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How visual ergonomics interventions influence health and performance - with an emphasis on non-computer work tasks

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- with an emphasis on non-computer work tasks

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Evaluations of workplaces and interventions with lighting and spectacles were performed in the studies presented in this thesis. The interventions were evaluated by direct observations such as an expert approach and by indirect observations by means of questionnaires. After the evaluation and measurement of the lighting at the recycling facilities, a number of lighting recommendations were suggested to increase visibility and reduce accident risks.

For the younger postal workers in particular, better lighting reduced eyestrain and musculoskeletal discomfort. Pre-intervention, the individuals with eyestrain had lower productivity than those without; their productivity increased with better lighting.

The musculoskeletal discomfort from the neck decreased especially from the static side for the postal workers after they were provided with correct power in their spectacles. In visually demanding work such as surgery, the luminance contrast within the visual field is essential. It is thus vital to increase the general lighting in an operating room, especially around the operating table, to decrease the luminance contrasts and facilitate the operating personnel's visual ability. In this intervention study, the operating personnel rated the improved lighting as improving their perceived visual ability and a decreasing tiredness.

All together, the studies show that visual ergonomics is a multidisciplinary science that requires a holistic approach. This thesis will hopefully contribute to increasing the awareness of the effects of a good visual environment and its benefits for the individual's health.

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"There are two kinds of light -
the glow that illumines and
the glare that obscures."

- James Thurber

Contents

Abstract

Visual ergonomics evaluations and interventions were performed on non-computer work tasks at recycling facilities, post sorting facilities and operating theatres. The results can to some extent be applicable to other professions and workplaces.

The purpose of the research was to investigate the effects of visual ergonomics interventions on eyestrain, musculoskeletal discomfort, headache, and visual performance at work.

Individuals with eyestrain reported more musculoskeletal discomfort than individuals without eyestrain. Factors shown to have an impact on eyestrain and musculoskeletal discomfort were the visual environment, the individual's perceived visual ability and need for spectacles. Such findings have been reported among computer users. The results presented here show that non-computer work tasks may induce similar findings as well.

Evaluations of workplaces and interventions with lighting and spectacles were performed in the studies presented in this thesis. The interventions were evaluated by direct observations such as an expert approach and by indirect observations by means of questionnaires.

After the evaluation and measurement of the lighting at the recycling facilities, a number of lighting recommendations were suggested to increase visibility and reduce accident risks.

For the younger postal workers in particular, better lighting reduced eyestrain and musculoskeletal discomfort. Pre-intervention, the individuals with eyestrain had lower productivity than those without; their productivity increased with better lighting. The musculoskeletal discomfort from the neck decreased especially from the static side for the postal workers after they were provided with correct power in their spectacles. It is possible to improve the work posture of presbyopic postal workers with customised sorting spectacles, in particular because using the sorting spectacles results in a decrease of the backward tilt of the head.

In visually demanding work such as surgery, the luminance contrast within the visual field is essential. This is especially the case for the scrub nurse who has to look into the very bright operating light and also see the less highly lit instrument table and other important aspects in the operating room. The visual focus of the surgeons is in the operating cavity, and their eyes are completely adjusted to that level. It can take up to two minutes before their vision is fully functioning again after being exposed to the high illuminance from the operating cavity. This poses a risk if something happens in the operating room outside the operating cavity that requires good visibility from the

surgeon. It is thus vital to increase the general lighting in an operating room, especially around the operating table, to decrease the luminance contrasts and facilitate the operating personnel's visual ability. In this intervention study, the operating personnel rated the improved lighting as improving their perceived visual ability and a decreasing tiredness.

All together, the studies show that visual ergonomics is a multidisciplinary science that requires a holistic approach. This thesis will hopefully contribute to increasing the awareness of the effects of a good visual environment and its benefits for the individual's health.

Sammanfattning

Synergonomiska bedömningar och interventioner genomfördes på icke-dator relaterade arbetsuppgifter vid återvinningsanläggningar, postsorteringsanläggningar och i operationssalar. Resultaten kan i viss mån tillämpas på andra yrken och arbetsplatser.

Syftet med forskningen var att undersöka vilken påverkan synergonomiska interventioner hade vad gällande ögonbesvär, muskuloskeletala besvär, huvudvärk och synförmåga. Intervention utvärderades genom direkta observationer, t.ex. en expertbedömning och genom indirekta observationer med hjälp av frågeformulär. Individer med ögonbesvär rapporterade mer muskuloskeletala besvär än de utan. Faktorer med påverkan på ögon- och muskuloskeletala besvär var den visuella miljön, den visuella förmågan samt behov av glasögon. Resultaten visar att även icke-dator relaterade arbetsuppgifter kan framkalla besvär liknande de som tidigare rapporterats bland datoranvändare.

Utvärderingar av arbetsplatser och interventioner med belysning och glasögon utfördes i de studier som presenteras i denna avhandling. Interventionerna utvärderades genom direkta observationer, t.ex. en expertbedömning och genom indirekta observationer med hjälp av frågeformulär.

För yngre brevbärare innebar bättre belysning en minskning av ögon- och muskuloskeletala besvär. Före interventionen hade individer med ögonbesvär lägre produktivitet än de utan, efter interventionen försvann denna skillnad. För brevbärarna som fått styrkan i sina glasögon korrigerad minskade nackbesvären, särskilt på sidan med statisk muskelbelastning under brevsortering. Det är möjligt att förbättra arbetsställningen för brevbärare med presbyopi (åldersynthet) med anpassade sorteringsglasögon vilka ger en förbättrad arbetsställning med minskad bakåtlutning av huvudet.

God luminanskontrast är viktigt vid visuellt krävande arbete såsom kirurgi. Detta gäller särskilt för operationssköterskor som ser in i mycket starkt operationsljus men som även ska kunna se på lägre upplysta instrumentbord och andra funktioner i operationssalen. Kirurgens visuella fokus är i operationsområdet, och dennes ögon är helt ljusadapterade till den höga belysningsstyrka som finns där. Det kan ta upp till två minuter innan deras syn mörkeradapterat för att fullt ut även se övriga delar av operationssalen. I interventionsstudie påvisades att en ny typ av starkare allmänbelysning minskade luminanskontraster mellan operationssåret och omgivningen särskilt runt operationsbordet. Dessutom ökade operationspersonalens synförmåga i kombination med en minskad trötthet.

Avhandlingen visar att synergonomi är en tvärvetenskaplig disciplin som kräver helhetssyn. Den bidrar förhoppningsvis till att öka medvetenheten om effekterna av en god visuell miljö och dess fördelar för individens hälsa.

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I am grateful for having the opportunity to write this thesis on a subject that I am passionate about; even though it has been difficult at times it has still been a stimulating and enlightening process.

My interest in visual ergonomics originated in a course on visual quality offered by the Optometry Department at Karolinska Institute. Bo Persson and Roger Wibom inspired us to consider the importance of the visual environment and not just the lens power or type of lenses needed. I want to offer a special thanks to my favourite teacher there, Ulla Bremö, for challenging me to become better.

When I started working as an optometrist I noticed that many visual problems were related to the lighting situation at work or at home. That discovery resulted in me wanting to know more about lighting, and I went on to study the subject while still working as an optometrist.

After that, Sigbjörn Olofsson, head of Optikerförbundet (Optometry Society of Sweden) at the time, asked if I was interested in applying for a PhD student position. So I wish to say thanks to Optikerförbundet, Optikbranschen and Sigbjörn for supporting me on my path to the licentiate degree.

I received my licentiate degree at Linköping University, Institute of Technology, at the Department of IKP, and I wish to thank to all of my co-workers there. I want to particularly thank Jörgen Eklund and Roger Wibom who guided me along the way. A special thanks to Peder Wibom who taught me a great deal about lighting.

Then I moved back to Skåne with my family and continued my PhD studies at Lund University and the Department of Design Sciences. I wish to thank all of my co-workers there who contribute with energy every day. Going to work at IKDC is something that I do with joy; everyone is so nice and the mixture of backgrounds and interests among the people here often result in new ideas, projects and interesting discussions.

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Finally, I want to thank my family for the tolerance of “Not now – mom has to work!” and the support they have shown for my work. Janne, Alexander and Isak – I love you all!

Glossary

Accommodation – the lens inside the eye becomes thicker to facilitate near distance vision.

Addition – the amount of power the eyes need to focus clearly at a near distance, measured in dioptres.

Adaptation luminance – the eyes adapt to the average luminance within a 20 degree area around the centre of the visual focus.

Asthenopia – An eye condition that manifests itself through nonspecific symptoms such a s fatigue, red eyes, eye strain, pain in or around the eyes, blurred vision, headache and occasional double vision.

BLT – Bright light therapy, light therapy with blue enriched light at high illuminances.

BUT – Break-up time is used to assess the quality of the tear film. It is the time it takes for the outer tear film layer to break up before the next eye blink. It is visible when staining the eye with fluorescein. If the time is too short, so that the normal blink reflex is too long compared to the break-up time, the individual needs to blink more often. When looking at a computer screen the blink rate is reduced by about 70% and if the break-up time is too short, the individual will experience dry eyes.

CCT – Correlated colour temperature is a way to describe the colour of the light by using Kelvin (K). The CCT scale starts with warmer light and the higher the colour temperature, the cooler the light. Warm white is 3000K and daylight is between 5000 and 6500 K.

Circadian system – The human sleep-wake cycle that can be affected by blue-enriched light via the photosensitive retinal ganglion cells on our retinas.

Computer PAL – Progressive addition lenses, either room PAL, near PAL or single vision lenses. Spectacles adjusted for the distances used while performing computer work. (See **PAL**, **Work PAL** and **Room PAL** for more information).

CRI – Colour rendering index indicates how well a colour can be perceived correctly under different light sources. The CRI is measured on a scale of 1-100, the higher the CRI, the better colours are perceived under that light. The rating consists of a general index (CRI) which is the mean of a value coming from a rating of eight colours with the light source being evaluated compared to a reference illuminant with the same CCT.

Disability glare – Stray light that casts a veiling luminance on the retina, reducing image contrast and impairing vision, making it harder to see clearly.

Discomfort glare – Glare that causes annoyance by too intense illumination or a too high luminance contrast within the visual field, often so much that it causes a diversion of the eyes, looking away.

Fixation disparity is a small misalignment of the eyes when viewing with binocular vision. The misalignment may be vertical, horizontal or both and is measured in prism dioptres.

Light – In this thesis, light is defined as the visible part of the electromagnetic spectrum, the human visual response, with a sensitivity spectrum of 380-780 nm.

Melatonin – A sleep hormone. The levels are low during the daytime and increase at night.

Mesopic vision is the intermediate zone between the photopic and scotopic vision.

Miosis – This is when the pupil becomes smaller (constricts) in response to accommodation or an increase of light entering the eye.

Near triad – When trying to see clearly at a near distance three things happen that are included in the near triad: accommodation (the lens becomes thicker), convergence (the two eyes converge to a near focus point) and miosis (smaller pupil to enhance focus).

Nomogram – nomograph or alignment chart is a graphical calculating device, a two-dimensional diagram designed to allow the approximate graphical computation of a function, usually consisting of three scales where two values from two of the scales are known. By drawing a line between the two known values a third value can emerge.

PAL – Progressive addition lenses. When looking straight ahead in a PAL the eyes are looking through the "far distance" zone. When lowering your gaze to the bottom of the lens the eyes are looking through the reading zone (focussing at about 40-60 cm, depending on the addition), in between these zones there is the intermediate zone which allows focussing for the distances in between 60cm and 2m.

Photopic vision – Vision with eyes adapted to light. It occurs when the adaptation luminances are higher than approximately 3 cd/m^2.

Presbyopia – Presbyopia is a condition where, with age, the eye exhibits a progressively diminished ability to focus on near objects. With age the lens becomes more rigid leading to a loss of accommodation.

Room PAL – Progressive addition lenses, computer lenses. In room PALs there are mainly three zones: the computer distance (when looking straight ahead through the lens), reading (when looking down at the table), and a room distance (usually 3-4 m) when looking through the upper part of the lens.

Scotopic vision – When there are low levels of light the scotopic vision is active and some of the 115 million rod photoreceptors are used. Scotopic vision occurs at less than 0.001 cd/m^2. Scotopic vision is more sensitive to the shorter wavelengths such as blue, cool light.

VDU – Visual Display Unit, Computer Screen

Work PAL – Progressive addition lenses (computer lenses) mostly designed for computer work. In near work PALs there are only two distances: computer distance (looking straight ahead in the lens) and reading distance (looking down at the table).

Appended papers

Paper I
Hemphälä, H., Kihlstedt, A., Eklund, J., 2010, Vision Ergonomics at Recycling Centres, *Applied Ergonomics*, 41, 368-375

The authors designed the study together. I performed the measurements, drew the conclusions and was the main author.

Paper II
Hemphälä, H., Eklund, J., 2012, A Visual Ergonomics Intervention in Mail Sorting Facilities: Effects on Eyes, Muscles and Productivity, *Applied Ergonomics*, 43, 217-229

The authors designed the study together. I performed most of the study, carried out the measurements, followed up on the intervention and analysed the data. I was the main author.

Paper III
Hemphälä, H., Nylén, P., Eklund, J., 2013, Optimal Correction in Spectacles – Intervention Effects on Eyestrain and Musculoskeletal Discomfort Among Postal Workers, *WORK: A Journal of Prevention, Assessment & Rehabilitation* (accepted for publication)

I initiated and designed the major part of the study. I performed the study, gathered the data, analysed the data and was the main author.

Paper IV
Hemphälä, H., Dahlqvist, C., Nordander, C., Nylén, P., Gao, C., Kuklane, K., Hansson, G-Å., 2013, Working Spectacles for Sorting Mail, *WORK: A Journal of Prevention, Assessment & Rehabilitation* (accepted for publication)

The authors designed the study together and I initiated it. I participated in all the measurements and was in charge of the intervention and was the main author.

