyes darkness adaptation curve. The light intensity is expressed in relative units and the time in minutes." The curve shows at what rate our eyes adapt to darkness.

and again when there were 30 seconds left to go.

The three optotype charts used (att. 7, att. 8, att. 9) were pre-tested on time consumption with 4 participants that did not later participate in the main test. It was found that it took the participants between 1½ and 2½ minutes to mark answers for an optotype sheet. A slightly longer time limit of three minutes was therefore used in the main test in order to give participants enough time to go through all optotypes, but not to overanalyse their answers.

When 3 minutes were up, participants were told to turn their answer sheet over. On the back side of the paper they could now see Part 1 of the questionnaire (att. 10), which they were instructed to answer. This part of the questionnaire was aimed at evaluation of the current scene, containing Likert scale questions on different aspects.

Once both participants had handed their questionnaire/answer sheet back to the test manager, further instructions were given. The participants were told that the test would be performed once more, following the same procedure. They were also handed another answer sheet, identical to the first one used. Then the light was turned off for another 5 minutes. Once the second light scene (150 or 500 lux) was started, the optotype charts were changed once more (to chart A or B depending on which was used in the first test). The test was then performed with the same time frame (3 minutes with indications when there were 1 minute and 30 seconds left), followed by the answering of Part 1 of the questionnaire for the new scene.

Once both participants had handed their second questionnaire/answer sheet back, they were handed Part 2 of the questionnaire. This part had participants state whether they had noticed any difference in different aspects between the lighting scenes. Directly after Part 2 participants answered the final part (Part 3) of the questionnaire, which contained background questions like age and hand dominance.

3.8 Follow-up Questions

In order to further evaluate how big of a difference participants experienced between the two light levels, two follow-up questions were sent by email to the 22 participants that stated that they noticed a difference in light level between the two scenes.

The questions were sent out in Swedish and English as follows;

Swedish:

1. Du angav i frågeformuläret att en av scenerna hade starkare belysning än den andra. En av styrkorna som användes var 500 lux, vilket motsvarar minimumkravet på belysning vid kontorsarbetsplatser idag. Hur stark tror du att belysningen var i den scen som inte hade 500 lux? (ange i lux).

2. Vad gjorde att du noterade att belysningsstyrkan skiljde sig åt mellan scenerna?

English:

1. One of the scenes in the experiment had a lighting strength of 500 lux, which corresponds to the minimum requirement of lighting in office work environments today. How many lux would you guess that the other scene had?

2. What made you notice that the lighting strength varied between the two scenes?

The aim of question 1 was to see whether participants experienced the 150 lux scene as uncomfortably dark. As most participants were unfamiliar with the term lux the exact numbers suggested were of little interest, the answer sought was whether they would correctly state that the 150 lux scene had less light than normal office lighting or believe that it had 500 lux and consequently also that the 500 lux scene was brighter than 500 lux.

4 Results

The results are based on visual acuity tests and questionnaire answers of 28 participants. The results have been analysed in Microsoft Excel and are presented in diagrams and text through the following chapter.

4.1 Description of Participants

This section presents background data about the participants, that was collected during part 3 of the questionnaire (att. 12).

The 28 participants were between the ages of 11 and 76 years, with the majority being between the age of 20 and 59. Two thirds of the participants were woman. Complete age and gender statistics are presented in fig. 4.1 and fig. 4.2.

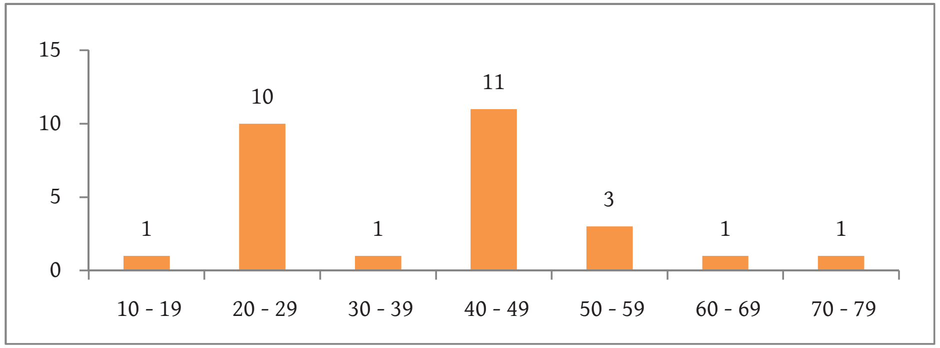

fig. 4.1, Age distribution of participants.

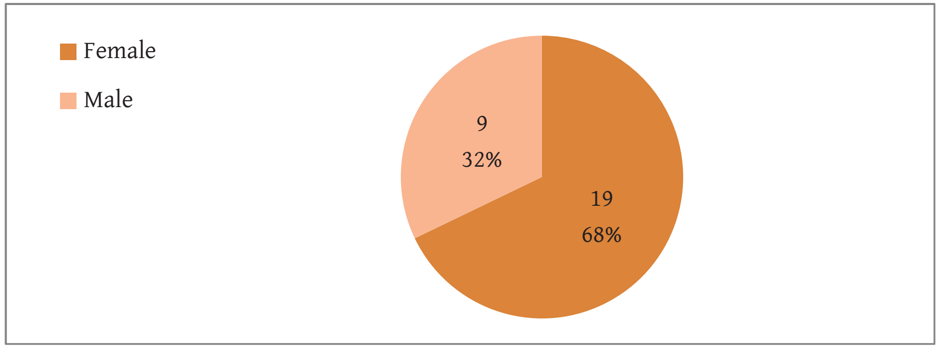

fig 4.2, Gender distribution of participants.

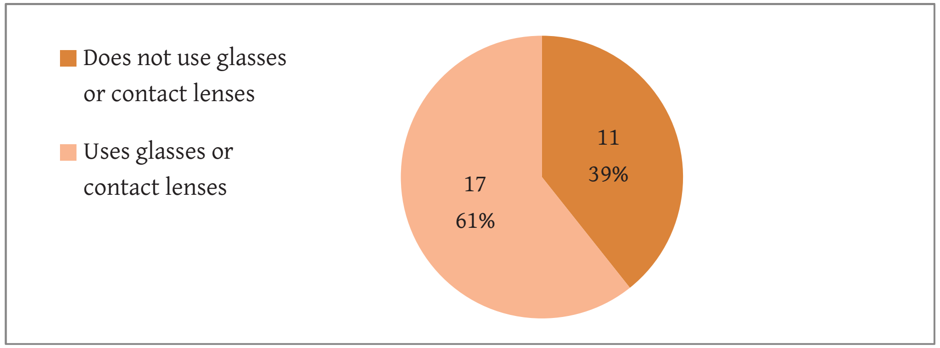

fig 4.3, Usage of glasses and contact lenses.

Glasses or contact lenses were used by 3 out of 5 participants (see figure 4.3). Only 3 out of the 28 participants were left handed. 26 participants had an university education, while 1 had only finished high school and one was studying in elementary school.

Answers to question 6 and 7 in part 3 of the questionnaire are presented in diagrams 4.4 and 4.5. In those questions participants were asked to state how often they feel they need to increase the lighting around them in order to see well and how interested they are in lighting, on Likert Scales of seven steps. The results (fig. 4.4 and 4.5) show a balanced distribution of answers, which is desirable for the report in order to have participants with varying experience of noticing the lighting around them. All participants wrote their email on question 8, stating that they were open to answering follow-up questions.

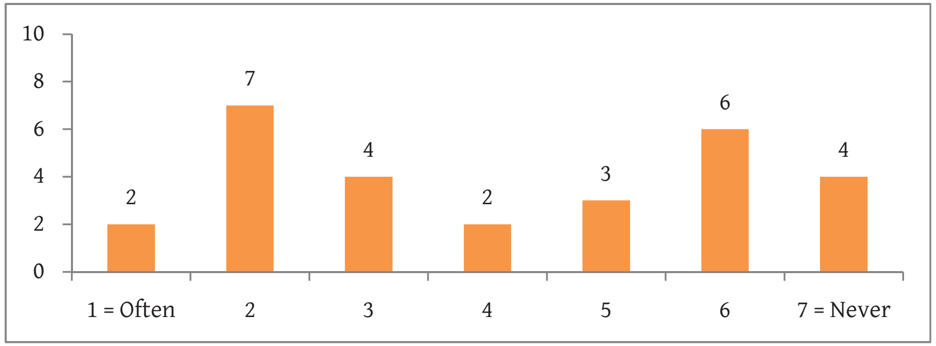

fig. 4.4, Number of participants that believe that they need to increase the light level around them in order to see well on a Likert scale of 7 steps between “Often” (1) and “Never” (7).

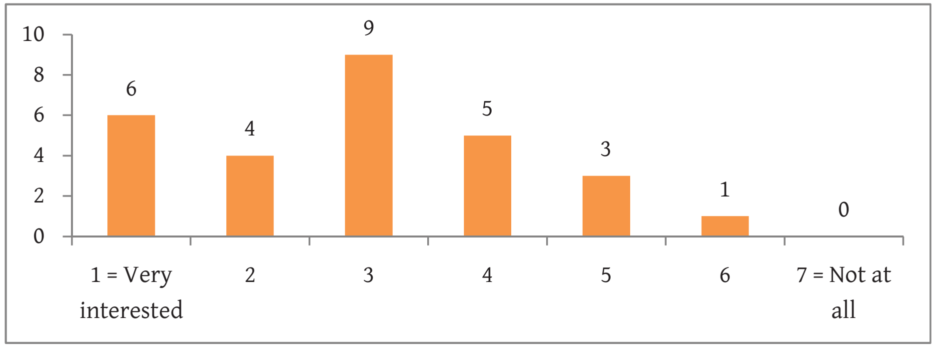

fig. 4.5, Participants interest in lighting. Number of participants that marked each step on a Likert scale between “Very interested” (1) and “Not at all” (7).

4.2 Visual Acuity

In this section results of the visual acuity tests are presented. 2 of the participants did not fill in all answers to optotype sheet A (att. 7) in 150 lux, leaving four blank squares on row 10 and six blanks squares on rows 9 and 10 respectively. The blanks were left during the participants first visual acuity test of the experiment. The blanks have been counted as incorrect answers, it is however unknown whether they were left due to difficulties in seeing the optotypes or due to time pressure. No other blanks wee left by any participant.

Figure 4.6 shows correct answers in both lighting scenes for each participant. Figure 4.7 shows how many participants made more correct answers in 150 lux (L), 500 lux (H) and equally many correct answer in both light settings (E). Figure 4.8 shows the mean of correct answers for all participants.

Figure 4.10 shows at which row of the optotype chart each participant made their second mistake, in each lighting scene.

The difference in both mean and median between amount of correct answers in the two lighting scenes is less than 1 (fig. 4.8). In the present context where there are 5 optotypes of each testing size within the optotype chart used, the difference is thus insignificantly small.