Paper V

Hemphälä, H., Johansson, G., Larsson P.A., Borell, J., Xu, Y., Odenrick, P., Nylén, P., 2013, Evaluating General Lighting Situations in an Operating Theatre, *Lighting Research and Technology* (submitted)

The authors designed the study together. I performed all of the measurements and tests and was the main author.

Paper VI

Hemphälä, H., Larsson P.A., Nylén, P., Borell, J., Runefors, M., Odenrick, P., Johansson, G., 2013, Lighting Intervention for an Operating Theatre, *British Journal of Surgery* (submitted)

The authors designed the study together. I performed the data collection and I was the main author.

1 Introduction

There are three main areas in visual ergonomics: the physical environment, the individual's visual ability, and the work task. The physical environment concerns artificial lighting, ergonomics, workplace design, daylight, etc. The individual's visual ability concerns visual acuity, individual correction, ageing of the eye, work spectacles, etc. The work task concerns readability, visibility of the work object, visually demanding work, etc. An insufficient physical environment or insufficient visual ability will increase the risk for eyestrain, musculoskeletal discomfort, headaches, and can negatively affect the individual's work performance. The Swedish Work Environment Authority (SWEA) has published Belastningsergonomi (in Swedish) "Physical Workload and Ergonomics" (AFS 2012:2) which contains regulations and advice. It states that visual conditions should be investigated to see if they negatively affect work postures and movements.

The following definition of visual ergonomics has been approved by the International Ergonomics Association's Technical Committee for Visual Ergonomics (IEA, 2012).

> Visual ergonomics is the multidisciplinary science concerned with understanding human visual processes and the interactions between humans and other elements of a system. Visual ergonomics applies theories, knowledge and methods to the design and assessment of systems, optimising human well-being and overall system performance. Relevant topics include, among others: the visual environment, such as lighting; visually demanding work and other tasks; visual function and performance; visual comfort and safety; optical corrections and other assistive tools.

According to Vos (2009), visual ergonomics is a joint venture of illuminating engineering, vision research, optometry and ergonomics.

> Visual ergonomics is just a term but paraphrasing Goethe's famous saying, this term may have been just the work needed to formulate a completely different approach to the visibility problem. Once having the term, the direction of thinking follows suit. (Vos, 2009, p. 128)

Visual ergonomics is an attitude, a perspective "to consider problems from the viewpoint of human visual capabilities" (Vos, 2009, p. 128). See Figure 1.1.

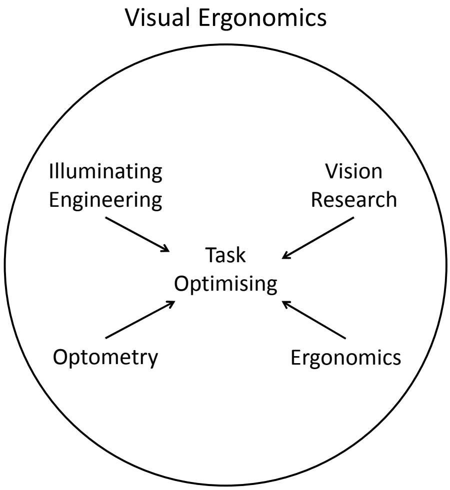

Figure 1.1.
Visual ergonomics – a joint venture of illuminating engineering, vision research, optometry and ergonomics (modified after Vos, 2009, p. 128).

1.1 Visual ergonomics studies

In lighting intervention field studies it is usually difficult to distinguish between the contribution of lighting and other changes such as décor, furnishings and people. Reported lighting interventions where just the lighting has been changed are very rare (Boyce, 2003). According to Cuttle (2013) there is a considerable difference in what lighting designers consider to be the purpose of the lighting: whether it is to provide visibility or appearance. This divides lighting professionals into two distinct camps with a focus on different factors, and the differences appear to be widening. Cuttle (2013) states that this can result in more visual performance problems at work, due to increased glare luminance contrasts that are too high within the visual field when the lighting designer is only focused on the appearance of the room.

Since visual ergonomics has multifaceted problems, it is important to work with other professions in a multidisciplinary holistic manner when evaluating the visual ergonomics environment (Long, 2012; Long & Helland, 2012). To understand these issues at a higher level, to see what needs to change at a workplace to improve the visual environment, and to understand the individual's visual requirements requires collaboration, especially between lighting designers, ergonomists, and optometrists with a degree in visual ergonomics.

There are several factors to consider when developing a visual ergonomics risk assessment of subjective symptoms and discomfort from the eyes (Conlon et al., 1999;

Borsting et al., 2008; Knave et al., 1985). Checklists are also used in eye examinations or assessment visits (Sheedy & Shaw-McMinn, 2002; Wilson & Corlett, 2005).

Steenstra et al. (2009) have published an eye-complaint questionnaire. They found that depending on the time of day, there was a considerable difference in the prevalence of reported complaints from 66% to 93%. In their study, questions about teariness, tiredness, itchiness, redness, dryness, eye pain, and difficulty seeing clearly were included on a seven graded scale from not at all to very much.

2 Research objectives

The overall aim of this thesis was to investigate the influence of visual ergonomics interventions on eyestrain, musculoskeletal discomfort, headache, and visual performance in non-computer work tasks.

The research questions were:

- Do individuals with subjectively reported eyestrain report more musculoskeletal discomfort? (Paper II, Paper III, Paper V)
- How will an improved visual environment influence visual performance and/or visual ability, eyestrain and/or musculoskeletal discomfort? (Paper II, Paper VI)
- How will a change to correct power in spectacles (improved visual ability) influence eyestrain and musculoskeletal discomfort? (Paper III)
- How will a correct type of lens for presbyopic individuals influence work posture and thereby risks for eyestrain and musculoskeletal discomfort. (Paper IV)
- What factors are important when suggesting lighting recommendations and performing lighting interventions to improve visual performance? (Paper I, Paper V, Paper VI)

3 Theoretical framework

3.1 Visual ergonomics

If the visual environment is inadequate, we strain our eyes (Hopkinson & Collins, 1970; Sheedy et al., 2003; Boyce, 2010) and our bodies to improve our vision (Helland et al., 2008; Zetterberg et al., 2013; Anshel, 2005). It is important to reduce the health risks that can arise from insufficient lighting and therefore have good working standards on how the lighting should be for that specific work task (Horgen, 2003).

There are several such standards. Two examples are the “American National Standard Practice for Office Lighting” (ANSI/IESNA RP-1-04, 2004) and the European Standard, “Light and Lighting – Lighting of Work Places – Part 1: Indoor Work Places (SS-EN 12464-1, 2011). These offer recommendations for how to design specific facilities. Unfortunately, they only provide recommendations in terms of illuminance (lux), and for a younger person the recommended value is often too high. According to Weston (1962), the loss of visual accommodation (presbyopia) begins around 45 years. The eyes then need more light – higher illuminance – so that the pupils become smaller to enhance focus and depth perception. A 60-year-old individual needs at least three times more light than a 20 year old.

3.2 Visual system

A well-functioning visual system is essential in visually demanding work (Anshel, 2005). The eventual individual refraction errors have to be adjusted with spectacles and the presbyopic effects have to be corrected. With age, presbyopia will negatively affect the ability for the eye to accommodate, which will then affect the near-triad and result in a need for increased illuminance in order to see clearly at a near distance. The binocular function has to be examined and if any irregularities exist, they have to be corrected as well. Visually demanding work, such as computer work, is associated with eye problems, headaches and muscle pains in the neck and shoulders (Rosenfield, 2011). For computer workers in North America, studies show that 75-90% of the subjects reported subjective eye symptoms or computer vision syndrome (CVS) (Anshel, 2005). In a study by Glimne et al. (2013), the binocular visual ability was affected negatively by glare, and an increase of fixation disparity was found when performing tasks binocularly at a viewing distance of 60 cm. Measuring fixation disparity in a clinical optometric diagnosis is well documented and based on the assumption that when the binocular alignment is under stress, it will have a negative effect on the binocular visual function.

Specific work spectacles may be needed in some occupations, especially for individuals developing presbyopia. Most focus has so far been on computer spectacles, although there are other occupations that need a specific solution for their spectacles while at work. SWEA has published regulations that cover specific spectacles for working at a computer (AFS 1998:5). The remaining occupations in need of work spectacles are covered by other sets of regulations: "Workplace Design" (AFS 2009:02) and "Use of Personal Protective Equipment" (AFS 2001:3). The wrong type of lens in spectacles or the wrong power can cause eyestrain that can contribute to musculoskeletal discomfort (Horgen, 2003).

According to Horgen et al. (2012) elderly individuals that still live in their own homes usually have low illuminance levels and these need to be further optimized. Older adults tend to exhibit a contrast sensitivity loss that is aggravated by decreasing luminance (Sloane et al., 1988). Flicker and amount of luminance affect contrast sensitivity for all humans (Sloane et al., 1988).

The pupil size can change from about an 8 mm diameter to about 2 mm; the higher luminance the smaller pupil. The pupil size becomes smaller with age, especially in scotopic and mesopic vision, which results in less light reaching the retina (Watson & Yellot, 2013). Miosis caused by accommodation differs depending on age; the harder it is to accommodate (straining your eyes) the more activated is the pupil – the pupil diameter changes more often (Radhakrishnan & Charman, 2007). The size of the pupil is predominantly controlled by the scotopic energy content from the light present. Light sources with a high scotopic component (cool light) or a large scotopic/photopic (S/P) ratio are more visually efficient and can be operated at a much lower power than a lamp with a low S/P ratio (Berman, 1992).

The adaptation luminance is estimated as the average luminance within about 20° of the fixation point. If the observer has many fixation points, the average luminance should be an estimation of the whole visual field. The periphery of the visual field is basically a detection system indicating where in the visual field the fovea should be directed. The fovea – the part of the retina where we see clearly – is about 1° of the total visual field (Boyce, 2003).

3.3 Light

According to Mainster and Turner (2012), one of the most common inconveniences of light is glare. Glare is caused by light entering the eye that does not aid vision. Disability glare, or stray light, casts a veiling luminance on the retina, reducing image contrast and impairing vision, making it harder to see clearly. Discomfort glare causes annoyance because of too intense illumination or a too high luminance contrast within the visual field. Discomfort glare is a normal response to abnormal illumination; the threshold (photosensitivity) varies considerably between individuals. Older individuals are more sensitive to glare. It takes them longer to adapt from one light level to another (North, 1993). When measuring disability glare, it is important to measure the difference in contrast sensitivity or visual acuity caused by the glare source according to Zadnik (1997).

The standards provide a glare index that is so complex to calculate (one value is calculated for each line of sight) that it is not used in the regular lighting design process. To use luminance contrast ratios is one way to control the visual environment for the work task. Luminance contrast ratios do exist in some specific standards, such as "The Lighting Handbook" of the Illuminating Engineering Society of North America (IESNA, 2011; ANSI/IESNA RP-1-04, 2004), where they have recommendations for luminance contrast ratios. Unfortunately, this is not something most lighting designers use when designing a facility.

If there is daylight present in a workplace the reported eyestrain is significantly less. Glare is also more tolerated if it comes from daylight compared to artificial light (Dubois & Blomsterberg, 2011). Daylight contributes to the dynamic changes of the visual work environment by having a positive influence on mood and stimulation (van Bommel & van den Beld, 2004).

Light can affect our alertness levels via the photosensitive retinal ganglion cells in our retinas (Brainard et al., 2001) and affect our melatonin onset/offset and circadian system. The amount of blue enriched light, called circadian light, along with the time of exposure and its duration can boost the circadian rhythm (Rea, 2011). Bright Light Therapy (BLT) at lower levels can also affect the melatonin levels and the circadian rhythm depending on the wavelength spectrum, amount of illuminance hitting the eye and time of day for the exposure. Lowden et al. (2004) found that BLT at 2500 lx administered at breaks during night work supressed sleepiness and the melatonin levels. But other studies have shown an increased risk for breast cancer when working at night. One hypothesis is that the increased risk is caused by melatonin levels that are too low during the night due to the stimulating effect of light on circadian rhythm (Cos et al., 1991; Hansen, 2001; Lie et al., 2006).

3.4 Task performance

One factor that supports a good visual environment is a highly visible work task object. One of the first recommendations for the visual work task was a nomogram, where you can decide the minimum detail of a work task for a specific viewing distance and visual acuity of the individual (Weston, 1962). Weston was one of the first researchers in the field of work and light. He introduced the term "visual performance" in many reports and articles in the 1940s. In his book "Sight, Light and Work" (Weston, 1962), there is a chapter entitled "Ergoramic Lighting". Today we would most likely call this "ergonomic lighting" or "task-specific lighting".

Weston (1962) found that those individuals that are provided the highest amount of illumination are satisfied that they yield better results than lower values do. However, this does not mean the highest values are the best. It comes down to the saying "the more the better", which is not always the case when it comes to lighting. Good lighting research should study the relationship between illumination and visual efficiency.

Lighting, vision and posture are different factors that can contribute to visual performance, which is why it is important to carry out a workplace evaluation. Anshel (2007) recommends the following for a workplace lighting evaluation:

- Use a luminance meter, a general illuminance meter, a tape measure, and possibly a camera.
- Consider the general room illumination and placement of luminaries in relation to workstations.
- Check lighting on the work area and determine whether task lighting might be appropriate.
- Talk to employees to determine if any subjective complaints exist.
- If possible, include pictures in a report to effectively demonstrate visual stress concerns to management.

According to Boyce (2003), lighting can affect human performance via three routes: through the visual system/visual performance, the circadian system/alertness, and the perceptual system (see Figure 3.1). The effect from lighting is the most obvious: with light we can see, without light we cannot. The stimulus to the visual system is described by five parameters: visual size, luminance contrast, colour difference, retinal image quality, and the retinal illumination. The effect on our circadian system can be a shift in our circadian rhythm or a suppression of the melatonin levels. The effect on the perceptual system can cause a sense of visual discomfort due to glare or flicker that can affect the worker's mood and motivation, particularly if the work is prolonged. Lighting a visually demanding task is difficult; there are many factors that can contribute to visual discomfort.

The most common effect of lighting on health is eyestrain. According to Boyce (2010), eyestrain is likely to appear whenever the viewer experiences: visual task difficulty, under- or overstimulation (the visual environment presents too little or too much information), distraction (main focus is on other objects than the work task), and/or perceptual confusion (hard to discriminate the work task from the

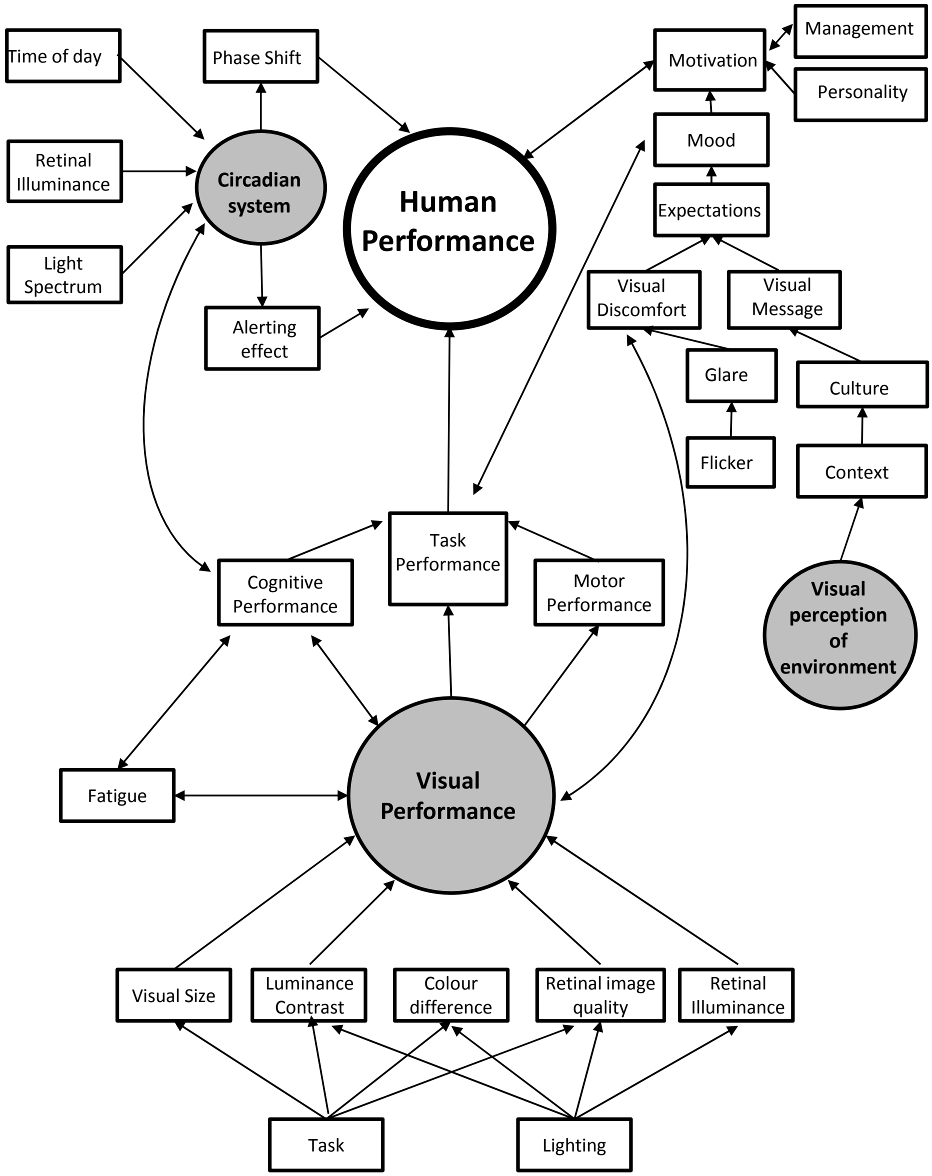

Figure 3.1
Human visual performance is affected via three routes: visual performance, the circadian system, and the perceptual system (modified after Boyce, 2003, p. 124).

environment). These problems can be caused by poor lighting, inherent features of the task and its surroundings, an inadequate visual system, or a combination of these factors. There are two mechanisms of visual performance that can cause eyestrain: the physiological and the perceptual. The physiological consists of muscular strain in and around the eyes due to a straining of the vision. The perceptual is the stress that occurs when a person's visual system experiences difficulties in making sense of the visual environment due to luminance contrasts that are too high within the visual field.

A high level of visual performance without visual discomfort can reduce the negative effects of prolonged work. This can be achieved by improving the quality of the retinal image by ensuring correct optical refraction for the individual, by lighting the task well above the necessary level required, and by good visibility of the work task in terms of size, luminance contrast, and colour difference (Boyce, 2003).

If an individual needs a specific power in his or her spectacles, or a specific work spectacle, such as work progressive computer lenses (computer PAL), providing them will increase that individual's productivity. A Finish study concluded that 59% of the employers reported that the cost of computer PAL was recovered through reduced sick leave and increased productivity (Niskanen et al., 2010).

3.5 Physical environment

The sensation of fatigue of discomfort in the eyes is more common when eyestrain is present. Prolonged performance of a visual task or a task made difficult by poor lighting may well lead to symptoms such as soreness, irritation and general discomfort of the eyes, and if muscular fatigue is involved these visual symptoms will be displayed together with headaches, fatigue and tiredness (Hopkinson & Collins, 1970).

In office landscapes it is hard to provide a good visual environment. The risk for glare increases when trying to design an office landscape to suit all employees. In one study by Gavhed and Toomingas (2007), glare or reflexion was present at almost 70% of the workstations.

The visual discomfort increased in a study by Helland et al. (2008) when the participants moved from a single unit office to an office landscape with similar ergonomic design. Visual discomfort explained the majority of the neck and shoulder pain the personnel experienced after the move.

In another study about a move from a poorer ergonomic design to an office landscape with better ergonomic structure, there was no significant change in visual discomfort. But the lighting was better in the office landscape with a lower risk for glare (Helland et al., 2008).

In a third study, Helland et al. (2011) investigated a move from single unit offices to an ergonomic office landscape workplace with optimised luminaires and optometric correction. The participants reported less glare, a reduction of visual discomfort, fewer headache, etc.

In a hospital study, it was discovered that radiologists reported a higher degree of eyestrain than ophthalmologists, with eyestrain indexes of 8.4 to 4.1(eyestrain index calculated according to Knave et al., 1985), respectively. Women reported significantly more eyestrain than men, more than double (Teär Fahnehjelm et al., 2012). The factor behind this could be the intensive computer work in dark rooms looking at X-rays, for example.

Other factors besides lighting at workplaces that can affect vision or the eyes are for example, smoke, dust, and humidity (Wolkoff, 2013) Mocci et al. (2001) found a correlation between visual discomfort (asthenopia) and the environmental factors of noise and smoke. According to Pansell et al. (2007), the tear film stability and the “break-up time” (BUT) also contributes to the feeling of dryness in eyes. Exposure to ultraviolet radiation affects the eye and can cause photokeratitis of the cornea; electromagnetic radiation in the 400-1400 nm range can damage the retina by heating the tissue - a chorioretinal injury (e.g. “blind spot”) caused by a prolonged exposure to intense radiation (Boyce, 2010). Infrared radiation can cause cataract (“glass workers cataract”) (Lydahl & Glansholm, 1985). Medical staff who are exposed to low doses of ionising radiation such as X-ray are at higher risk for developing cataracts (Chodick et al., 2008). Within the visible spectra, the blue light with the highest energy can cause photoretinitis (“blue-light hazard), when a person is exposed to large amounts of light. Usually the glare is too bright and the eyes converge, avoiding damage (Boyce, 2010).

Visual ergonomic problems also exist in professions where computer work is not dominant. It is not only our health and well-being that are affected by a poor visual ergonomic work environment, but also the quality of our work and our task performance (Eklund, 2009).

A database literature search was carried out in Scopus, Medline and Google Scholar using the following search terms: “lighting/illuminance”, “eye/vision”, “strain/load” and excluding all computer work. No references were found regarding lighting intervention studies that analysed visual comfort, eyestrain or musculoskeletal load.

3.6 Psychosocial conditions

The lighting at a workplace can induce positive effects and influence task performance (Baron, Rea & Daniels, 1992). The light distribution and the availability of individual light controls have a positive effect on ratings of comfort at the workplace (Boyce et al., 2006).

In a study by Mocci et al. (2001), a correlation was found between the psychosocial environment and visual discomfort (asthenopia). The individuals with asthenopia experienced low co-worker support, group conflict, underuse of skills, high workload, low self-esteem, role conflict and role ambiguity.

Pain, such as headache, involves both a sensory and an affective component. A negative affect, such as a negative response to the psychosocial environment (anxiety, depression and anger), and emotions can influence the likelihood an individual will experience a headache attack, the intensity of headache pain, and headache-related disability (Nicholson et al., 2007).

According to Nahit et al. (2001), “psychosocial factors, in particular aspects of job demand and control, influence the reporting of regional musculoskeletal pain” that occurs “even after only short term exposure. The odds of reporting these adverse exposures are increased when pain is reported at multiple sites” (Nahit et al., 2001, p. 1378).

Veitch et al. (2011) found that light appraisals predict workplace satisfaction and work engagement. People that rate their lighting as good will also rate their room as more attractive, be in a more pleasant mood, be more satisfied with the work environment and more engaged in their work (see Figure 3.2). It is therefore important to investigate what employees think of their lighting, as this will affect work satisfaction and work behaviours. Before the study by Vetich et al., the hypothesis was that the lighting appraisal would have an effect on task performance, but no such connection was found. This reflects the separation between the purely visual aspects of work performance and the role of affective responding to the work environment.

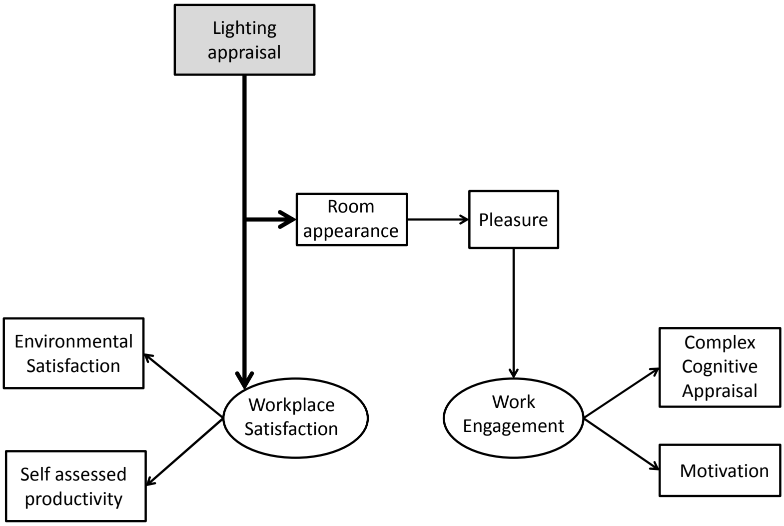

Figure 3.2.
Model of the chain of variables that influence work behaviours, modified after Veitch et al. (2011)

In 1930 Pennock published an article about studies performed at the Western Electric Company at the Hawthorne Factory in Chicago. Previous studies had been performed there to examine the effect of increased illuminance on productivity. The workers at the factory produced better when the illuminance levels were increased, so the levels were increased again and the workers' production increased even more. They then decreased the illuminance levels, but again there was an increase in productivity. Pennock came to the conclusion that this showed a "Hawthorne effect", that it was the attention from the researchers and their interest in the employee's work that resulted in the difference in productivity. It was the emotional effect among the employees that was the main contributor to increased productivity. Mayo (1960, year uncertain) continued with Pennock's study and concluded that if the psychosocial environment was good, productivity increased. In 2011 the old material from Pennock's study was found and examined again by Levitt and List (2011). They found that the lighting intervention study was poorly performed and left many questions unanswered. But the Hawthorne effect has had a large impact on research in the psychosocial work environment. Without these initial studies, the work environment might not have been researched as extensively as it has. The Hawthorne effect now refers to subjects changing their behaviour because they know they are being studied, not in response to the experimental intervention, and is often connected to lighting interventions.

3.7 Eyestrain

Eyestrain is according to Knave et al., (1985) a syndrome consisting of up to eight symptoms; smarting, itching, gritty feeling, aching, sensitivity to light, redness, teariness and dryness.

According to Sheedy et al. (2003), eyestrain can be categorised into two types: internal and external. Internal eyestrain consists of sensations of strain and ache felt inside the eye and usually caused by accommodative and convergence mechanisms. External eyestrain consists of sensations of dryness and irritation in the front of the eye caused by factors in the visual environment such as glare, upward gaze, small font size and flicker (Sheedy et al., 2003). Asthenopia is usually called eyestrain but it includes more symptoms: eye fatigue, discomfort, burning, irritation, pain, ache, sore eyes, headache, photophobia, blur, double vision, itching, tearing, dryness, and foreign-body sensation (Sheedy, 2007).

Computer vision syndrome (CVS) is a classic combination of symptoms that are vision-related (e.g. headache and neck pain) or vision specific (eyestrain and accommodation disorder) and that are usually caused by near work at a computer together with intense computer work for more than 3 hours a day. These two factors (near work and long hours of work) combined cause eye fatigue and other computer vision symptoms (Yan et al., 2008).

3.8 Visual fatigue or eye fatigue

“Visual fatigue” and “eye fatigue” are commonly-used terms in articles and books. They seem to have the same symptoms, but may have different causalities.