This conclusion is further supported by the fact that 12 participants made more mistakes in 150 lux than in 500 lux while 11 participant made more mistakes in 500 lux than in 150 lux, making he difference only 1 participant as seen in figure 4.7. The results in figure 4.10 also point towards that there was no significant difference in visual acuity between the two lighting scenarios, as the mean for at which row the second mistake of the test was made is 9,96 in both scenarios and the mean difference between at which row the second mistake was made is exactly 0.

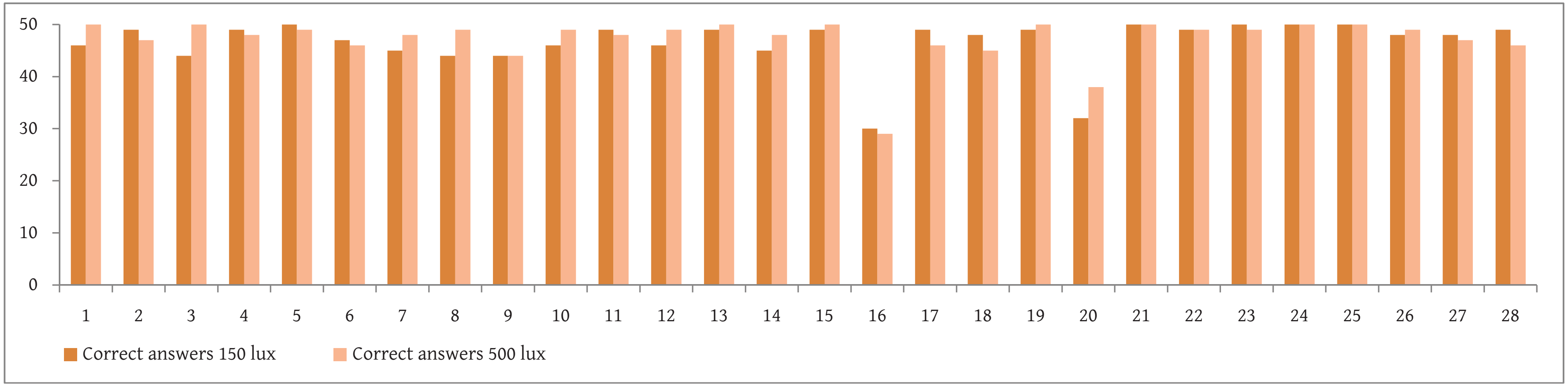

fig. 4.6, Correct answers on visual acuity test with 50 optotypes of different sizes for each participant.

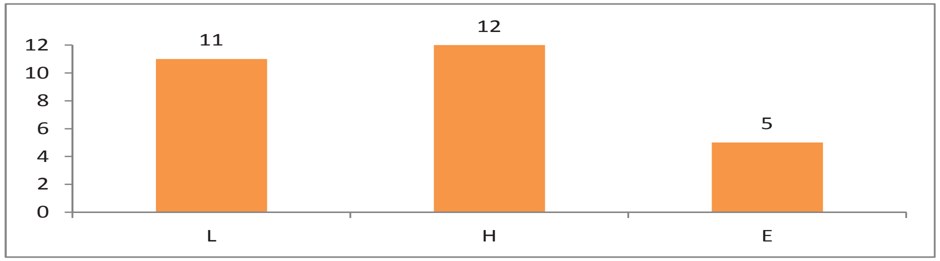

fig. 4.7, Number of participants that gave most correct answers in the lower lighting scene of 150 lux (L), the higher lighting scene of 500 lux (H) and an equal amount of correct answers in both scenes (E).

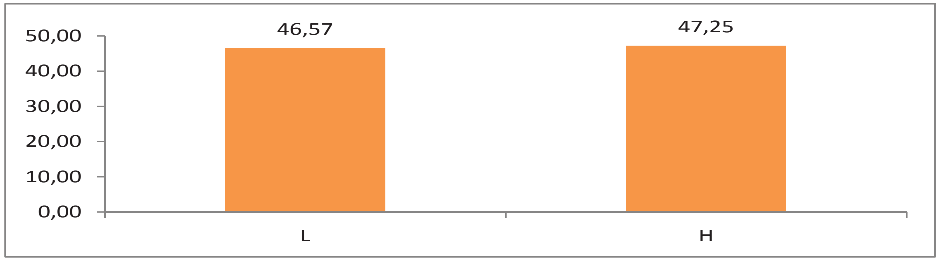

fig. 4.8, Average amount of correct answers in the lower lighting scene of 150 lux (L) and in the higher lighting scene of 500 lux (H) out of 50 optotypes. The median of correct answers was 49,5 out of 50 in the 150 lux light setting and 50 out of 50 in the 500 lux light setting.

Mean correct answers divided by order (1st and 2nd) in which the test was made by each participant, and by which optotype sheet (A or B) was used in the test, can be seen in figure 4.9. The mean of correct answers was slightly higher in scene 2 (47,36) than in scene 1 (46,46), suggesting that a few participants performance may have been enhanced by being used to the test. As the difference is small it may however be due to pure chance as well. The difference between mean correct answers for the two test sheets was very low (0,4).

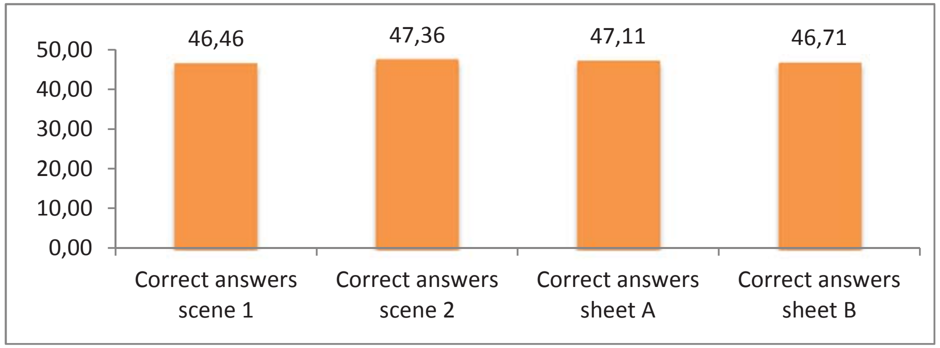

fig. 4.9, Average amount of correct answers in the first and second scene of every participant, and average amount of correct answers on each optotype sheet (A and B).

fig. 4.10, This diagram shows at which row (1 - 10) of progressively smaller optotypes each participant made their second mistake. It also shows how many rows earlier (negative numbers) or later (positive numbers) the participant made their second mistake in the lower lighting scene (150 lux) than in the higher one (500 lux). The second mistake is used as a measurement rather than the first one in order to minimize the effect of single mistakes made early on in the test on the results, as those are more likely to have been made due to temporary inattention than due to difficulties in seeing the optotypes. The average difference between at which row the second mistake was made is exactly 0.

4.3 Visual Comfort and Experienced Brightness

The results in this section are from Part 1 (att. 10) and 2 (att. 11) of the questionnaire.

Part 1 of the questionnaire was comprised of scene evaluations of 8 parameters on Likert scales with seven steps, and was made separately for each scene following the completion of a visual acuity test. Figure 4.11 shows the mean values for each parameter marked in Part 1, separately for both lighting scenarios. Figure 4.12 shows how many participants marked a higher value for each of the parameters in 150 lux than in 500 lux (L), a higher value in 500 lux than in 150 lux (H), and equal values in both scenes (E).

Part 2 of the questionnaire contained 7 questions where participants were asked to state whether they noticed any difference between the two scenes in regards to seven different parameters. The answers to those are shown in figure 4.13.

In figure 4.11 it can be seen that participants on average believed that the 500 lux scene was brighter than the 150 lux one, however the difference was only 0,32 steps. Figure 4.12 show that 10 participants believed that the 500 lux scene was brighter (opposite to darker which is shown in the diagram) while 6 participants noted the 150 lux scene as the brighter one. 12 participants marked the same value for both scenes. While there were slightly more participants who correctly identified the brighter scene (500 lux) to be brighter than those who thought the other scene (150 lux) to be so, they comprised only 35,7% of the respondents. 21,4% believed the lower lighting scene to be brighter and 42,9% marked the two scenes as equally bright. These result suggest that participants found it difficult to distinguish between the brightness of the two scenes.

The 150 lux scene got slightly higher values on both how hard it was to read (+0,53 steps), how uncomfortable (+0,25 steps), and how strenuous (+0,32 steps) it was (see fig. 4.9). However, as seen in figure 4.12, there was no unanimous preference for the 500 lux scene i regards to any of the parameters. Interesting to note is also that while 46,4% (13) of the participants believed it to be easier to read in 500 lux and only 17,9 (5) that it was easier in 150 lux, the numbers for how strenuous it was were 35,7% (10) and 28,6% (8) respectively. Further noted should be that the mean values for all three parameters are below the average possible answer of 3,5, suggesting that both scenes were found to acceptably good on all accounts compared to previous references of the participants.

Experienced glare values were low for both scenes, as expected with the experiment set-up used. The deviation was only 0,11 steps with a higher mean value in the scene with 500 lux. Equally many participants found the 150 lux scene and the 500 lux scene to be more glary respectively (6 participants each), while a majority of 57,1% (16 participants) found them to have equally much glare.

The 150 lux scene was experienced to have a hazier atmosphere than the 500 lux one, with the highest mean variation (+0,66 steps) of any parameter in the test.

The mean for strong shadows was slightly higher in 500 lux (+0,47 step) as was the mean for warmer atmosphere (+0,22) as seen in fig. 4.11. As the color temperature was kept constant throughout the tests, the deviation of 0,22 steps between the mean evaluations of the lighting scenes has to be seen as something that can occur through standard deviation.

In figure 4.13 answers to the comparison between the scenes are shown. The comparison (Part 2) was made after both visual acuity tests and evaluative questionnaires, participants did not get to view the previous lighting scene again and had to rely on the memory of their experiences.