According to Watten (1994), “Visual fatigue is the consequence of long-term, intense, visual near work, commonly associated with complaints of a vague nature such as discomfort localised in either the head or the eyes” (Watten, 1994, pp. 428-429). The USA National Research Council defines visual fatigue as, “any subjective visual symptoms of distress resulting from the use of one’s eyes” (National Research Council Committee on Vision, 1983, p. 153).

If a visual task such as computer work is considerably brighter than the surrounding visual field it contributes to visual fatigue. The resolution and the readability of a work task will also affect eye fatigue. Eye fatigue increases if reflections and glare are present in the work area (Anshel, 2005).

Eye fatigue and discomfort can be caused by the eyes having to adjust and readjust to different near range distances while working, which usually takes place thousands of times a day when shifting between different viewing distances (computer screen and paper manuscript) and puts stress on the eye muscles (Yan et al., 2008). Eye fatigue can also be caused by constant changes between negative and positive polarity (dark or light background) between different work tasks such as a visual display unit (VDU) with a positive polarity and a dark keyboard (Blehm et al., 2005).

3.9 Headache

Headaches that are caused by visual conditions such as glare, flicker and eyestrain usually appear during the day and are usually located around the eyes, forehead, and temples (Anshel, 2005). Non-visual flicker from light sources can cause eyestrain, headaches, tiredness, difficulty to concentrate, and sometimes lowered performance (Wilkins et al., 1989; Wilkins et al., 2010).

Kowacs et al. (2004a) also hypothesised that the brains of those with migraine respond in a similar way to those with photosensitive epilepsy, but with migraine attacks instead when they are exposed to flickering light.

Migraine can be caused by pupil anomalies, visual field defects and pattern glare. Pattern glare, such as too high luminance contrast within the visual field, is one of the most common visual triggers to migraine (Harle and Evans, 2004).

Hagen et al. found that “both migraine and non-migrainous headache were strongly associated with musculoskeletal symptoms” (Hagen et al., 2002, p.527). The prevalence of headache more than 14 days a month was four times higher in the group with musculoskeletal symptoms than in those without. Individuals with neck pain were more likely to suffer from headache.

3.10 Musculoskeletal discomfort

Women report more musculoskeletal discomfort in general than men, but individuals that work at computers report more neck problems than other occupations without any gender differences (Arbetsmiljöverket, 2010).

Fostervold (2000) has proposed a systemic link between visual near-point strain and near work related syndromes. In the system of interacting motor functions and neurological pathways it appears that manual work affects the whole body.

A number of studies support a link between visually demanding work, eye problems, headaches and / or muscle activity/ problems (Aarås et al., 2001, 2005; Helland et al., 2008; Lie & Watten, 1994; Richter et al., 2010a; Richter et al., 2010b).

"The eye leads the body"; if we cannot see clearly we adapt our body position to facilitate vision (Anshel, 2005). A study of call-centre workers in Sweden showed that 21% of them had both eyes and neck problems (Wiholm et al., 2007).

In a study of computer use among students, there was a connection between the amount of hours spent in front of the computer and neck/shoulder symptoms for both men and women; an additional connection to eyestrain and forearm symptoms among the women was also found (Palm et al., 2007). Eyestrain during visually demanding computer work is associated with increased muscle blood flow in the orbicularis oculi muscle, possibly secondary to different muscle activity patterns in subjects experiencing eye pain (Schiøtz Thorud et al., 2012).

Zetterberg et al. (2013) have found a significant relationship between accommodation and increased activity in the trapezius muscle, but it was only present during binocular trials. The effect was only present when both convergence and the accommodation were present. Visually demanding near work may contribute to increased muscle activity that over time can cause neck/shoulder discomfort.

Horgen (2003) found a correlation between optometric corrections and reduced visual discomfort and musculoskeletal pain among VDU workers. The musculoskeletal discomfort decreased with correct power in their spectacles.

Zetterlund et al. (2009) found a connection between individuals with age-related macular degeneration (AMD) and an increase of musculoskeletal discomfort from the neck and shoulder region. When the visual acuity became too low, and the AMD was too advanced, the musculoskeletal discomfort decreased. The hypothesis is that straining the eyes increases musculoskeletal discomfort, but when the incentive for the eyes to continue to try to see clearly disappears because of low visual acuity, the eyes stop trying and the musculoskeletal discomfort decreases.

The most common method used in the Nordic countries to evaluate the presence of musculoskeletal disorders is the "Nordic Musculoskeletal Questionnaire" (Kuorinka, et al., 1987). In this questionnaire the individuals rate how often they have problems in different body parts, if they have experienced any accidents, and information about their work tasks.

According to Gremark Simonsen et al. (2012) many surgical staff members have several ergonomic risk factors. The scrub nurses were found to have a very static working posture and the rotating nurses had a high physical load. But the right proportion of muscular rest in relation to muscular load may be protective.

3.11 Intervention or experimental research

Sanders and McCormick (1993) state that human factors are to a large extent an empirical science. The purpose of experimental research is to test the effects of some variable on behaviour. Evaluation research evaluates the effects on the performance and behaviours.

The data in descriptive studies and experimental research can be collected in the field or in a laboratory setting. Surveys and interviews are used to collect data. Collecting data in an evaluation research study is often more difficult; most common is observation and interviews of users regarding the problems they encountered and their opinions of the equipment evaluated.

The requirements for research criteria are both practical and psychometric such as reliability, validity, freedom from contamination, and sensitivity. The six practical requirements for criterion measures are, when feasible (Sanders and McCormick, 1993):

- Be objective
- Be quantitative
- Be unobtrusive
- Be easy to collect
- Require no special data techniques or instrumentation
- Cost as little as possible in terms of money and experimenter effort

The reliability of studies refers to the consistency or stability of the measures of a variable over time or across representative samples. Several types of validity are relevant to human factors research. They all share in common the determination of the extent to which different variables actually measure what was intended. Face validity refers to the extent to which a measure looks as though it measures what is intended. Where possible, researchers should choose measures or construct tasks that appear relevant to the users. Content validity refers to the extent the measurements measure tasks that are relevant to the subjects. Content validity is typically used to evaluate achievement tests, "things in the construct being assessed by the measure" (Sanders & McCormick, 1993,

p. 38). Construct validity refers to the extent to which a measure is really tapping the underlying “construct” of interest (basic type of behaviour or ability in question) and the size of the deficiency (things in the construct not assessed by the measure) and contamination (things assessed by the measure that are not part of the construct). (Sanders & McCormick, 1993, chapter 2)

3.12 Ergonomics and human factors assessment

Many methods can be applied to assess the effects that different environments, jobs or equipment have on people. These effects can be medical, physical or psychological and the methods can vary from direct observations to indirect observation. In most circumstances the data collected are not useful on their own but have to be interpreted. If an assessment methodology is appropriately developed, the data obtained can be generalised to basic data. (Wilson & Corlett, 2005, chapter 1)

Both objective and subjective evaluations of the visual environment have been performed using both quantitative and qualitative approaches with a focus on the assessment of effects on people. The methods used in the field of ergonomics and human factors can be categorised into six groups (Wilson & Corlett, 2005, chapter 1, Table 3).

1. General methods (direct/indirect observation, etc.)
2. Collection of information about people (physical/physiological measurements, etc.)
3. Analysis and design (task analysis, expert analysis, etc.)
4. Evaluation of human (human-machine) system performance (subjective assessment, performance measures, measurement by instrumentation, etc.)
5. Evaluation of demands on people (posture analysis, fatigue measurement, etc.)
6. Management and implementations of ergonomics (implementation, participative methods, etc.

Laboratory experimentation is an important source of information and insight about isolated work variables, but it may not be a valid approach for understanding work in practice. If complemented by well-planned field studies, the information gained can be valuable (Wilson & Corlett, 2005, chapter 1).

4 Methodology

The studies reported in the appended papers are visual ergonomic evaluations and interventions with pre- and post-studies.

All of the studies were parts of larger projects. The recycling project started with an evaluation of the high risk for accidents that employees are exposed to at work (Engkvist, et al., 2010; Eklund, Kihlstedt, Engkvist, 2010; Krook & Eklund, 2010). One of the researchers realised that the insufficient visual environment could contribute to the accident risk. Funding was acquired for the visual evaluation study as a complement to the other project studies.

The intervention studies at the post office were also a part of a larger project. Several articles and one book about the difficulties of performing a larger intervention study have been published about this project (Berglund & Karltun, 2012; Erlandsson, 2002; Karltun, 2007; Westlander et al., 2008). The project was initiated because problems arose at the Swedish Post Service (Posten AB) after implementing a new sorting method called "Best Method". It consisted of new sorting racks and a new way of sorting the mail in which the postal workers were standing up instead of sitting down. Paper II was a part of this project, but this lighting intervention study showed that there were still individuals with eyestrain after the lighting intervention. The correlation analysis showed that this was related to a need for new spectacles. So a second intervention study was initiated and sponsors for the lenses and frames were found. During the second intervention with the personal spectacles it became clearer that progressive lenses could contribute to a larger back tilt of the head and could also contribute to more musculoskeletal discomfort. Thus, a third intervention study with customised sorting spectacles was initiated. The post office studies were longitudinal and performed with mostly the same individuals over seven years (two new individuals were included in the last study).

The studies on visual ergonomics in the operating theatres were a part of a larger project about team work in operating rooms (Rydenfält et al., 2013). The operating staff in that project informed the other researchers that they were dissatisfied with the lighting in the operating theatres. Room was found in the project budget to include a visual ergonomics evaluation. This study showed that the lighting in the operating theatres was insufficient with high luminance contrast (Hemphälä et al., 2011). A specific lighting intervention study in an operating theatre with test lighting was initiated and funded from another source. The studies with the postal workers and the operating staff have both been iterative processes.

4.1 Methods and techniques

The methods and techniques used in the studies have been categorised into six groups according to Wilson & Corlett (2005, chapter 1) (see Table 4.1).

1. The general methods used were:
   - direct observations in the field consisting of human recording such as scored assessments and walkthroughs
   - indirect observations in the field via questionnaires and subjective ratings
   - standards and recommendations that were enforced via the intervention

In this manner, multiple methods were used to achieve triangulation and validation of the results.

2. To collect information about the participants the following methods were used:

   - physical measurements such as how individuals performed body movements and visual tests
   - physiological measurements such as EMG and inclinometry

3. For the analysis and design the following methods were used:

   - expert analysis often involving, walkthroughs and scored assessments
   - work measurements with time studies

4. To evaluate human performance the following methods were used:

   - instrumentation such as light meters to measure the illuminance and luminance
   - subjective assessment by means of questionnaires and ratings
   - performance measures by means work rate (time studies)

5. To evaluate the demands on the participants the following methods were used:

   - fatigue measurements of ocular function and asthenopia (eyestrain and eye fatigue).
   - job and work attitudes measurements of by means of rating scales in questionnaires

6. In the management and implementation of ergonomics, the interventions required the instalment of test lighting or new spectacles for the participants.

Table 4.1.
A table of the methods and techniques used in the studies (see appended papers) divided into the six groups according to Wilson and Corlett (2005).

Methods used		Techniques used	Paper					
			I	II	III	IV	V	VI
1 General methods	Direct observation	expert evaluation	•	•			•	
		rating	•	•			•	
	Indirect observation	questionnaires		•	•	•	•	•
		rating		•	•	•	•	•
	Standards and recommendations	intervention/field + lab studies		•	•	•	•	•
		assessment	•	•			•	•
2 Collection of information on participants	Physical measurement	body movements				•		
		visual tests/eye examination		•	•	•	•	
	Physiological measurement	EMG				•		
		inclinometry				•		
3 Analysis and design	Expert analysis	walkthrough	•	•	•	•	•	•
		scored assessments		•	•	•	•	•
	Work measurement	time studies		•			•	
4 Evaluation of human performance	Measurement by instrumentation	light meters	•	•			•	
	Subjective assessment	questionnaires		•	•	•	•	•
		rating		•	•	•	•	•
	Performance	work rate (time studies)		•			•	
5 Evaluation of demands on participants	Fatigue measurement	ocular function		•	•	•	•	
		asthenopia		•	•	•	•	
		tiredness						•
	Job and work attitude measurement	rating		•	•	•	•	
6 Management and implementation	Interventions	new lighting		•				•
		new spectacles			•	•		

The research in Papers I, II and V included partial or full visual ergonomics assessments. The workplaces were evaluated for visibility, risk for glare, and lighting quality through observations and photos taken. Questionnaires with subjective ratings of the visual environment were used in Papers II, III, and V. Illuminance and luminance measurements were performed with light meters, Hagner's S1 or S2. The luminance was either measured directed at the work surface/current surface or directed at a piece of white paper.

Papers III and IV involved spectacles interventions with subjective ratings of the visual environment. In Paper VI there was a lighting intervention where the operating staff evaluated two lighting situations during surgical procedures.

4.1.1 The questionnaires

The visual ergonomics questionnaire used in Papers II, III, and V was based on that of Knave et al. (1985) but the questions regarding computer work were excluded. A second part was added that included questions about the postal workers' tasks, perceived work stress and well-being. Questions about how the postal workers perceived the lighting pre- and post-intervention were also added to the questionnaire used in the winter post-intervention study in Paper II. See Appendix 11.1 for the full version of the questionnaire.

Questions about headaches were added to the visual ergonomics questionnaire in Paper V. In the first version of the questionnaire, headache was only included under the eyestrain question (question 1), but only in terms of reporting frequency and severity. Other studies, however, show that depending on the location of the headache and the time of day the headache appears, one can determine if it is caused by the visual conditions or not (Anshel, 2007). Other additions were questions about the participants' subjective experience of how well they could see at different distances "visual ability", if they used working spectacles, and if so, what sort (bifocals, progressive, work progressive, etc.). The number of alternatives was reduced to a maximum of five (a few had four) and the work stress questions were removed. A question about how static the work posture felt during surgery was added, however. The subjects in the laboratory study in Paper V also rated the different lighting situations by marking a position on a 10 cm long line visual analogue scale (VAS).

A similar evaluation questionnaire with a VAS scale was used in Paper VI in which the participants evaluate the lighting situations during surgical procedures (see Appendix 11.1). In this second questionnaire used in Paper VI, personnel that had worked in both lighting situations rated the existing and the test lighting on the same questionnaire. This was done to validate the results from the first evaluation of lighting questionnaire in Paper V. But the questions about tiredness were excluded based on the hypothesis that an individual would find it difficult to remember if they felt more tired in the existing or the test lighting, thus resulting in unreliable answers.

5 Summary of papers

5.1 Paper I – Vision Ergonomics at Recycling Centres

The aims of this study were to: 1) describe user and employee experiences of lighting and signs at Swedish recycling centres, 2) measure and assess the lighting system at the two recently built recycling centres in Linköping and assess the legibility and visibility of the signs used, and 3) propose recommendations regarding lighting and signs for recycling centres.

There are no specific Swedish or European recommendations on how lighting should be distributed over the recycling facilities. The lighting should make it easy to see where to go and to see containers, signs, etc. To make this possible, some demands must be placed on luminance and illuminance and on their uniformity, adjusted to the reflection qualities of the different surfaces.

Questionnaires were distributed to employees as well as users at several recycling facilities (Engkvist et al., 2010). Half of the employees (51%) from the 42 recycling centres did not consider that the lighting at their workplaces was insufficient (too weak or causing glare), while the others reported that they perceived insufficient light at least 10% of their working time. The visual environments at two of the recycling centres were evaluated. The light measurements performed showed that the illuminance varied between 5 and 550 lx and the luminance from 0 to 100 cd/m^2.

Unfortunately, there are no recommendations for both driving and pedestrian traffic in the same area. Thus we needed to specify some. Paper I suggests how these recommendations can be suggested. Lighting recommendations for areas with both driving and pedestrians should have a minimum of 30 lx, reading signs/sorting waste a minimum of 100 lx, and reading signs/sorting hazardous waste a minimum of 200 lx. To reduce the risk for accidents, lamp posts should be avoided at recycling facilities and instead line-suspended luminaires should be used.

5.2 Paper II – A Visual Ergonomics Intervention in Mail Sorting Facilities: Effects on Eyes, Muscles and Productivity

The purpose of this visual ergonomics intervention study was to evaluate the visual environment in mail sorting facilities and to explore opportunities for improving the work situation by improving the visual work environment and hereby reducing visual strain. The effect on mail sorting time was also examined before and after new lighting and labelling on the sorting racks were installed.

The pre-intervention study included a questionnaire on their experiences of the lighting, perceived visual ability, health, and musculoskeletal symptoms. The amount of eyestrain and musculoskeletal discomfort (MSD) was calculated and measured pre- and post- intervention. Measurements of lighting conditions and productivity were also performed along with eye examinations.

The results from the pre-intervention study showed that the postal workers who suffered from eyestrain had a higher prevalence of musculoskeletal discomfort and sorted slower than those without eyestrain. The amount of MSD among participants with eyestrain was three or four times higher than among participants without eyestrain. Two post-intervention studies were performed, summer and winter. In the summer post-intervention study, the reported eyestrain correlated to the requirements for new power in their spectacles as found in the eye examinations. Out of the 11 with eyestrain in the winter post-intervention study, only one participant could not be explained with the new power requirement.

Illuminance and illuminance uniformity improved as a result of the intervention and the risk for glare decreased. The visibility of the labelling increased. After the intervention, the postal workers felt better in general, experienced less work induced stress, and considered that the total general lighting had improved. There were also small decreases in both the eyestrain index and the number of individuals with eyestrain. The previous differences in sorting time for employees with and without eyestrain disappeared

Individuals that reported eyestrain also reported musculoskeletal discomfort to a higher degree. The younger individuals with pre-intervention eyestrain and musculoskeletal discomfort in particular benefitted the most from the improved visual environment, as was shown by a decrease in musculoskeletal discomfort.

5.3 Paper III – Optimal Correction in Spectacles – Intervention Effects on Eyestrain and Musculoskeletal Discomfort Among Postal Workers

The purpose of this study among postal workers was to examine the effects of new spectacles with optimal correction. In particular, the effects on visual strain (eyestrain), musculoskeletal discomfort and how the postal workers rated their vision with their habitual (existing) spectacles and their new spectacles were evaluated.

Eye examinations were carried out on all of the postal workers in the study and they were provided with the appropriate spectacle correction. They were all given the type of lenses that they used or needed: progressive, bifocals or single vision. The participants answered a questionnaire before and after they received their new spectacles. The second questionnaire was answered two to three months after they received their new spectacles. They evaluated their visual environment (such as too warm/cold light, too much light from luminaires, and shadows in the reading material), personal eyestrain and musculoskeletal discomfort.

After an eye examination the postal workers were divided into two groups: those who needed new spectacles and those who did not. Those who needed new spectacles showed a higher prevalence of eyestrain and musculoskeletal discomfort pre-intervention. Post-intervention, all the postal workers rated their vision better and the average eyestrain and musculoskeletal discomfort decreased for both groups. Having the wrong lens power can result in straining of the eyes (i.e. asthenopia or eyestrain).

When right-handed postal workers sort mail they have a static side (the left side) and a dynamic side (the right side) (all of the postal workers in this study was right handed). This study found a significant decrease of neck pain from the static left side especially among those who needed new spectacles. There was a tendency toward a decrease in neck pain on the right dynamic side as well. The improvement was strongest for the postal workers that needed new spectacles. Some of the postal workers that did not need new power also reported a decrease of musculoskeletal discomfort. One explanation for this finding may be a better and more upright work posture for the postal workers who were able to see more clearly.

5.4 Paper IV – Working Spectacles for Sorting Mail

The aim of this study was to investigate the effects of customised mail sorting spectacles, with reversed reading and distance zones, on the working posture and muscular load of presbyopic postal workers while sorting mail. The hypothesis was that the new customised sorting spectacles would reduce the backward inclination of the head and the muscular load of the shoulders.

Twelve male presbyopic (minimum of 1.75D addition) postal workers with an average age of 59 years (48-64 years), sorted mail on two occasions: once using their private PAL (progressive addition lenses) and once using customised sorting spectacles with an inverted work PAL (room progressive, with three zones, for reading distance, intermediate distance and room distance of about 3.5 meters). Postures and movements of the head, upper back, neck, and upper arms were measured by inclinometry and muscular load of the trapezius by electromyography.

With the private progressive spectacles, the postal workers inclined their heads and flexed their necks backward when sorting mail. With the customised sorting spectacles, there was a slightly less backward inclination of the head and backward flexion of the neck. However, there was a tendency to an increased neck forward flexion. The major reason for this could be that the postal workers flexed their necks forward more with the customised sorting spectacles when reading the envelopes in their hands because the reading zone was mounted higher in the lens.

This could be resolved by using near progressive PAL (computer lenses) with just two zones for the intermediate and reading distance with a maximum difference of 1 D between the two zones, perhaps even smaller with 0.75 D as a maximum. It might also be a good idea to lower the addition for reading distance by a quarter of a dioptre to allow a bit longer reading distance to accommodate several more distances, enabling a less fixed work posture.

5.5 Paper V – Evaluating General Lighting Situations for Operating Theatres

The purpose of this study was to see if an improved general lighting with an increased illuminance and higher CCT (correlated colour temperature) in an operating theatre can affect the operating personnel's visual conditions for open surgery.

In this laboratory study, three different light levels from the operating light were used (low, T1; medium, T2; and high, T3) together with four different general lighting situations, one existing and three test lightings. New luminaires for the general lighting were installed in an operating theatre. The test lighting was programmed to three different general lighting situations; the illuminance and the colour temperature of the lighting could be set at different fixed levels. The first test lighting situation was similar to the existing except for the colour temperature, the second was twice the amount of general light and the third was about three times as much general light. The different lighting situations were tested on 29 participants. They were exposed to glare from the operating light and then they performed visual tests, for example a contrast visual acuity test. They also rated the different lighting situations.

The results from the laboratory study showed that the test lighting situation with the highest illuminance (T3) gave similar or better results than the existing lighting situation. The participants also rated the T3 better than the others. They rated the operating light best for the low illuminance in the lighting situations with a higher amount of illuminance from the general lighting, indicating a higher tolerance for more illuminance from the operating light when the illuminance from the general lighting is higher. It is interesting that the two other situations, T1 and T2, were rated lower and produced poorer results. With the lower illuminance levels, the cooler CCTs were rated worse on the contrast test than the warmer CCTs. When the illuminance increased to double the amount over the contrast vision test (with T3) even with a cooler CCT, the results on the contrast test were better. The results show that if the colour temperature is increased there may also be a need for an increase in illuminance in order to achieve the same visual ability.

5.6 Paper VI – Lighting Intervention for an Operating Theatre

The purpose of the study was to evaluate two lighting situations, existing and test lighting, in surgical procedures to study differences for the operating personnel regarding tiredness and perceived visual ability in particular.

The test lighting situation had been previously tested against other lighting situations in a laboratory study (Paper V) and the best one was chosen for this field study. The existing and the test lighting situations were tested in a real operating theatre without any access to daylight and daily randomised between the existing and the test lighting. During the field study, which lasted about five months, the personnel (surgeons, scrub nurses, anaesthetic nurses and circulating nurses) who performed open surgery in the operating theatre rated the two lighting situations for general lighting quality (ranging from extremely bad to very good), the colour of the light from the general lighting (ranging from too warm to too cool), their visual ability during the procedure (ranging from extremely bad to very good), and their level of tiredness during the procedure (ranging from not at all tired to very tired).

The results were similar to those from the laboratory study and they favoured the test lighting over the existing.

Some personnel from all of the professions present in the operating theatre rated the test lighting situation significantly better than the existing when it came to lighting quality and visual ability. Concerning tiredness, the surgeons did not notice any differences between the existing and test situations. The other personnel felt a significant improvement in alertness in favour of the test lighting situation.

The results show that an increased general lighting illuminance together with a higher CCT can improve the visual ability, the subjective lighting quality and the alertness levels among the personnel in an operating theatre.

6 General discussion

The appended papers present six studies focussed on the visual work environment, visual performance/ability and well-being of the workers. Figure 6.1 presents a chart model of how different factors can affect the eyes, muscles, headache, circadian rhythm, visual performance and productivity. Figure 6.1 concentrates on the factors that can help explain what impacts visual ergonomics. It is not, however, a complete model that explains the causality between the different factors.

The lighting situation, the visual aids, the psychosocial environment and the physical work environment (work task) can affect vision and perceived visual ability. Visual ability can affect musculoskeletal activity. Studies show that if vision is strained (eyestrain), muscle activity increases in the neck and shoulders (Lie & Watten, 1994; Fostervold, 2000; Richter et al., 2010a; 2010b; Zetterberg et al., 2013). Straining the eyes may cause musculoskeletal discomfort, but the relationship between eyestrain and musculoskeletal discomfort in the neck and shoulders is still unclear. If the visual system is exposed to glare or other visual disturbances it might cause headaches. Visual performance and productivity can be affected by the physical work environment, any musculoskeletal discomfort, any eyestrain, and the level of alertness (circadian rhythm). In the questionnaires the participants were asked to rate their perceived visual ability; visual performance is harder to rate.

There are three main types of visual ergonomics interventions that can improve the visual environment at a workplace: change the lighting situation, improve the perceived visual ability with visual aids, improve the visual environment such as the visibility of the work task. The interventions in the appended papers focussed on different relationships among the factors presented in Figure 6.1.

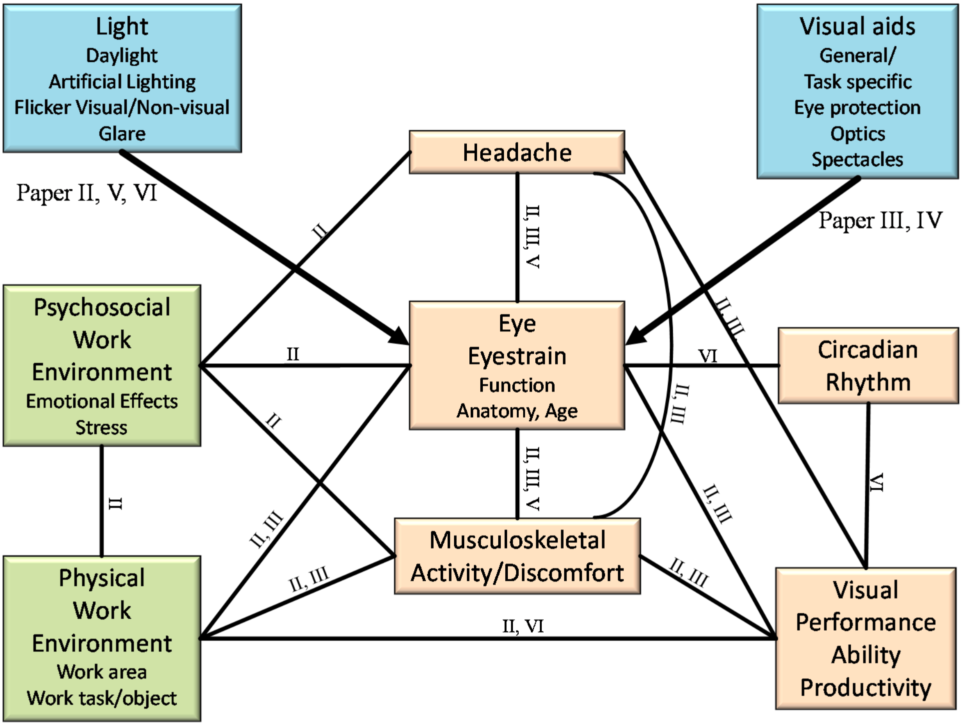

Figure 6.1.
Lighting and visual aids can affect vision. This chart model shows how the different visual ergonomics factors studied can affect each other (the appended paper numbers are placed close to the topics included in them). The blue boxes with arrows show the interventions. The green boxes show the environment. The beige boxes show the human responses. The causality for most of the factors is not known.