It can be seen in the diagram that the evaluations of which scene was more comfortable and which was easier to read in are fairly

different from what was obtained during the evaluative part (Part 1) of the questionnaire. The amount of participants that correctly noted the 500 lux setting to be the brighter doubled from the evaluation of each scene (10 participants, 35,7%) to the comparison between scenes

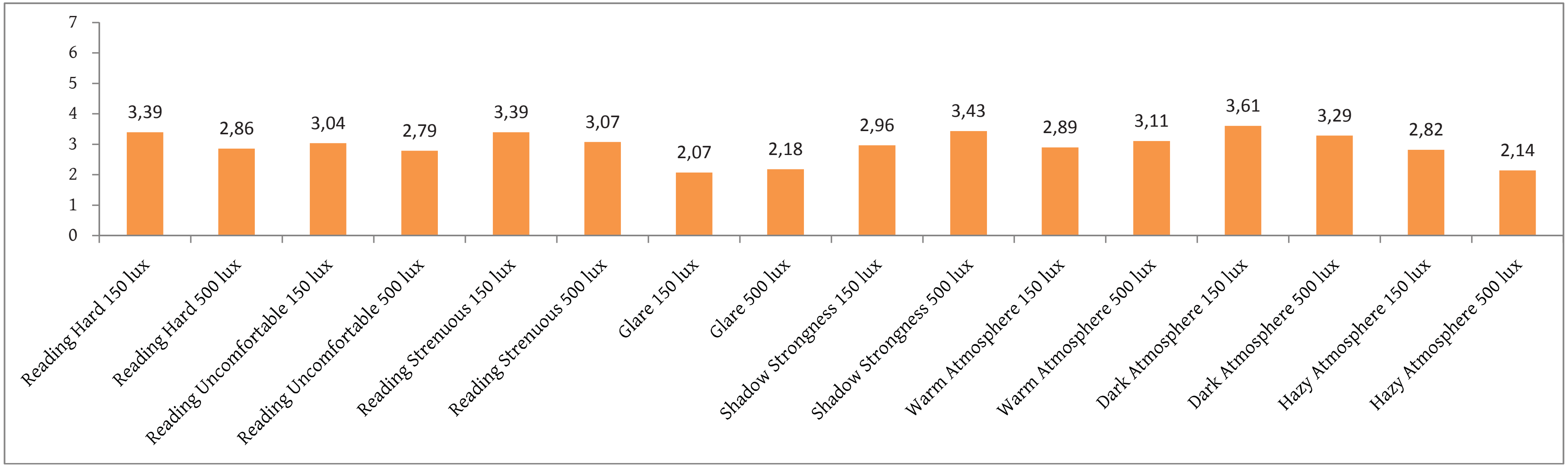

fig. 4.11, Mean value of participants answers to Part 1 of the questionnaire, that were marked on Likert scales with values between 1 and 7. Higher values show that markings were made closer to the parameter stated in the diagram while lower values show that markings were made closer to its opposite, complete question formulations can be seen in the attached questionnaire that was used (att. 10).

consistent with the resaults obtained in the evaluative part (Part 1) of the questionnaire. The evaluation of which scene is better to work in is fairly consistent with the results on confirmability and ease in reading obtained in the evaluative part of the questionnaire, as would be expected.

The result on comparison of brightness is on the other hand very

(20 participants, 71,4%). During the comparison, only 2 participants thought that the 150 lux scene had been brighter compared to 6 participants during the evaluation. The results suggest that several participants became aware of factors they had not considered while doing the task, when directly asked to compare the brightness of the two scenes. In order to evaluate this phenomenon further, two

follow-up questions were sent out to the 22 participants who marked either of the scenes to be brighter than the other in the comparative part of the questionnaire.

Half of the participants (14) believed that there was a difference in contrast between the two scenes, 13 of who marked the brighter setting (500 lux) as having stronger contrasts. Together with brightness, this is the factor where a clear tendency in difference

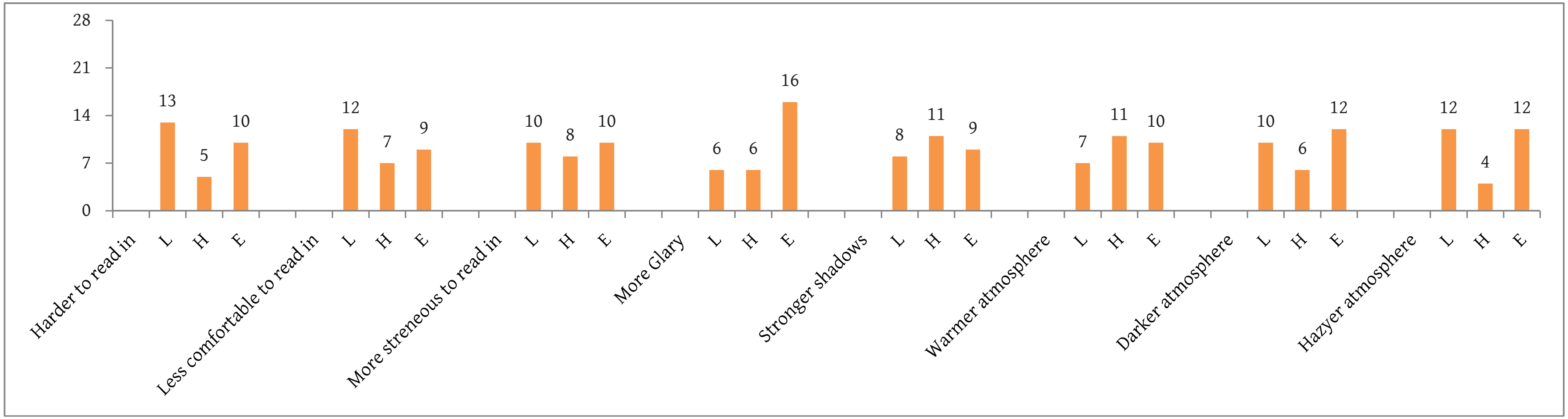

fig. 4.12, Number of participants that marked a higher value for each stated parameter during Part 1 of the questionnaire (att. 10) in the lower lighting scene of 150 lux (L), the higher lighting scene of 500 lux (H) and participants that marked the same value in both scenes (E).

between the scenes can be found in the answers obtained. It is unknown whether participants comparison of contrasts was affected by their simultaneous comparison of brightness.

For warmness and shadow strongness, the amount of participants that believed there was no difference between the two scenes increased with 5 (17,9%) and 6 (21,4%) participants respectively. This may be because participants recognised the difference they had thought to depend on variation in color temperature and shadow contrasts, was actually caused by a variance in light level.

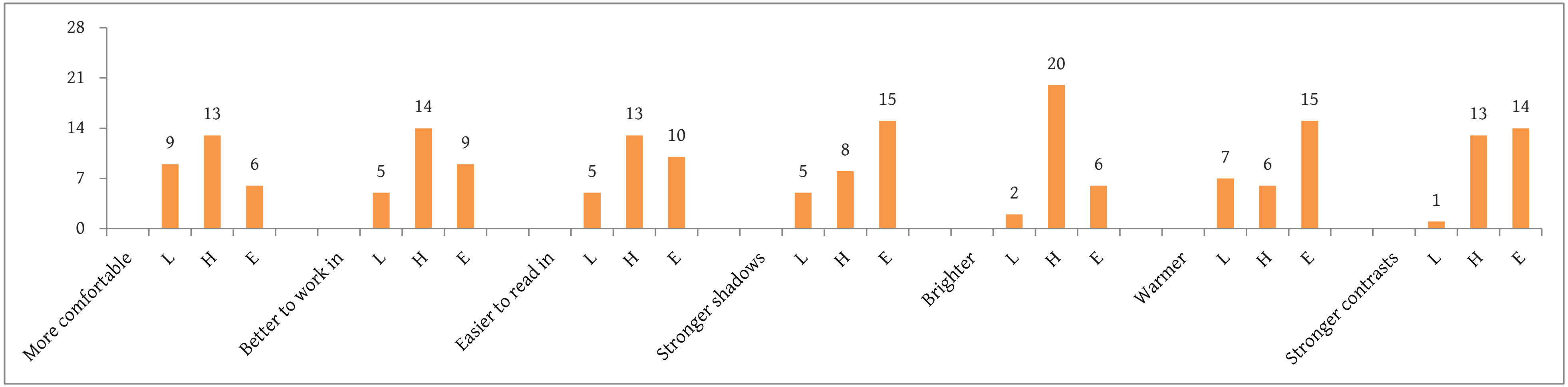

fig. 4.13, Answers to part 2 (att. 11) of the questionnaire, where participants were asked whether they noticed any difference between the two scenes experienced in regard to 8 different parameters. The diagram shows how many participants considered the lower lighting scene of 150 lux (L) to correspond better to each stated parameter, the higher lighting scene of 500 lux (H) to do so and participants that considered the scenes to be equal (E).

4.4 Relation of test results and evaluation to statistical parameters

Participants using glasses or contact lenses had a slightly lower score on the visual acuity test with an average score of about 2,5 less correct answers than those participants who do not use glasses or contact lenses. The difference was found in both lighting scenes. No correlation was found between usage of glasses or contact lenses and higher ratings on visual comfort parameters for either of the two lighting conditions in the test.

A similar correlation was found for gender, where men had approximately 2 correct answers less than woman in both lighting scenarios. Again, no difference in rating of visual comfort parameters between the two lighting scenarios could be correlated with gender.

The usage of glasses and gender thus had a bigger correlation with difference in correct answers on the visual acuity test than the light level had. What is more, as the difference was consistent throughout the two lighting scenarios, the findings speak against that people with a lower visual acuity are affected more severely by a lowered light level than others. This is further supported by the fact that no correlations were found between usage of glasses or gender and higher visual comfort ratings of either of the lighting scenarios.

No general correlations were found between visual acuity test score and rating of visual comfort parameters, suggesting that participants were quite unaware of their performance.

No correlation of either visual acuity or visual comfort ratings could be found either with participants interest in lighting, or how often they feel they need to increase the lighting around them. As 26 out of the 28 participants had university education with only 1 participant each having stated the two other options, no efforts to make correlations between test results and educational background were made.

Left-handed participants had a mean visual acuity score similar to that of right-handed participants with 47,00 out of 50 correct answers in both scenes compared to right-handed participants score of 46,52 in 150 lux and 47,28 in 500 lux. However, left-handed participants rated reading to be significantly harder with a mean rating of 5,3 in both scenes, than right-handed participants who had a mean rating of 3,6 in 150 lux and 3,0 in 500 lux. No correlation with other visual comfort parameters was found. It could be discussed whether the left-handed participants evaluation of the scene was affected by that the light set-up was designed for right-handed participants with light shining from the left, thus making left-handed participants shadow the spot on the answer sheet where they were writing with their hand. As only 3 (10,7% of the total participants) left-handed participants took part in the test, those results do however bear the risk of being coincidental.

Visual acuity test scores were significantly lower for participants above the age of 60 in both lighting conditions. As only two participants were above the age of 60 it is hard to draw further conclusions from the results, but it can be noted that one participant had a higher visual acuity score in 500 lux, while the other had a higher score in 150 lux. One of the participants rated reading as “harder” in 150 lux while the other believed it to be equally hard in both scenes, all other visual comfort parameters were rated equally by the two participants above 60 years of age. No correlation to age with either visual acuity or visual comfort ratings were found for the 26 participants between the ages of 10 and 59.

4.5 Follow-up questions

Two follow-up questions were sent out to the 22 participants who had stated that they noted a difference in brightness between the two experiment set-ups, as follows;

1. One of the scenes in the experiment had a lighting strength of 500 lux, which corresponds to the minimum requirement of lighting in office work environments today. How many lux would you guess that the other scene had?

2. What made you notice that the lighting strength varied between the two scenes?

Results were received from 21 out of the 22 initial participants. One out of the 21 participants had found out details about the light levels of the the experiment between performing it and receiving the follow-up questions, this persons answers are therefore excluded from the results.

The results to question 1 are presented in diagrams 4.14 (18 participants) and 4.15 (19 participants). One participant answered question 1 with “I don’t know”, this answer is therefore not among the results. Another participants answer to question 1 was "above 500 lux", this result is included in figure 4.15 but excluded from diagram 4.14 as no specific level was suggested. Several participants answered question 1 with a range within which they believed the lux level of the scene that did not have 500 lux to be, in those cases the middle value of that range has been presented in figure 4.14.

As participants could not be expected to be familiar with the measurement of lux, which several also mentioned in their answers, it would be unwise to draw conclusions based on the exact values stated by the participants.

Of great interest is however whether the participants answers were above or below 500 lux. As they were given a reference in 500 lux being the minimum standard for lighting in offices and the light level in one of the experiment scenes, they had to decide whether they believed it was the setting with higher or lower light that corresponded to 500 lux.

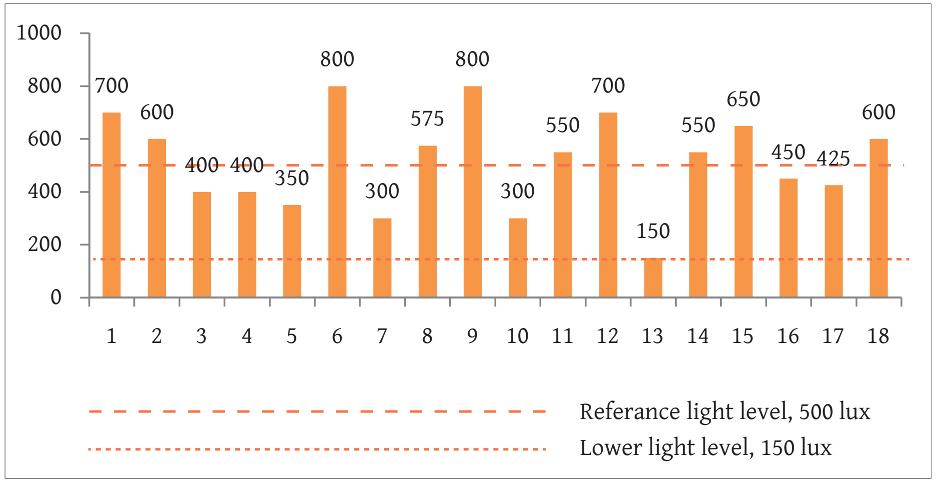

fig. 4.14, Answers from 18 participants when they were told that one of the scenes in the experiment had a light level of 500 lux and were asked to guess the light level of the other scene.

As seen in figure 4.15, there were slightly more participants (11) who believed that the two lighting scenes had light levels of 500 and >500 lux than those who thought the levels to be 500 lux and <500 lux (8 participants). This result suggests that while participants in general were able to tell the difference in light level when comparing the two scenes in the experiment, as seen in figure 4.13, they were not able to correctly relate the amount of light to that in other well-known environments. These findings also strengthen the notion that the 150 lux scene was not generally experienced as uncomfortably dark.

The answers to question 2, why participants experienced one of the scenes to be brighter, were quite varied. 5 participants stated that it was easier to read in general or to see the bottom optotypes in one of the scenes. 2 participants stated that they had noted a difference in contrast and 2 other that the light spread differently within the

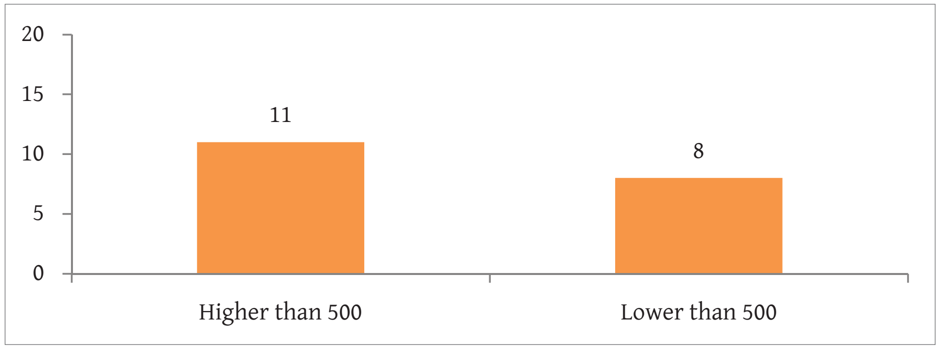

fig. 4.15, How many out of 19 participants believed the light setting that was not 500 lux to have a higher and lower light level respectively.

room. 1 participant disregarded their previous answer as incorrect stating that they had mistaken a difference in color temperature as a difference in brightness, and another 4 participants attributed their detection of difference in light level to atmospheric qualities of one scene being clearer, colder or whiter. 2 participants stated that one of the scenes felt uncomfortably bright. 2 other wrote that they did not know what made them notice a difference, and 2 participants stated they had not actually noticed any difference but had assumed that there was one as there was a question about it.

5 Discussion

The aim of this thesis was to examine whether humans can tell the difference between the light level of 500 lux standardized since the 1960ies and that of 150 lux which was commonly used before that, when no direct comparison can be made between the scenes.

A further aim was to evaluate how human visual performance and comfort level is affected by the change in light level, and whether the higher light level is really preferred when participants are properly adapted to each level of light.

It is believed today that humans prefer light levels between 1000 and 3000 lux[52], according to that notion at levels between 150 and 500 lux the brighter one would be preferred. In this thesis the aim has been to investigate whether this holds true when participants can not directly compare the lighting scenes with each other. The aim was broken down into the following three questions;

- Can humans tell the difference between two distinctly different light levels when no direct comparison between the scenes can be made?
- Is the performance of human vision enhanced, by a higher light level than 150 lux, all other factors being constant, when the eyes are properly adapted?
- Is a light level of 500 lux generally preferred over one of 150 lux by

52 Starby, 2006a, pg. 264

humans, once their eyes have been properly adapted to each light level and no direct comparison between the two light levels can be made?

An experiment was performed with 28 participants, in order to measure their visual acuity in and impressions of the scenes. The participants completed visual acuity test in each of the scenes and evaluated their experiences of them. The results from both visual acuity tests and evaluations were compared for the two light levels. It was further checked whether differences in visual acuity or scene evaluations could be correlated with age, gender, hand dominance, possible usage of glasses or contact lenses, experienced need of a high light level or interest in lighting.

5.1 Methodology Discussion

The study was limited to evaluating the effects of change in light level between two light levels of 150 lux and 500 lux, and is thus specific for those levels and the difference between them. While it would have been interesting to investigate whether results would vary if using a wide range of light levels, this would have required a far longer time investment from each participant. Considering subject fatigue as a limiting factor this would not have been practical.

The experiments were performed during single-blind conditions as the participants were not told what was changed between the scenes, and as they were not aware that the light level would vary they were obviously not aware of whether the higher or lower light level was shown first either. The evaluation of the experiments has been based on participants answers to visual acuity tests and questionnaires, no behavioural factors observed during the experiments were considered. It can therefore be concluded that the results have not be affected by confirmation bias caused by observer expectations.

It could however be considered whether future similar experiments should be performed during double-blind conditions, where the experiment conductor is not aware of what is being changed in the scene just like the participants, in order to neutralize any influence of the conductors behaviour on participants during the experiment.

As the study was concerned with detail photopic vision the adaptation periods in darkness consisted of 5 minutes each. While the cone receptors in our eyes reach their maximally dark adapted state after 5 minutes, the rods keep becoming more sensitive until 40 minutes after they were last exposed to bright light. While the photopic detail vision is believed to be completely reset after 5 minutes in darkness, it is unknown whether the rod receptors may have had an influence on the experienced brightness also during photopic vision. It could be of interest to perform similar test with adaptation periods of 40 minutes, but such tests would require consideration of possible subject fatigue.

No participants made any mistakes in the first 3 rows of the visual acuity test. This was desirable so that the participants had a chance to get comfortable with marking the test before experiencing difficulties in detecting the optotypes. As a few participants marked all 100 optotypes of the two tests they performed correctly, using more challenging visual tasks could be considered in future experiments in order to obtain a higher resolution around the limit of each participants visual acuity. In such a case the presentation method of optotypes might have to be changed, as edge noise becomes a problem when printing optotypes of smaller sizes than the minimum ones used in this test. It should however be noted that the smallest optotypes used in the test were far smaller than any text normally read in an office environment.

Many studies could be made that compare the effects of light level during different compositions of other factors such as direction and spectral composition of light. This study has focused solely on the light level in a specific space with one type of lighting system, it is therefore hard to generalize the results to a wider context. The study does however give an indication of that scenes with a lower lighting level than we are used to today are evaluated less negatively when participants are unable to directly compare them to other reference lighting.

The three thesis questions will be discussed below in order.

5.2 Discussion of Results to Thesis Questions

- Can humans tell the difference between two distinctly different light levels when no direct comparison between the scenes can be made?

In this experiment it can be seen that participants did recall a difference in light level between the two lighting scenarios of 150 lux and 500 lux when asked to compare their impression of brightness between the scenes, despite having spent 5 minutes in darkness between exposure to the different lighting scenes. When asked whether they found any of the scenes to be brighter than the other, 20 out of 28 participants stated that the 500 lux scene was in fact brighter.

Before participants were asked to compare the scenes they made an evaluation of brightness while in each of them on a likert scale of 7 steps between bright and dark. The answers to this evaluation were far more ambiguous. 12 participants marked the scenes as being equally bright, 10 marked the 500 lux scene as brighter and 6 marked the 150 lux scene as the brighter one. It is unknown whether the participants who marked the scenes as equally bright did not notice any difference in light level, or did notice a difference but found it to small to motivate different ratings on the Likert scale. While more participants rated the 500 lux scene as brighter than the 150 lux one, more than half as many did rate the 150 lux scene as the brighter one. It can therefore be concluded that many participants did not pay much attention to the light level until asked to compare the two lighting scenes after the experiment.

The participants that had perceived a difference in light level when comparing the lighting scenes after the experiment were later also asked to compare their experience of those light levels with general office lighting. They were told that one of the scenes shown in the experiment had a light level of 500 lux and that this level corresponded to minimum lighting requirements in office environments, and were asked to guess what the light level of the other scene could have been. A majority, 11 out of 19 respondents answered with light levels above 500 lux. Consequently they believed that the light levels they had experienced had been 500 lux and > 500 lux rather than 500 lux and < 500 lux.

From those three evaluations it can be seen that most participants were not conscious of the light level while they were performing the visual acuity tasks. When asked to compare the two scenes where they had performed the same task, they were however able to correctly recall a difference in light level. On the other hand, they were not able to relate the light levels to those in other environments.

- Is the performance of human vision enhanced by a higher light level than 150 lux, all other factors being constant, when the eyes are properly adapted?

The results of this study show that there was no difference in visual acuity between the two lighting scenarios of 150 lux and 500 lux.

It is believed today that people with a lower vision in general need more light than others in order to perform visual tasks. No correlation between possible factors affecting vision such as usage of glasses or age with better visual performance in 500 lux than in 150 lux was found in this study. Neither was there any correlation between a higher number of mistakes on both test together and the majority of them being made in the lower light level.