6.1 Lighting interventions

The visual surroundings affect us via the eye (See Figure 6.1). Papers II and VI showed a positive connection between visual ability and an improvement of the visual environment. The operating personnel rated their visual ability as being better if they experienced the general lighting as being better, and the postal workers with eyestrain increased their productivity with better lighting. A poorly designed workplace can have a direct negative effect on performance and productivity (Weston, 1962; Veitch et al., 2011; SS-EN 12464-1; 2011).

In Paper II there was a negative correlation between the uniformity of the illuminance and the individuals' well-being before the lighting intervention. After an intervention with better lighting and more uniform illuminance this correlation disappeared. Paper II also showed a correlation between well-being/stress and headache/eyestrain (see Figure 6.2). The correlation between work induced stress and musculoskeletal discomfort that was shown before the lighting intervention disappeared after the intervention (See Figure 6.2 and 6.3). A good psychosocial work environment is an important factor at a well-functioning workplace. Excessive stress and negative emotional effects at work can result in headache and musculoskeletal discomfort (Nicholson et al, 2007, Nahit et al., 2001). Headache can be affected via the visual system (glare, flickering light, etc.), the psychosocial work environment and musculoskeletal discomfort. Headache can also affect or be affected by the productivity (Wilkins et al., 1989; Anshel, 2005; Boyce, 2003).

In Papers II, III and V a connection between eyestrain, headache and musculoskeletal discomfort was shown (see Figures 6.2 and 6.3). In Paper II the musculoskeletal discomfort for those individuals with eyestrain increased for the older age group while it decreased for the younger age group after the intervention. So the repetitive work task of sorting mail for many years can have had a long-term impact on the musculoskeletal discomfort. An interesting fact was that the younger postal workers that still had eyestrain had a decrease in the musculoskeletal discomfort after the new lighting, with a better visual environment.

6.2 Visual aids interventions

Papers III and IV examine spectacle interventions to see how they affect the individuals' eyestrain and perceived visual ability. Visual aids are sometimes needed and specific work spectacles such as computer spectacles are quite common to improve visual ability and to reduce visual stress such as visual fatigue (Anshel, 2005). Providing computer PALs to presbyopic computer workers can increase productivity and decrease sick leave (Niskanen et al., 2010). In Paper III a decrease in musculoskeletal discomfort from the neck, especially on the static side was found among individuals in need of new power. In Paper IV working posture improved partly with the correct work spectacles. These results support other studies showing that optometric correction can have a positive impact on musculoskeletal discomfort (e.g. Horgen, 2003). Most of these types of studies have been performed on VDU workers, so it is interesting that this type of intervention also has a positive effect on individuals with a visually demanding work who do not use a VDU.

6.3 Correlations

In Paper II, correlation analyses were carried out before and after the intervention. If the factors in the correlation analyses were limited to just include the factors in the hypothesis for Paper II, some very interesting facts became more perspicuous, namely the impact of good lighting and correct power in spectacles on discomfort and well-being.

Before the intervention the lighting was insufficient, had a low uniformity and produced glare. The glare was rated by an "expert observer's approach" were an individual experienced in glare assessment can evaluate the degree of discomfort they feel in a certain situation (Wilson & Corlett, 2005). The risk for glare from the lighting affected eye fatigue. The lighting (risk for glare and amount of illuminance) affected the eyestrain and showed a positive correlation to musculoskeletal discomfort. The level of uniformity from the illuminance had an effect on general well-being that in turn correlated with work-related stress and headache (see Figure 6.2).

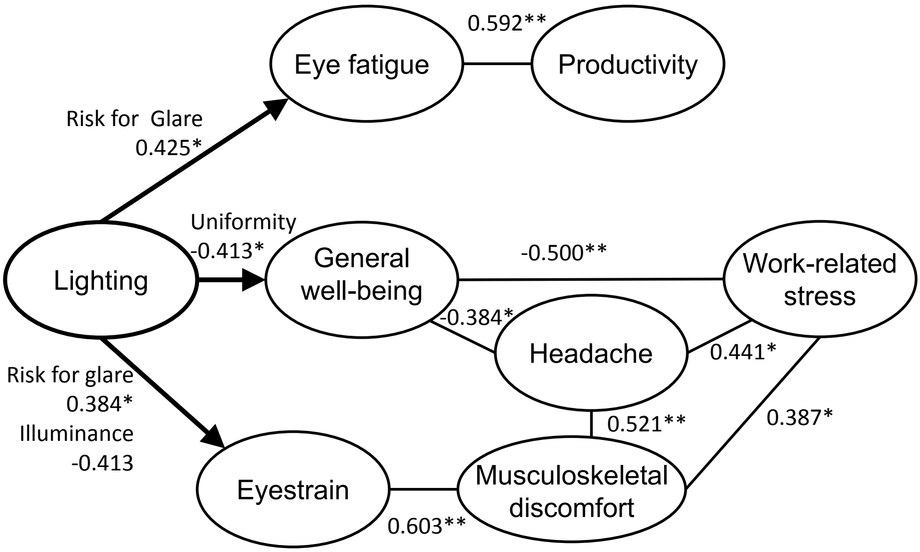

Figure 6.2.
The correlation between relevant factors before the intervention in Paper II. Only the significant factors based on the hypothesis are shown. The effects of the intervention are shown with arrows. For the other factors the causality is unknown.

After the intervention the lighting only correlated to productivity, while the other correlations to eyestrain and general well-being disappeared (see Figure 6.3). The uniformity value had a positive correlation to productivity; unfortunately some districts had still a lower uniformity after the new lighting due to other general lighting luminaires that could not be changed in the study. When adding the need for new spectacles a correlation was found with eyestrain; the other factors then had a similar correlation between themselves except for the correlation between musculoskeletal discomfort and work-related stress. Could it be that a good visual environment can reduce the effects of work-related stress on musculoskeletal discomfort? If it is easier to see the work task, the reduced eye strain that results from this may decrease the musculoskeletal discomfort. A correlation between eye fatigue and a need for new spectacles was anticipated (if the power in the spectacles is incorrect, one of the most common asthenopia is visual fatigue), but the results showed no such correlation. There was, however, a correlation between eyestrain and the need for new spectacles. As shown in Paper III, having correct power in lenses reduced the eyestrain. The musculoskeletal discomfort was also reduced with new power in lenses, for those who needed it. This supports the hypothesis that if you strain your eyes you will increase the musculoskeletal discomfort from your neck and shoulders. But this needs to be further examined.

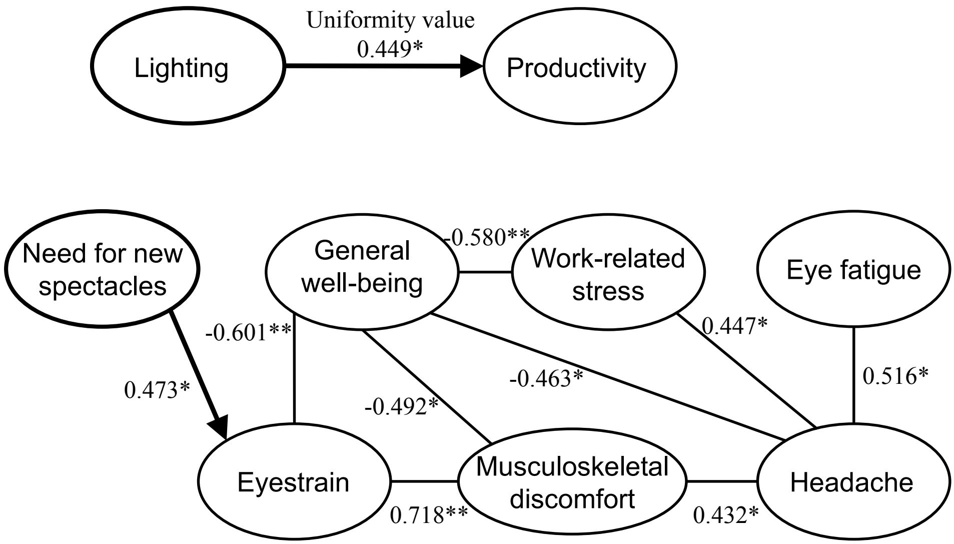

Figure 6.3.
The correlation between the relevant factors after the intervention in Paper II in the first post-study. Only the significant factors based on the hypothesis are shown. The effect of the intervention and the result from the eye examination are shown with arrows. For the other factors the causality is unknown.

The risk for glare decreased with the new lighting in Paper II and the direct correlation between risk for glare and eye fatigue disappeared. Is there any connection between risk for glare, eye fatigue and younger individuals' musculoskeletal discomfort? With the older workers the musculoskeletal discomfort might become more rigid after many years of sorting post, which could be the reason for the small effect from the new lighting.

As shown in Paper III, the musculoskeletal discomfort decreased for the individuals who needed new spectacles after they had received them. This shows that both the lighting and eye examinations followed by acquisition of correct spectacles are important to consider when doing workplace investigations.

6.4 Study settings

The visual evaluation of the recycling facilities in Paper I was part of a larger study about the physiological environment and its impact on the workers. The visual environment was found to be inadequate at many of the recycling facilities included in the larger study (see Engkvist et al., 2010), and no lighting recommendations for similar outdoor activities were found. Thus, two of the recycling facilities were further analysed and measured to see how lighting recommendations could be designed.

The lighting and labelling intervention for postal workers was initiated by other researchers. They developed the recommendations for the labelling and for the light distribution and illuminance levels for the luminaires at the postal sorting rack. Two years elapsed between the pre- and post-intervention studies that were included in Paper II. It was important that the post-intervention study took place at the same time of year, due to the daylight factor, since the amount of daylight can affect the productivity (van Bommel & van den Beld, 2004). Would the results of the eyestrain and musculoskeletal discomfort measurements have been different if it had been just one year or less between the pre-study and the first post-study? Usually when working in the same profession under the same conditions, the strain on the body should be the same or worse if it is work induced. But in this case, even though it was two years later, the younger postal workers had instead showed a decrease in musculoskeletal discomfort, which was better than expected. This indicated that the intervention had resulted in ergonomic improvements. In the second follow-up study during the winter months, a questionnaire was sent out to the postal workers. Many of them were found to need new glasses in the summer and we wanted to investigate if the eyestrain had changed after they had bought new glasses. But none of the participants had actually done so six months after the eye examination. This was the start for the study in Paper III.

Paper III was a pre- and post-intervention study before and after the postal workers received new spectacles. The post-intervention study was performed about two-three months after they got their new spectacles. The results showed a decrease in eyestrain and musculoskeletal discomfort even in the small timeframe of the project. Did the short timeframe have any effect on the results? Would the results have even been better with a longer timeframe? For some of the individuals the measurements might have been carried out too soon. Sometimes it can take several months before the user is totally accustomed to a new power and new sort of lens. During the studies in Papers II and III, it was noted that the individuals that needed progressive lenses had a straining working posture for the neck when looking at the top shelf of the sorting rack. Some of them had a large back tilt of their heads. In Paper IV an intervention with specially designed sorting spectacles was evaluated. The spectacles had two fronts: the posterior with single vision lenses and an anterior flip-up front with up-side down mounted room progressive PAL (with three zones). The results showed a decrease in the back tilting of the heads but an increase of the forward flexion of the head was observed. This could probably be solved by using a near progressive (computer lens) PAL instead. If a similar study were to be performed again, a near progressive lens should be used.

The three studies with the postal workers were part of a longitudinal study carried out over seven years; almost all of the participants in the studies (except two) were the same from the start. It has been interesting to follow the postal workers, seeing what actually can be done for people in this occupation to improve their visual environment and visual ability. In longitudinal studies it is easier to study changes and the trust between the researcher and workers also improved over the years (Noro & Imada, 1991).

In Paper V different lighting situations were evaluated, this time in a very visually demanding work situation: surgical procedures. In this laboratory study (no real life surgical procedures involved) the participants performed different visual tasks to evaluate their perceived visual ability in different general lighting situations and the three levels of illuminance from the operating lamp. The laboratory study was performed in a real hospital operating theatre. One problem with this was its availability as a laboratory. On weekdays it was used for planned surgery and on weekends and evenings it was sometimes used for emergency surgical procedures. It was also hard to get participants; to take a participant not used to a surgical environment into the situation is not always possible due to all the rules, regulations, dress restrictions, special circumstances with acute patients etc. Fortunately, some of the staff and medical students could participate in the study on weekends and evenings. There is an advantage to having employees from the workplace under study as participants because they understand the difficulties of the work tasks and the importance of the possible improvements. The medical students were not as familiar with the environment in the operating unit as the regular operating staff, which could be a disadvantage.

The recommendations for the field study in Paper VI were formed based on the results of Paper V. The field study in Paper VI was a lighting intervention study that evaluated two different lighting situations for five months from January to June, performed in the same operating theatre as in Paper V. The two lighting situations were mounted in the ceiling in the same operating theatre. The lighting situations were used according to a randomised schedule, so that every other day the lighting changed. The different professions – surgeons, nurse anaesthetists, scrub nurses and circulating nurses – rated the lighting, perceived visual ability and their tiredness. It was difficult to get the personnel to answer the questionnaires and to get the coordinator of the surgical procedures to schedule only open surgery (with minimally invasive surgery the general lighting is dimmed down during the entire surgical procedure) in the operating theatre with the test lighting installed. The personnel also answered the questionnaires more often when it came to the new lighting compared to the existing, even though there had been several information meetings about the importance of rating both lighting situations.