This study does hence not support the belief that visual acuity increases in 500 lux compared to in 150 lux. It is unknown whether other results would have been obtained if comparing visual acuity in 150 lux with that in a higher light level than 500 lux.

The result of this study suggest that visual acuity is not enhanced by the currently recommended light level of 500 lux compared to that of 150 lux normally used before the 1960ies, when the light is provided as task lighting diagonally from behind to the left of the participant.

- Is a light level of 500 lux generally preferred over one of 150 lux by humans, once their eyes have been properly adapted to each light level and no direct comparison between the two light levels can be made?

No clear general preference for the higher light level was shown in this study. It was however shown that slightly more participants preferred the brighter lighting scene in regards to the visual comfort parameters of how comfortable/uncomfortable, easy/hard, relaxed/strenuous reading felt and which of the scenes was better to work in. About a third of the participants rated the scenes equally. The exact results can be seen in figures 4.12 and 4.13.

As most participants noticed the difference in light level between the two scenes, it is unknown whether this knowledge may have affected their evaluation of visual comfort parameters.

It should be noted that between 5 and 9 (17% - 32%) of the participants rated the 150 lux scene as better on each of the visual comfort parameters. This points towards that while we are able to read in far higher illuminances than what can be found in offices today, increased illuminances are not necessary found more comfortable by all occupants.

In most current studies where participants were shown lighting scenes consecutively or could vary the lighting themselves, higher illuminances than 150 lux were preferred by basically all participants. A few studies have shown that lower light levels may be preferred when also other factors are in play, like Kronqvists study where a day lit room with a table top illuminance of 151 lux was preferred over rooms with higher illuminances created be electric lighting[53]. Both lighting scenes in the experiment described in this thesis had below aware ratings on negative visual comfort parameters of how hard, uncomfortable and strenuous is was to read, as can be seen in figure 4.11.

The results thus further support the idea that lower light levels then the ones recommended today can provide good lighting conditions for office work if designed in a good way.

5.3 Hypothesis discussion

The hypothesis was that lower light levels may be found more comfortable when no direct comparison can be made with other lighting, than otherwise.

As described on pg. 10 the lighting levels considered to be preferred by humans tenfolded between 1929 and 1960. It is unlikely that any major changes in human perception of light happened during that short period. The change in lighting recommendations came around the same time as energy efficient fluorescent lamps became widely available. As described on pg. 8, the recommendation of 500 lux as the minimum light level in office work environments was highly opposed when it was first released. Many people believed the 500 lux was to bright to work comfortably, when they were not used to it.

Today people are used to working in light levels of 500 lux and above, and a widespread belief is that we always see better the more light we have. With those reference frames 150 lux has been considered way to low of a light level to work in by basically all participants in recent experiments where they were able to directly compare the light with other references.

In the experiment described in this thesis participants spent 5 minutes in darkness before seeing each of the light levels of the experiment. In this setting participants rated the scene that had a light level of 150 lux above average on all visual comfort parameters. More than half of the participants asked thought that the scene had as much light as the minimum light level in offices today.

From those results it can be seen that the evaluation of the light level was significantly affected by the fact that participants could not directly compare it to a reference light level. This supports the opinion that participants evaluations of different light levels may be affected by their expectations of what effects the light level will have.

5.4 Suggestions on further research

As lighting experiments are often examined through subjective evaluations of lighting scenarios, a general suggestion to design experiments to minimize influence of subjects expectations is desired to be made.

Depending on what is being tested achieving single-blind or double-blind conditions might be anywhere from easy to impossible.
As an example it would be hard to study human behaviour in monochromatic light at photopic levels without the subjects being aware of what color they are being exposed to. Other current questions

53 Kronqvist, 2010, pg. 215

are perfectly suited for suited for single- or double-blind experiments.

An example is the question of whether daylight in itself has qualities that enhance performance and well being, or if the effects are rather created by having a view to the outside and peoples tendency to prefer daylight. This could for example be studied in rooms where daylight enters through thin curtains compared to rooms with the same type of curtains covering not windows but artificial light sources.

As shown in this study, experiments on preferred light levels are also a type of studies that benefit from being performed in single- or double-blind conditions. When participants evaluations are not affected by their expectations, results that are independent of the lighting conditions we are currently used to, can be obtained.

6 Conclusions

It has been shown in this study that most participants accepted a light level of 150 lux as pretty comfortable, the results thus support the initial hypothesis that lower light levels may be found more comfortable when no direct comparison can be made with other lighting, than otherwise.

It was also found that a significant amount of participants preferred the lower light level. My suggestion is therefore that it should be considered to not only make recommendations for minimum light levels, but also for maximum ones.

Further it was seen that visual acuity did not vary between the light levels of 150 and 500 lux.

The hope is that the results presented in this thesis may open up for a discussion on how experiments on preference for different light levels are conducted. It is my firm belief that actual consequences of the light level need to be separated from the consequences caused by participants expectations on how a lowered or increased light level affects them.

As Madsen wrote, lighting design is likely to become more complex as new health effects of different aspects of light are discovered[54]. In order to properly weigh health aspects with visual aspects, studies on the visual experience which are not affected by expectations will be needed.

54 Madsen, 2005, pg. 2

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8 Figures

fig. 2.1 Murray, Marjorie A. , "Neuroscience for Kids - Our Sense of Sight: Part 1. Eye Anatomy and Function, Teacher resource", read on the 10th of May, http://faculty.washington.edu/chudler/eyetr.html .

fig. 2.2 Boyce, Peter R., 2003, *Human factors in lighting*, 2nd ed., pg. 227, New York: Taylor and Franscis Inc
Original by Evan Mills; Nils Borg, 1999 "Trends In Recommended Illuminance Levels: An International Comparison", *JOURNAL of the Illuminating Engineering Society*, New York.

fig. 3.1 Illustration by author.

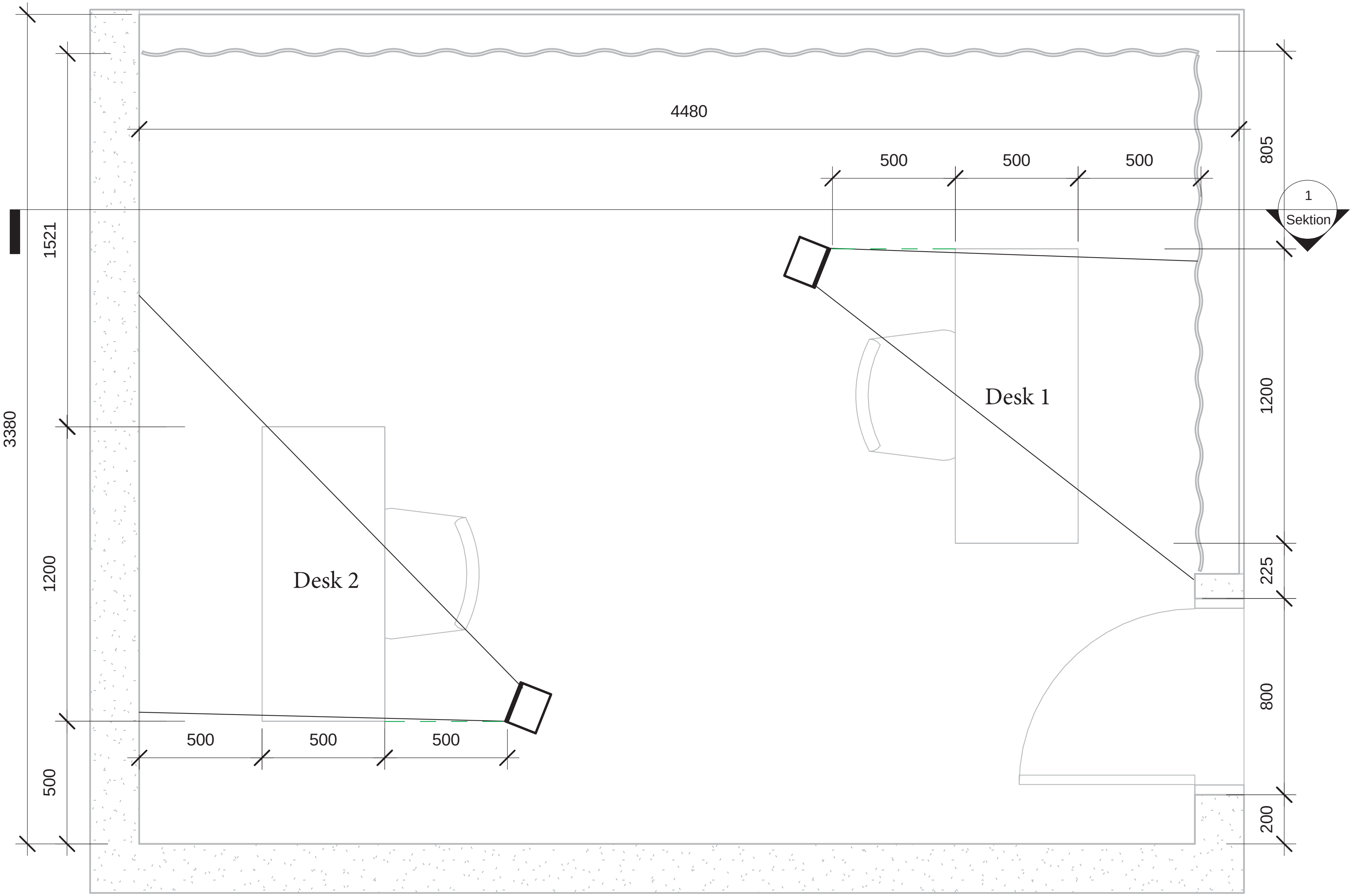
fig. 3.2 Diagram by author.

fig. 3.3 Illustration by author.

fig. 3.4 Kave, Bengt, 1979, "Synfysiologi och belysning - några yrkeshygieniska konsekvenser", *Arbetsbelysning*, pg. 6, ed. Nils Lundgren; Magnus Frantzell, Stockholm: Ljuskultur.

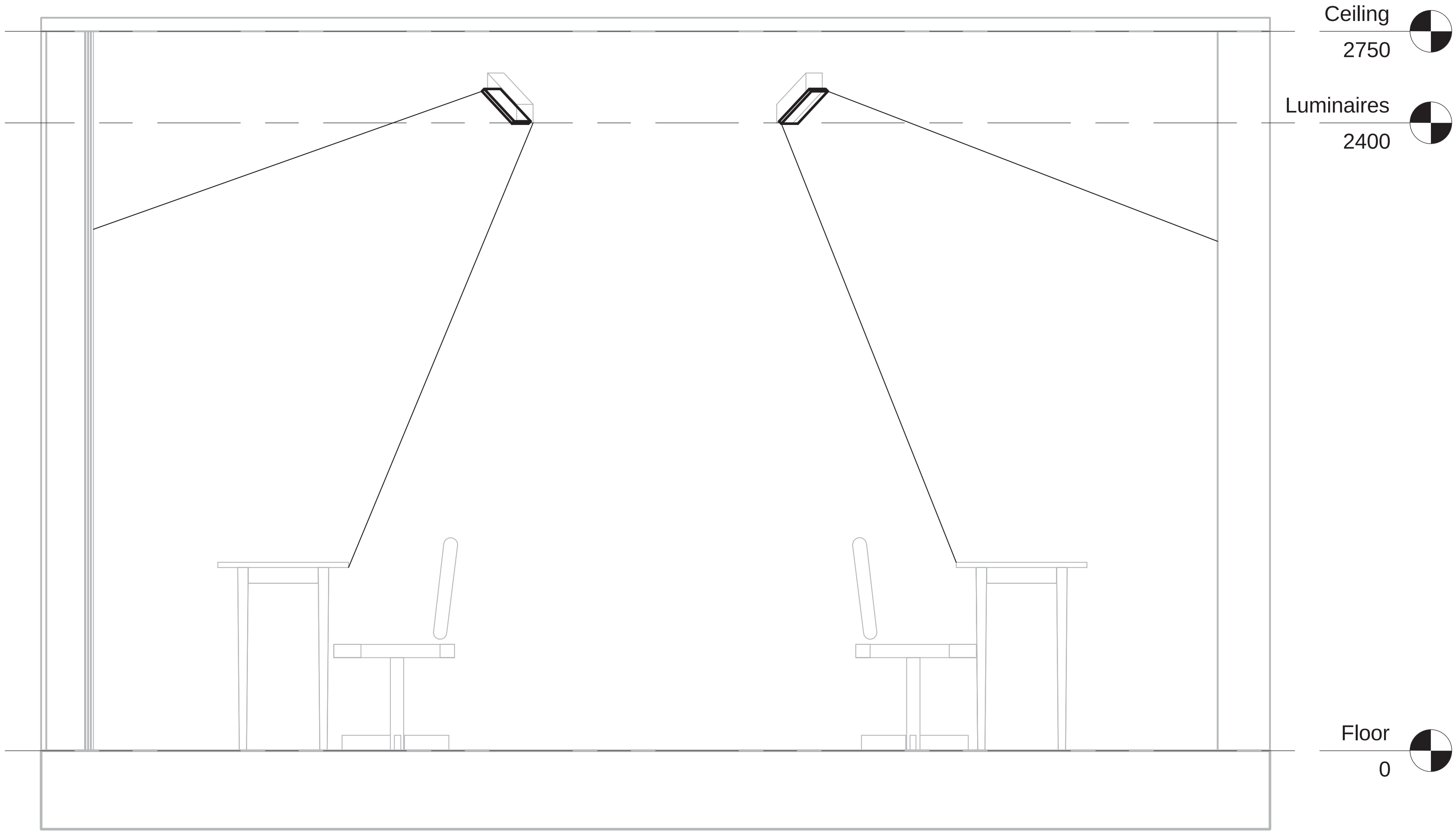
Attachment 1

Plan of experiment room, scale 1:20.



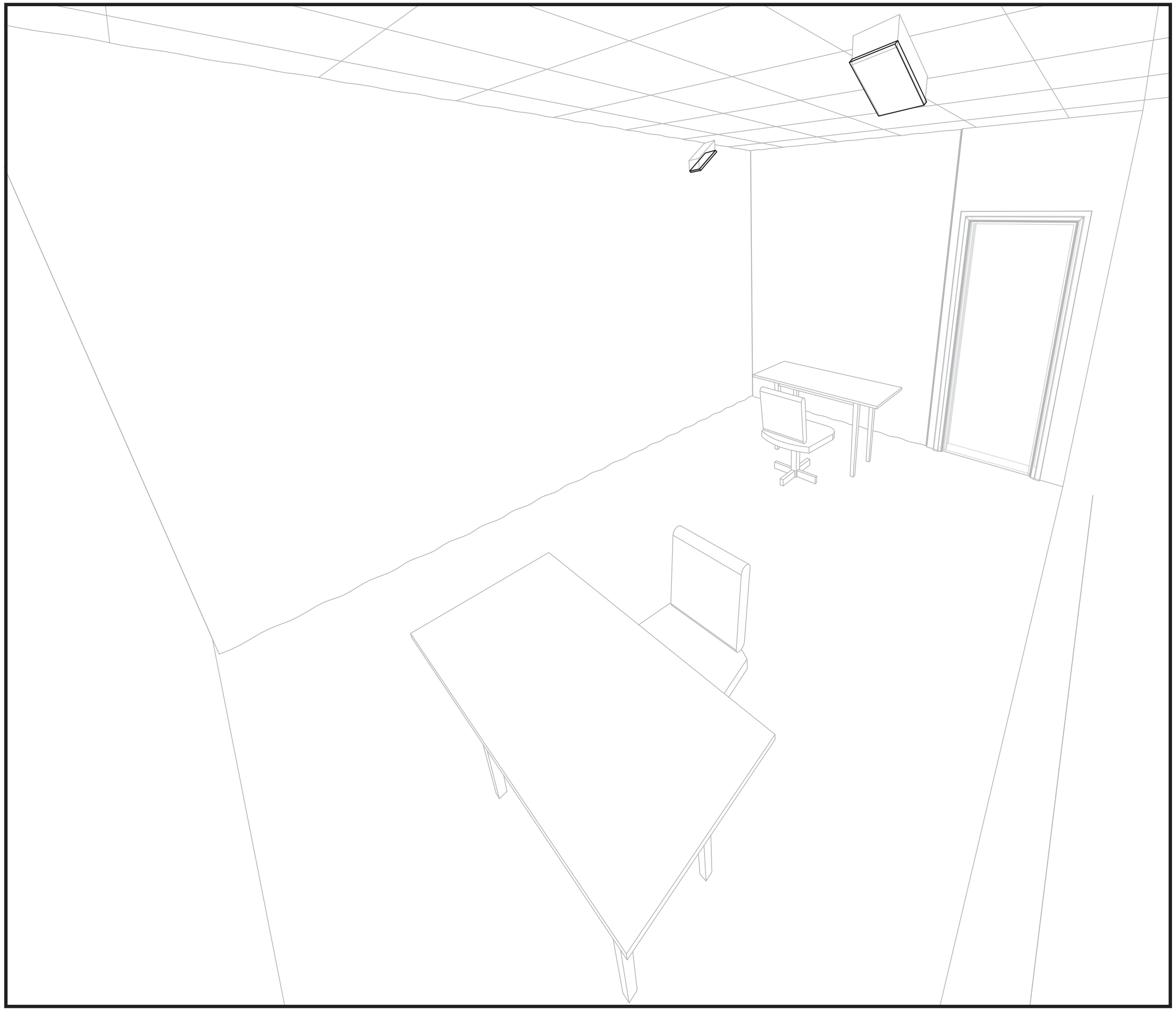
Attachment 2

Section of experiment room, scale 1:20.



Attachment 3

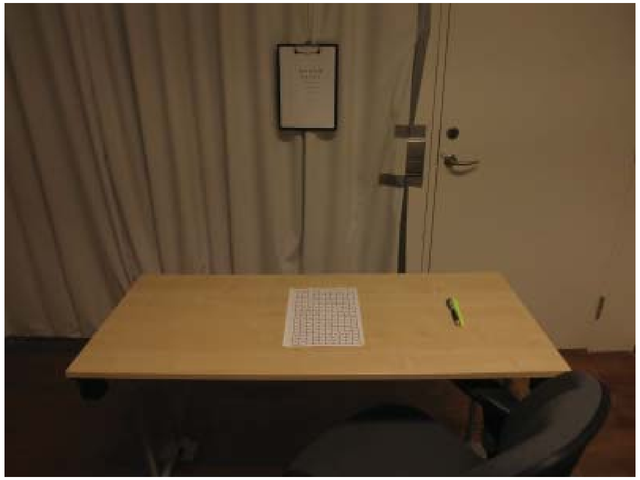
3D view of experiment room.



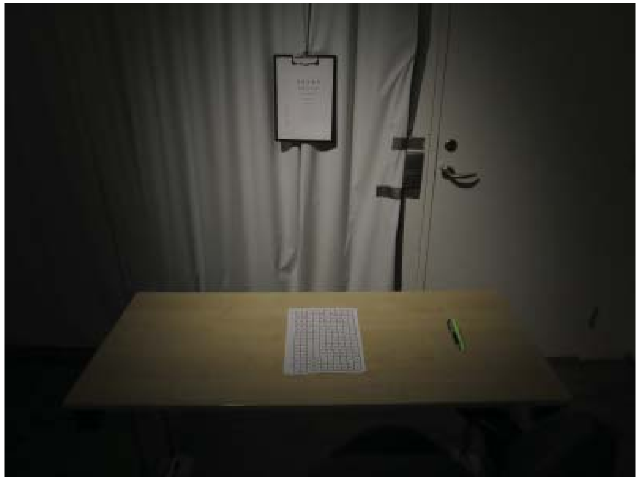
Attachment 4

Photographs of experiment spots. Taken with a Canon Powershot S110, ISO 800, Aperture 8, Shutter Speed 1/30, Manual White-Balance.

Please note that the difference seen on photographs does not correctly describe what humans see when inside the space due to constant eye adaptation.



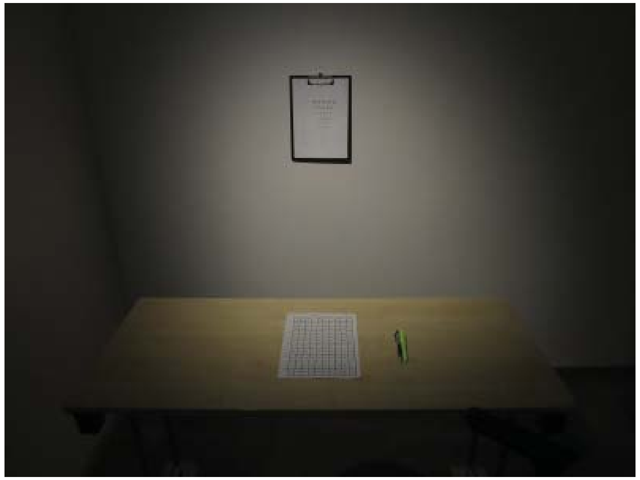
Place 1, light from permanent ceiling fixture.



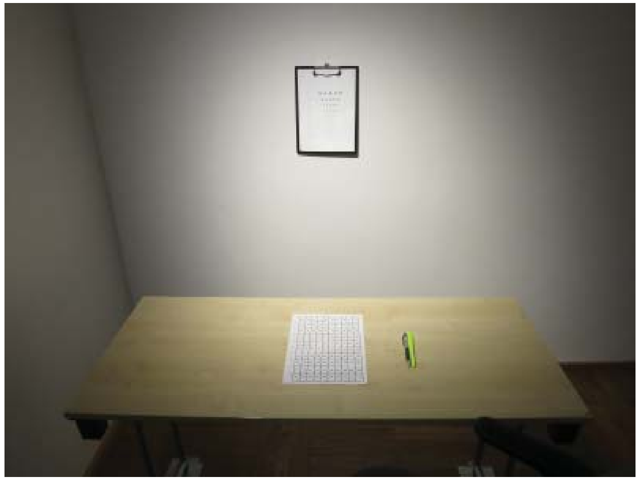
Place 1, 150 lux scene.