6.5 Methodology

All of the studies in this thesis included assessment of the visual environment and intervention research, except for the study reported in Paper I. The first intervention with the new lighting for the postal workers in Paper II was initiated by "Posten AB" and the next two interventions (Papers III and IV) with the postal workers was researcher initiated when the researcher noticed other things that needed to be changed to improve the visual ergonomics situation and to reduce the visual and musculoskeletal discomfort. The operating theatre laboratory study in Paper V was a prerequisite for the lighting intervention in Paper VI. It was fortunate that the same researcher (the author) could perform all of the studies at the same workplaces; otherwise much of the tacit knowledge about the studies would have been lost, making them harder to perform. In the first post-office study both the lighting and labelling were changed. This might have caused a bias, an uncertainty in what caused the major effect on the participants. In Papers III, IV and VI, though, only one intervention was evaluated thus reducing the bias in these studies.

The studies presented in the appended papers used one or more of the following methods as a base for developing the interventions: direct observations that included visual ergonomics evaluations, indirect observations through questionnaires, subjective ratings of the visual environment, and a comparison of the findings with standards and recommendations (see Table 4.1).

At the recycling facilities indirect observations were performed within the larger study (see Engkvist et al., 2010), but the questions about lighting were few and inconclusive. At the two recycling facilities studied more thoroughly in Paper I, only direct observations were performed. It would have been interesting to have carried out indirect observations at the time of the visual assessments and measurements as well, even though some incidental questions were asked. Results from what the employees actually think of their visual working environment is important since studies show that this can have an impact on workplace satisfaction and work engagement (Veitch et al., 2011); it also is a way of validating the direct observations. The objective expert analysis could have benefited from some validation from indirect observations, such as subjective ratings of the lighting.

In Paper II both direct and indirect observations were performed together with a comparison to standards and recommendations. The interventions in Papers III and IV were performed at the same workplaces (postal services) so the knowledge previously obtained from the direct observations could be applied in these studies together with the indirect observations via questionnaires. In Papers II, III and IV, eye examinations were performed supported by body movements and physiological measurements from EMG and inclinometry in Paper IV. This can be regarded as triangulation of the methods although performed over three consecutive studies. It is uncertain if the improved visual environment affected the work posture in Paper II. The direct observations might have been improved if a video analysis had been performed, in which case the work posture in the pre- and post-intervention could have been investigated as well. The questionnaire used was based on the visual ergonomics questionnaire (Knave et al., 1985) and more questions were added about the postal workers' well-being, work induced stress, labelling and the lighting. The design of the questions could have been more carefully planned, some of the questions could have been better phrased, and the scaling was different between the questions, which made the analyses more difficult and the result sometimes harder to analyse and evaluate.

In the studies performed in the operating theatres, Papers V and VI, many of the methods described in Table 4.1 were used. In Paper V, direct observations were performed before the tests and the values were compared to the existing standards. In order to produce the test lighting situations, the standards and recommendations had to be scrutinised. Physical measurements such as visual tests (visual acuity, colour vision, etc.) were performed together with work measurement while being exposed to glare. Indirect observations of the visual environment were performed before and during the operating theatre laboratory study. Indirect observations were performed in both Papers V and VI where the lighting situations were rated and evaluated by the participants. In Paper VI, only indirect observations were used but the field study was performed in the same operating theatre used in Paper V, so the results from the direct observations can be applicable here. The study might have benefited from measuring the alertness levels via the amount of serotonin/melatonin in the saliva as a complement to the subjective ratings.

The reliability and the validity of the results were checked in different ways. The first time the participants answered the questionnaire the researcher was present to guide them if needed. The process was similar for all of the studies and the same researcher performed the studies, ensuring that the different parts were performed in the same manner. The face validity of the eyestrain was checked with an eye examination, although most eyestrain symptoms cannot be identified in an eye examination since the symptoms are subjective. The eyestrain factors of redness, teariness and dryness can sometimes be objectively identified depending on the exposure prior to the eye examination. But the eyestrain index corresponded well to the need for new power in lenses resulting from the eye examination. The content validity was high in the appended papers. The research was mostly performed with common work tasks except for Papers I (recycling) and V (operating theatre). In Paper I, no evaluation of work tasks was performed and in the operating theatre laboratory study in Paper V, it was difficult to find work tasks that represented open surgical procedures. In Paper V the focus was instead to see if there were any differences while performing the same tasks in different lighting situations. In all of the studies that included participants, they were their own controls in the pre- and post-interventions, except for Paper VI (operating theatre) where they evaluated the test lighting and the existing lighting situation during the same period.

It is particularly interesting when studying lighting interventions to see if there is a Hawthorne effect (Pennock, 1930; Levitt & List, 2011). It is hard to exclude the Hawthorne effect in these studies, especially in the post office study. In the operating theatre study, the results from the field study were also found for performance in the laboratory study indicating a small Hawthorne effect if any. No control groups were used in any of the studies, which might have shown other aspects of the effects the presence of the researcher had. Control groups without interventions could have been one way of validating the results as well. In Paper VI this could have been performed by evaluating the lighting in the operating theatre next door, which is a duplicate of the one used in the study, but without the test lighting installed.

Physical measurements such as eye examinations were performed in Papers II, III, and IV (postal workers) while a more simple visual test with visual acuity, colour vision and contrast vision was performed in Paper V (operating theatre). For Paper V, it might have been better to do an eye examination of the participants before the laboratory study to understand their visual ability, since one (from the operating staff) had very low contrast vision which excluded her from the study. If we had known this, we could have invited another participant instead. But it provided us with the valuable insight that it is important to do eye examinations on the operating staff because of the high visual demands of the job. One of the subjects had a red-green colour deficiency, which is a natural deviation of vision present among 8 % of the men and 0.5 % of the women (Zadnik, 1997); so if one out of 29 subjects has this deviation, it is within the normal rage of human differences.

Most of the papers were approached with the method of expert analysis using the walkthrough and scored assessments techniques. Visual ergonomics is something that requires an expert analysis approach since it is a multifaceted science. In the walkthrough for each project, deviations from the norm were noted and if assessed to be wrong or potentially harmful to an individual (such as glare from the general lighting) they were changed. The scored assessment was mainly used to rate the risk for glare or contrast luminance in the visual field. Compared to the subjective ratings of the visual environment, this gave similar results. Work measurements such as time studies were only performed in Papers II (postal workers) and V (operating theatre), and focussed on the difference between lighting situations. Time studies can be affected by visual strain, for example from glare, but the studies were randomised to exclude any effect from the lighting situations or any learning effects.

The light measurements were performed in the same way for all of the studies and with similar instruments. In Paper I (recycling) this consisted of measuring the illuminance and luminance and calculating the uniformity values. It would have been good if the luminance contrast ratios had also been calculated, but this was not done; it would have given a better picture of what the actual visual surroundings would have looked like. The values were then compared to outdoor lighting recommendations for driving and walking. In Papers II (postal workers) and V (operating theatre), both the illuminance and luminance values were measured, but for Paper II the uniformity value was the main focus and for Paper V the luminance contrast was the main focus. What is the difference between using uniformity value and luminance contrast measurements? If the visual environment is similar with the same type of material and surfaces, the difference would be minor, but if you have larger differences between work surface and object, the luminance contrast is more adequate.

The subjective evaluation of the problems at the workplace was performed via questionnaires where the participants rated their visual ability and eyestrain, for example. Questionnaires were used in all studies except the one reported in Paper I (recycling). The questionnaires used in Papers II, III, IV and V were similar but the last questionnaire used in Paper II (winter, post-intervention study) was a shorter version that did not rate musculoskeletal discomfort, lighting or well-being. Preferably the entire questionnaire should have been used in the winter post-intervention study as well, because of the increase in eyestrain. It would also have been interesting to see if the musculoskeletal discomfort also increased during the winter. In Paper VI, the evaluation of lighting questionnaire consisted of only one page where the participants rated the general lighting, colour of the light, their visual ability, and tiredness. It would had been good if the questionnaires used were similar – making it easier to compare all of the studies. But in Paper VI, for example, it would have been too much work for the participants to answer a full questionnaire after surgery.

Measurements of fatigue were performed subjectively via questionnaires (Papers II, III, IV, V and VI) that asked about eye fatigue and tiredness. The participants' attitude towards their work was also evaluated. In the operating theatre laboratory intervention study (Paper V), only half of the participants were employees of the operating unit, so the results were unclear.

The interventions performed in the studies presented in this thesis were carried one at a time in most cases to examine the effects on eyestrain, musculoskeletal discomfort and performance. The exception was Paper II, where two interventions were performed at the same time: a change in the lighting, and in the appearance of the labelling on the sorting racks. The changes could instead have been done in two steps, one for the lighting and one for the labelling. Now we know that the labelling alone can have had an effect on the outcome of the study, separate from the lighting. The correlation analysis showed a stronger correlation for the lighting than for the labelling, but those calculations were based on subjective ratings.

Papers III and IV were intervention studies with spectacles for postal workers. The eye examinations were performed by the same optometrist at an optician shop. Based on the results, new lenses were ordered. The compliance for the private spectacles in Paper III were good, they used them all the time. In Paper IV, however, the postal workers were asked to use the spectacles as much as possible, but the compliance with the recommendations was not very good. Since it takes some time to get used to new lenses, the eyestrain or eye fatigue might have been higher than otherwise when the post-intervention study was performed.

The operating theatre lighting intervention in Papers V and VI was not a typical intervention study. It was divided into two parts – one laboratory study (Paper V) and one field study (Paper VI). In Paper V no real work tasks were performed in the different lighting situations as was done in Paper VI. No laboratory tasks that could imitate surgery were found. The different lighting situations were evaluated, tested and rated by the subjects during other visual tests. The lighting intervention in the laboratory study was in theory planned to have a consistent lighting outlay. But in reality the lighting differed from theory. The illuminance levels in the first of the test lighting situations was supposed to have the same illuminance throughout the operating theatre as the existing, but due to the amount of other equipment in the ceiling the luminaires could not be placed in a way so that the illuminance was identical (see Table 6.2 and Figure 1 in Paper V). The only difference should had been that the colour temperature for the T1 lighting situation was higher. The difference for the other situations (T2 and T3) after that should have been that the colour temperature was the same, but the illuminance levels should have increased. This was not the case, and there was even a smaller increase of the CCT. This might have affected the outcome of the study. But the average illuminance was similar for the existing and T1 even though there were differences for the maximum and minimum illuminance. The illuminance on the contrast vision acuity (CVA) test was more similar for the existing and the T2 lighting situations, so for these situations it was mostly the colour temperature that differed (see Table 6.2). The main difference in the colour temperature at the CVA between the existing and the T2 lighting situations was 3000 to 4100 K, and the existing lighting situation got a better result. The increased amount of blue light can have an effect on the pupil size making it constrict more – leading to a higher need for more light and therefore a lower result for the CVA.

Table 6.1
The amount of illuminance from the general lighting and on the contrast vision acuity (CVA) test together with the correlated colour temperature for each lighting situation.

	General lighting (lx)	CVA (lx)	CCT
Existing	1100	1260	3000
T1	1200	950	3900
T2	1650	1340	4100
T3	2950	2400	4300

The increased amount of illuminance did give a much better luminance contrast within the room. If this study was performed again it would be preferred to use the same colour temperature in all of the lighting situations or change the lighting for situations T2 and T3 so that they had the same high illuminance level, but different CCTs, just to see the difference (see Table 6.2).

The operating theatre field study in Paper VI involved a lighting intervention that at the same time studied two different lighting situations over five months. The existing and the test lighting situations were used according to a randomised schedule, so that every other day the lighting changed. The change was performed before the personnel came to work in the morning to avoid a direct change between the lighting situations when they were in the room in order to avoid affecting the personnel's feelings about the different lighting situations. There was a significant difference between the lighting situations so it was clear to the personnel which lighting situation was used on a given day. Since most of them rated the test lighting with the higher illuminance better, this could have affected the outcome of the study.

6.6 The questionnaires

The visual ergonomics questionnaire (Knave et al., 1985) has been used in some studies. Even though some questions were added the entire questionnaire needs to be revised, analysed and further improved to find other relevant subjective symptoms and environmental factors that can affect eyestrain, musculoskeletal discomfort and eye/visual fatigue. In the visual ergonomics questionnaire, eye/visual fatigue is not included in the eyestrain index. Some uncertainties exist as to which factors should be included in the eyestrain index. Sheedy et al. (2003) have divided eyestrain into two categories: external symptom factors (ESF) and internal symptoms factors (ISF). ESF are: burning (dry eyes), irritation (glare) and dryness (upward gaze, small font and flicker from the environment). ISF are: strain (lens flipper – binocular functions and accommodation), ache (close viewing distance) and headache (mixed astigmatism). Eye fatigue can also be caused by luminance contrast that is too high within the visual field (SS-EN 12464-1, 2002). Other studies show that you can get headaches from glare and flicker as well (Wilkins, 1989; Anshel, 2005).

The subjective symptoms are very similar (tiredness located to the eye) for eye and visual fatigue but the factors causing it can differ; they are often confused and are hard to distinguish. No references have been found that explain the exact difference between the two, but visual fatigue can be caused by binocular problems such as insufficient convergence and accommodative problems. Eye fatigue is mainly caused by anatomical problems and luminance contrast that is too high within the visual field. So even though the visual fatigue is a visual ergonomics problem, research shows that it is not caused by factors in the environment. It needs to be corrected but with the help of an optometrist and spectacles. These are factors that may need to be added to an eyestrain evaluation in a visual ergonomics questionnaire to see if the individual needs to see an optometrist as well as have his or her visual environment analysed by a visual ergonomics expert.

Eye and visual fatigue in Swedish is referred to as “eye fatigue”. We may need to start using two different phrases that are based on the factors causing the symptoms: “visual fatigue” and “eye fatigue”. Or is it better to have only one term for it? The symptoms are similar but the causality is different. There are benefits to both ways.