Place 1, 500 lux scene

Place 2, light from permanent ceiling fixture.



Place 2, 150 lux scene.



Place 2, 500 lux scene

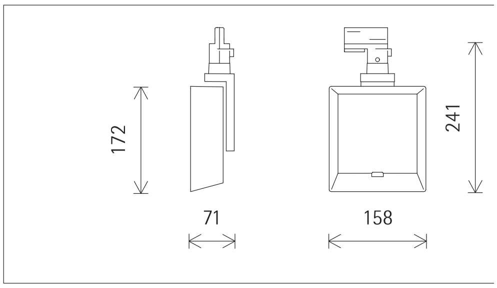
Attachment 5

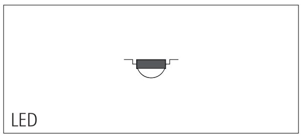
Specification of the luminaires used in the experiment.

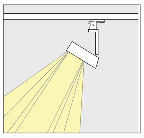
ERCO

Light Board strålkastare

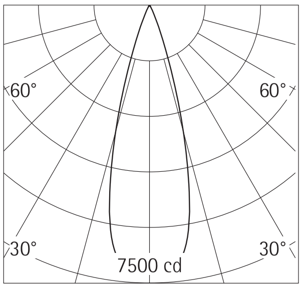
med LED







DALI
PLUG+
PLAY

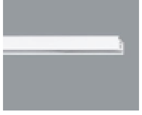


LED 24W 2400lm 4000K neutralvit

h(m)	E(lx)	D(m) 30°
1	7236	0.54
2	1809	1.07
3	804	1.61
4	452	2.14
5	289	2.68

72853.000 Vit
LED 24W 2400lm 4000K neutralvit
DALI
Version 2
Spherolit-lins flood

Produktbeskrivning
Hölje och arm: aluminiumgjutgods, pulverlackerat. Svängbar 0°-90°. Arm vridbar 360° på DALI adaptern. Invändig ledningsdragning.
DALI-driftdon, plug and play-kompatibelt.
ERCO DALI-adapter för DALI-strömskena: Plast.
LED-modul: högeffekt-LED på kretskort med metallkärna. Kollimatoroptik av optisk polymer.
Frontskydd: plast, svart.
Vikt 1,30kg
LMF E

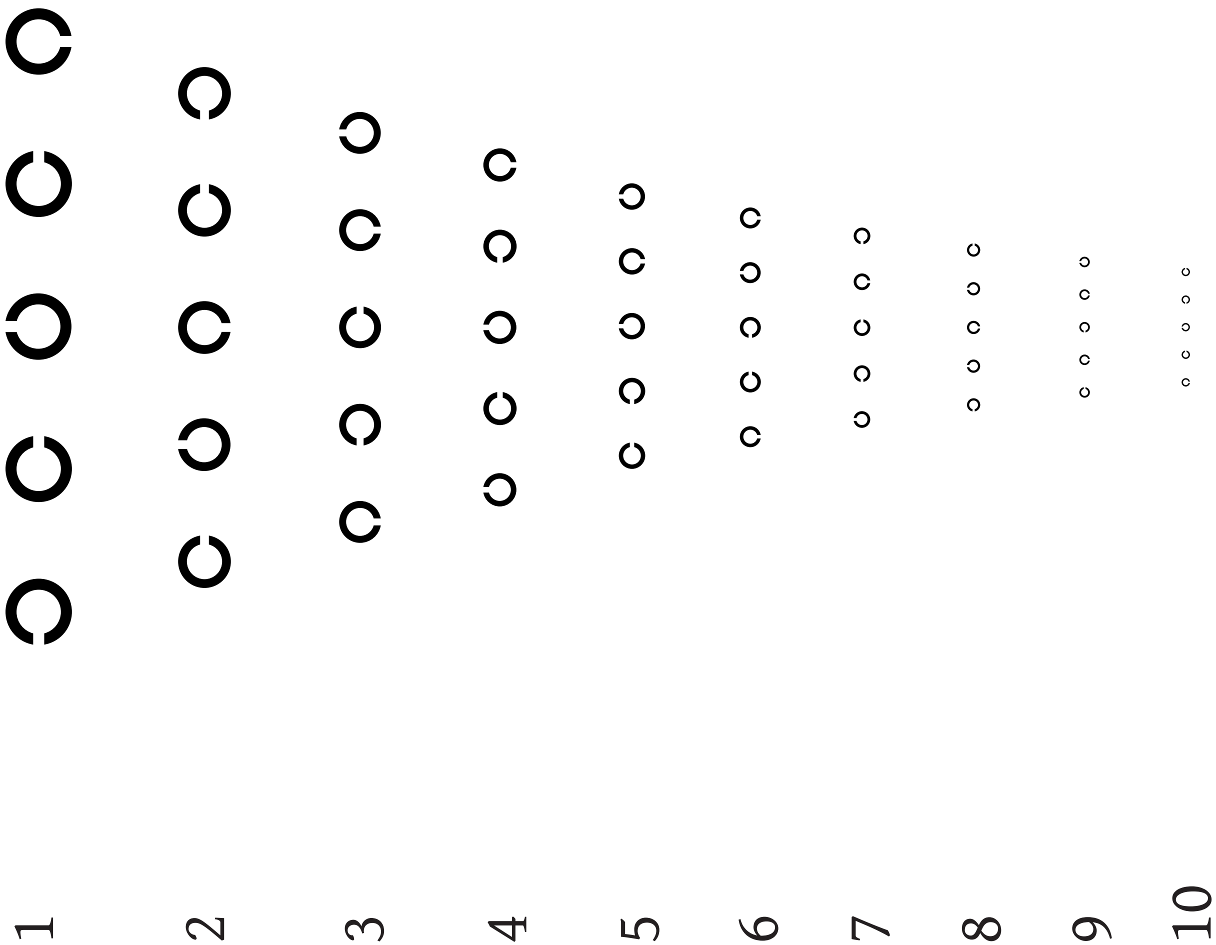


Montering
ERCO DALI strömskena
Hi-trac DALI strömskena
Monopoll DALI strömskena
DALI-uttag

ERCO Lighting AB
Birger Jarlsgatan 46
11429 Stockholm
Sweden
Tel.: +46 8 54 50 44 30
Fax: +46 8 54 50 44 39
info.se@erco.com

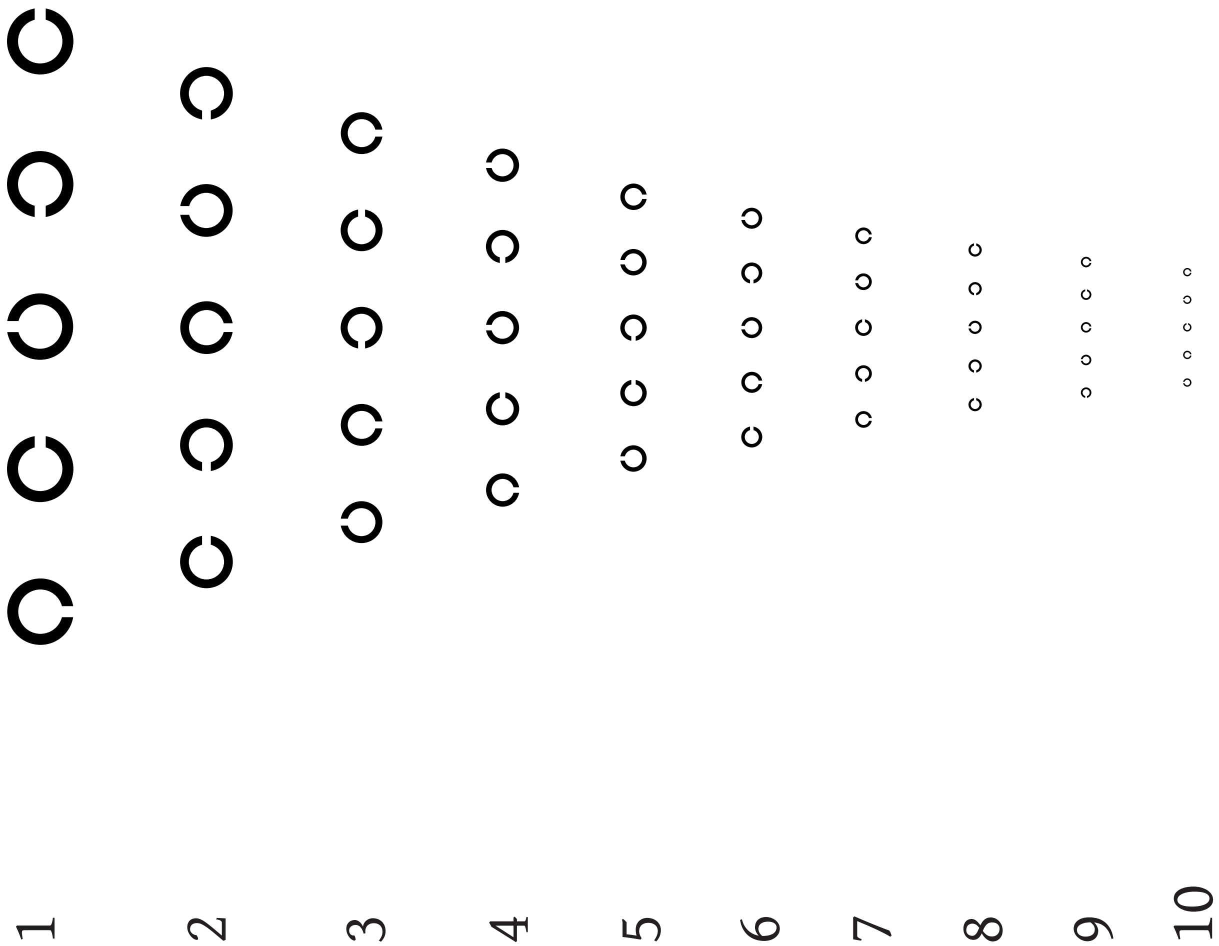
Attachment 6

Landholt Rings chart, type C. Shown here at original size. This chart was used during the explanation of the experiment to participants.



Attachment 7

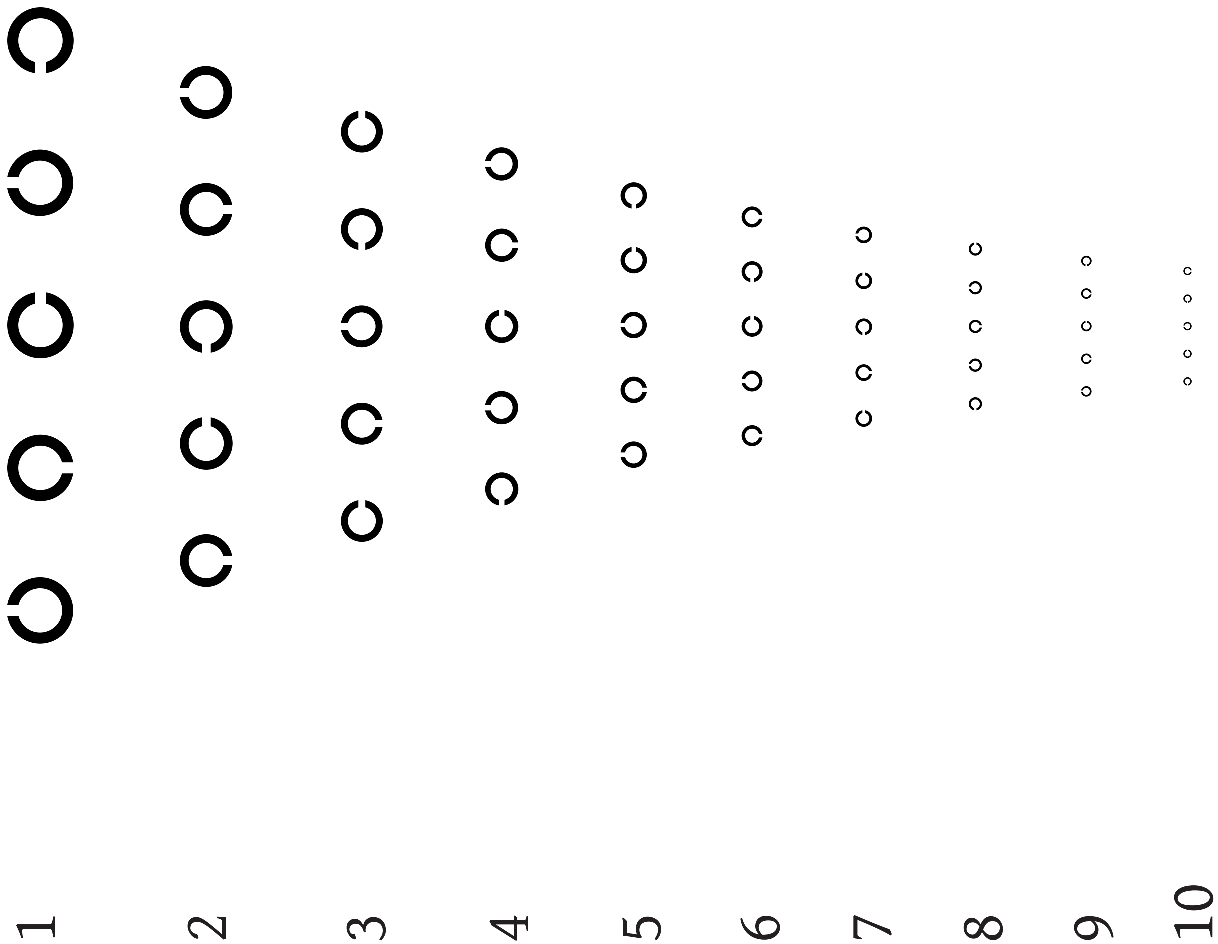
Landholt Rings chart, type A. Shown here at original size. This is one of the two charts used in the experiment.



B

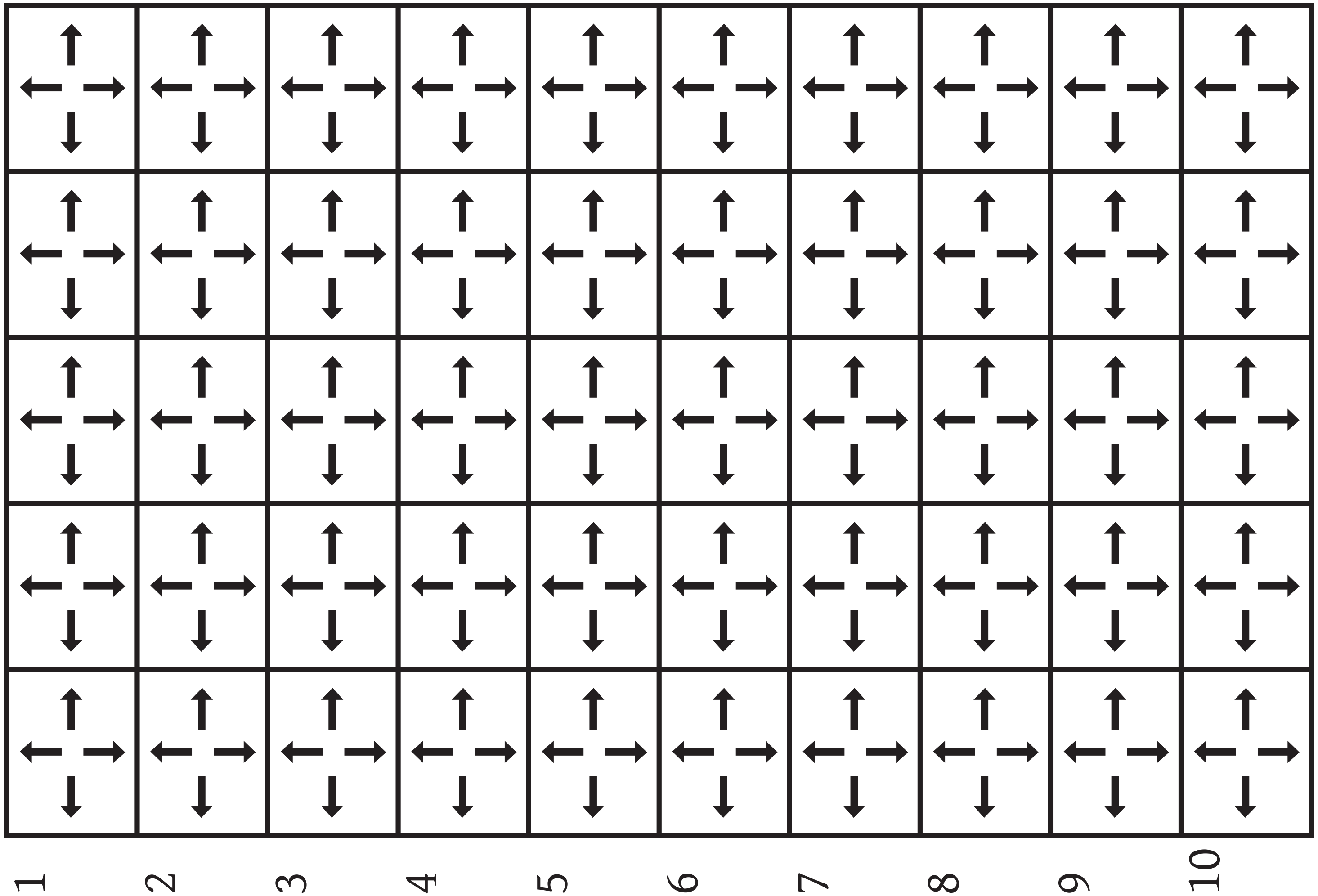
Attachment 8

Landholt Rings chart, type B. Shown here at original size. This is one of the two charts used in the experiment.



Attachment 9

Answer sheet for the Landholt Rings charts. Shown here at 70% of original size.



Attachment 10

Questionnaire Part 1, Evaluation of each lighting scenario.

Hur kändes det att läsa figurerna på väggen?
What did reading the shapes on the wall feel like?

1.	Lätt Easy	O	O	O	O	O	O	O	Svårt Hard
3.	Bekvämt Comfortable	O	O	O	O	O	O	O	Obekvämt Uncomfortable
3.	Avslappnat Relaxed	O	O	O	O	O	O	O	Ansträngande Strenuous

Blir du bländad av någon av ytorna i ditt synfält?
Do any of the surfaces in your feild of view feel glary?

4.	Inte alls Not at all	O	O	O	O	O	O	O	Mycket Very Glary

Hur är skuggorna i rummet?
What are the shadows in the room like?

5.	Mjuka Soft	O	O	O	O	O	O	O	Hårda Sharp

Hur är atmosfären vid skrivbordet du sitter vid?
What is the atmosphere like, where you are seated?

6.	Kall Cold	O	O	O	O	O	O	O	Varm Warm
7.	Ljus Bright	O	O	O	O	O	O	O	Mörk Dark
9.	Klar Clear	O	O	O	O	O	O	O	Dimmig Hazy

Attachment 11

Questionnaire Part 2, Comparison between the two lighting scenarios.

	Nej No	Ja Yes	Om ja, vilken? (1/2) If yes, which? (1/2)
1. Var någon av scenerna behagligare än den andra? Was one of the scenes more comfortable than the other?	O	O	
2. Skulle den ena scenen passa bättre än den andra att arbeta i? Would one of the scenes be more suitable than the other to work in?	O	O	
3. Kändes det lättare att läsa i en av scenerna än i den andra? Did it feel easier to read in one of the scenes than in the other?	O	O	
4. Var skuggorna starkare i den ena scenen än i den andra? Were the shadows stronger in one of the scenes?	O	O	
5. Kändes ljuset starkare i den ena scenen än i den andra? Did the lighting feel brighter in one of the scenes than in the other?	O	O	
6. Kändes ljuset varmare i den ena scenen än i den andra? Did the lighting feel warmer in one of the scenes than in the other?	O	O	
7. Var kontrasten mellan figur och papper större i en av scenerna? Was the contrast between figure and paper larger in one of the scenes?	O	O	

Attachment 12

Questionnaire Part 3, Statistical data.

1. Ålder
Age

O	O	O	O	O	O	O	O	O
10-19	20-29	30-39	40-49	50-59	60-69	70-79	80-89	90+

2.
O Kvinna
Female

O Man
Male

3.
O Högerhänt
Right-handed

O Vänsterhänt
Left-handed

4. Använder du glasögon / linser?
Do you wear glasses / contact lenses?

O Nej
No

O Ja
Yes

5. Utbildning
Educational background

O Grundskola
Elementary School

O Gymnasie
High School

O Högskola / Universitet
University

6. Behöver du höja ljusnivån på platser du normalt vistas på för att se bra?
Do you need to increase the light level at places you normally visit in order to see well?

Ofta (Often) O O O O O O O Aldrig (Never)

7. Hur intreserad är du av belysning?
How interested are you in the lighting around you?

Väldigt (Very Interested) O O O O O O O Inte alls (Not at all)

8. Beroende på vad analysen av experimentresultaten visar kan det bli aktuellt att kontakta ett antal deltagare för yttligare frågor, om du kan tänka dig att delta i detta, ange din epost-adress nedan. Du godkänner i så fall att kontaktuppgiften sparas tillsammans med dina svar, i forskningsrapporten kommer endast anonym data att presenteras.
Depending on what the analysing of this experiment shows, it might become interesting to contact a few participants for further questions, if you agree to participate in this, fill in your email below. By doing so, you accept that your contact information is stored together with your results, only anonymous data will be presented in the experiment report.

Acknowledgements

First of all, I would like to thank all the people who enthusiastically participated in the experiment that this thesis is based on.

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