The subjective ratings of the musculoskeletal discomfort in the visual ergonomics questionnaire are only for the upper body. Is there a need for the entire body or can the evaluation of relevant body parts be reduced? Since studies show a connection between eyestrain and musculoskeletal discomfort from the neck and shoulders, it may be enough just to evaluate these two areas. Should questions be added or changed to include questions from the Nordic Musculoskeletal Questionnaire (Kuorinka, et al., 1987)? What types of questions are relevant for finding the corresponding factors to eyestrain/eye fatigue? In the questionnaires used in the studies presented, no questions were asked about the individuals' physical status, how often they exercised or other physical interests in their spare time. This is something that should have been included into the questionnaire.

6.7 Participants

The participants were familiar with the work studied in both of the intervention studies. The postal workers had worked a minimum of five years and the operating personnel had worked there a minimum of three years. Half of the subjects in the operating theatre laboratory study, though, were medical students; they had experience in the hospital environment but were new in the operating environment. Most of the subjects from all of the studies were representatives of the professions studied.

It is an advantage to have participants that have experience of the work being studied when doing field studies and to see how it affects the workers at their workplace (Noro & Imada, 1991).

The post office studies in Papers II, III and IV have been part of a longitudinal study performed over seven years that had the same individuals throughout the studies, except for two participants that were new in Paper IV.

Age is a factor that was included in all of the studies. Body movements were particularly observed in Paper IV and physiological measurement such as EMG and inclinometry were included. The interventions were evaluated objectively.

To include other physical factors such as height, weight and other anthropometrical-relevant measurements may have contributed to a clearer understanding of the results. In Papers II, III and IV, the top shelf in the post office was mounted at shoulder height, and in Paper V the operating table was set at elbow height to remove some of the anthropometrical differences.

6.8 Aim of the thesis

According to Papers II, III and V, individuals with eyestrain report more musculoskeletal discomfort than those without eyestrain, even in non-computer working environments. Other laboratory studies show that if an individual is straining his or her eyes, the muscle activity of the trapezius increases (Richter et al., 2010a, 2010b; Zetterberg et al., 2013). So both the objective and subjective assessments and measurements support the hypothesis that there is a strong connection between eyestrain and musculoskeletal discomfort from the neck, shoulder and upper back, even in non-computer workplaces, but the causality is unknown.

According to the results presented in Paper II, the eyestrain and musculoskeletal discomfort decreased after introduction of an improved visual environment with better lighting and labelling. The eyestrain and musculoskeletal discomfort in the upper body decreased for individuals working with non-computer work tasks, especially for static working postures. Previous studies on computer work show the same effect. Any references for other similar studies for non-computer workplaces were not found.

According to the results presented in Papers II and VI, the perceived visual performance or visual ability increased after introducing better lighting with less glare, better luminance contrast and sufficient illuminance.

The change to correct power in spectacles reduced eyestrain and musculoskeletal discomfort, especially for individuals in need of new power in their spectacles.

According to the results presented Paper IV, the correct type of lens for presbyopic postal workers can partly affect body posture positively. This study also showed an increased forward flexion of the neck and head that use of the chosen PAL may have been responsible for. For presbyopic non-computer workers, the effect of a progressive lens may contribute to a negative work posture. Postal workers are in a profession where a standard progressive lens can negatively affect the work posture and therefore create a need for specific working spectacles. By choosing the correct type of lens together with a suitable frame, the work posture could in many situations be improved, even for non-computer professions. This shows that more studies with near progressive lenses should be performed as a complement to Paper IV.

In Papers I, V and VI, lighting recommendations are discussed, evaluated and recommendations presented and tried in intervention studies. The studies are a starting point to develop better lighting recommendations that are based on subjective ratings and objective measurements and not just expert analysis as many recommendations are today. Some of the main factors studied for increasing the visual performance and visual ability are: reduce the risk of glare, have sufficient illuminance and low luminance contrast, which are factors that are present in many lighting recommendations of today although not always emphasised. The participants' subjective opinions are relevant when performing lighting intervention studies; not just their ratings of the lighting but the subjective sense of well-being including eyestrain and musculoskeletal discomfort. Many lighting recommendation need to be examined with intervention studies and further analysed to include the individual adjustments of the lighting. There are many aspects that can be improved when studying and trying to improve the visual environment. Factors that need to be included are eyestrain and musculoskeletal discomfort, especially when performing productivity studies where eyestrain can affect the results, as shown in Paper II.

7 Conclusions

- By performing visual ergonomics evaluations, factors that can be improved and implemented can be identified to enhance visual ability. In the post-office studies the focus was to reduce eyestrain, and for the operating personnel the focus was to study the ways to increase visibility and alertness.

- In Paper II we also found a correlation between well-being and eyestrain and how participants experienced their visual working environment. Their well-being increased after the lighting intervention.

- If the visual environment improves after an intervention with a more suitable illuminance, less glare and better luminance contrast within the visual field, the visual ability will increase. This will especially help individuals with eyestrain as described in Paper II.

- Productivity can increase for the individuals with eyestrain and the eyestrain and musculoskeletal discomfort can be reduced especially for the younger individuals, although the causality between eyestrain and musculoskeletal discomfort is not known.

- Individuals with eyestrain report more musculoskeletal discomfort. This is shown in Papers II, III, and V. Studies about eyestrain and musculoskeletal discomfort have often been performed for computer related workplaces. In the studies carried out here, we could show the connection for some non-computer occupations as well. This shows that in visually demanding work tasks there is a correlation between eyestrain and musculoskeletal discomfort, although the causality is unknown.

- Musculoskeletal discomfort and eyestrain can be reduced further after implementing spectacles with correct power, especially for individuals with eyestrain and a static working posture as presented in Paper III. This shows the importance of having good correction in the spectacles.

- Lighting intervention studies often look at the difference in productivity with a new lighting situation. Here we found a large correlation between individuals with eyestrain and an increase in productivity (postal workers sorting letters) when the lighting situation improved. No other references to research have been found on the presence of eyestrain during a lighting intervention concerning the difference in productivity.

8 Future research

In the Swedish standard for" physical workload and ergonomics" (Belastnings-ergonomi, in Swedish) (AFS 2012:2) it states that the visual environment should be investigated because a poor visual environment can contribute to musculoskeletal discomfort. Work environment inspectors, ergonomists, optometrists and other visual ergonomics specialists have no established methods to use when evaluating the visual environment. It would be worthwhile to develop a computer based tool with both an objective and a subjective (from the worker) evaluation of the workplace and of the subjective symptoms along with ratings of the lighting to facilitate the evaluation process, and in this way improve the visual environments at workplaces.

Aspects that can be studied include:

- Is eye fatigue/visual fatigue a factor to consider for a possible contribution to musculoskeletal discomfort? What are the important factors?
- Should we follow Sheedy's (2003) recommendations and divide eyestrain factors into two areas – external and internal?
- How should we analyse the possible effects on musculoskeletal discomfort. Is it possible to detect the risk factors with subjective ratings?
- Is there a causality effect between eyestrain/eye fatigue and musculoskeletal discomfort?
- Should more symptoms be included from asthenopia, such as diplopia and blurry vision?

It would be worthwhile to investigate the subjective eyes/vision symptoms and the musculoskeletal discomfort together with an expert analysis of the visual environment in other studies to analyse the complexity of any possible causalities.

It would also be worthwhile to investigate how an intervention with correct power in spectacles affects non-computerised visually demanding workplaces with a static working posture for eyestrain, musculoskeletal discomfort and productivity. In the post-office study the musculoskeletal discomfort on the static side was reduced. It would be interesting to see the effect of correct spectacles on low income static work, where a new pair of spectacles might not be prioritised. Will a better visual environment have an effect on the level of productivity, the musculoskeletal discomfort and sick leave?

Continued examination of lighting for operating theatres is another area for further research. Aspects that can be studied include:

- Does the general lighting affect the body posture among the operating staff who work at the operating table, particularly scrub nurses?
- What colour temperature should the general lighting have in comparison to the colour temperature of the operating light? Currently operating lights are available in which you can change the colour temperature. What is the best colour temperature for both operating light and general lighting for the different kinds of surgical procedures?
- Are there any preferences as to when you should use different colour temperatures for the operating light? Open surgery, bone surgery or skin surgery? What colour temperature is the best for these situations?
- Will green and red coloured lighting improve visibility on the computer screen in the operating room and facilitate visual ability with a higher amount of white light over the anaesthetic nurse?

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11 Appendix

11.1 Visual Ergonomics Questionnaire

Name:______________________________ **Date of birth:**__________________
Date:____________________ **Phone no.:**_________________________

Profession: ____

1. Do you have any of the types of eyestrain listed below? If yes, please mark frequency and degree of severity for each type of eyestrain. *(Papers II, III, IV, V)*

			Frequency				**Severity**		
	Yes	**No**	few times (1)	every week (2)	daily (3)	x	insignificant strain (1)	average strain (2)	severe strain (3)
Smarting	O	O	O	O	O		O	O	O
Itching	O	O	O	O	O		O	O	O
Gritty feeling	O	O	O	O	O		O	O	O
Aching	O	O	O	O	O		O	O	O
Light sensitivity	O	O	O	O	O		O	O	O
Redness	O	O	O	O	O		O	O	O
Teariness	O	O	O	O	O		O	O	O
Dryness	O	O	O	O	O		O	O	O
Eye fatigue	O	O	O	O	O		O	O	O
Headache	O	O	O	O	O		O	O	O

2. Answer only if you answered yes to question 1. *(Papers II, III, IV, V)*
   Do you think that the cause of your eyestrain has any connection with your work?

   (1) O Yes, absolutely.
   (2) O Yes, maybe.
   (3) O Probably not. It might be caused by ___________________________
   (4) O Absolutely not. It is caused by _______________________________
   (5) O Have no opinion.
   What work task/tasks do you connect to your eyestrain? ______________________

____

3. How long have you worked at your current occupation? *(Papers II, III, IV, V)*

Number of years: ________

4. Do you use spectacles? O (1) Yes O (2) No

Do you use contact lenses? O (1) Yes O (2) No

(Papers II, III, IV, V)

5. Are you using specific work spectacles? *(Paper V)*

(1) O Yes, single vision
(2) O Yes, bifocal lenses
(3) O Yes, regular progressive lenses
(4) O Yes, work progressive lenses (for example, computer PAL)
(5) O Yes, but I do not know what type
(6) O No, I do not have any specific work spectacles

6. How do you rate your vision at the following viewing distances? *(Papers III, V)*

		Very Bad		**Ok**		**Very Good**	**Not relevant**
		1	**2**	**3**	**4**	**5**	
Distance (more than 6 m)		O	O	O	O	O	O
Spatial distance (approx. 3-4 m)		O	O	O	O	O	O
Mid-range (approx. 70-100 cm)		O	O	O	O	O	O
Near range (approx. 40 cm)		O	O	O	O	O	O
Other viewing distances: ___________		O	O	O	O	O	O
Operating distance	*(Paper V)*	O	O	O	O	O	O
Top shelf sorting rack	*(Paper III)*	O	O	O	O	O	O
Second shelf sorting rack	*(Paper III)*	O	O	O	O	O	O
Third shelf sorting rack	*(Paper III)*	O	O	O	O	O	O
Forth shelf sorting rack	*(Paper III)*	O	O	O	O	O	O
Letters in hand	*(Paper III)*	O	O	O	O	O	O
District sorting	*(Paper III)*	O	O	O	O	O	O

7. If you get a headache, were does it usually appear? (can choose several options) *(Paper V)*

(1)	O	I do not get headaches
(2)	O	Around the eyes
(3)	O	Temples
(4)	O	Around the whole head
(5)	O	Back of the head
(6)	O	Half of the head (right/left side)

8. When in the day do you usually get a headache? *(Paper V)*
(Answered only by individuals who get headaches.)

(1)	O	I wake up with it
(2)	O	In the morning
(3)	O	In the afternoon
(4)	O	At night

9. Do you have any of the musculoskeletal discomfort (muscle and joint strain) listed below? If yes, please mark frequency and degree of severity for each body part. *(Papers II, III, IV, V)*

				Frequency				**Severity**		
		Yes	**No**	few times strain	every week	daily		insignificant strain	average strain	severe strain
				(1)	(2)	(3)	x	(1)	(2)	(3)
Hand	left	O	O	O	O	O		O	O	O
Hand	right	O	O	O	O	O		O	O	O
Forearm	left	O	O	O	O	O		O	O	O
Forearm	right	O	O	O	O	O		O	O	O
Elbow	left	O	O	O	O	O		O	O	O
Elbow	right	O	O	O	O	O		O	O	O
Upper arm	left	O	O	O	O	O		O	O	O
Upper arm	right	O	O	O	O	O		O	O	O
Shoulder	left	O	O	O	O	O		O	O	O
Shoulder	right	O	O	O	O	O		O	O	O
Neck	left	O	O	O	O	O		O	O	O
Neck	right	O	O	O	O	O		O	O	O
Back	left	O	O	O	O	O		O	O	O
Back	right	O	O	O	O	O		O	O	O

10. How would you rate the light levels at your workplace? *(Papers II, III, V)*

(1)	O	Very high
(2)	O	Too high
(3)	O	Just right
(4)	O	Too low
(5)	O	Very low

11. Do you experience that the light at your workplace: *(Papers II, III, V)*

(1)	O	Gives very sharp shadows
(2)	O	Gives too sharp shadows
(3)	O	Is just right
(4)	O	Gives too flattened/diffuse light
(5)	O	Gives very flattened/diffused light

12. What is your opinion of the colour of the light from your lighting? *(Papers II, III, V)*

(1)	O	Very white/cool
(2)	O	Too white/cool
(3)	O	Just right
(4)	O	Too red/warm
(5)	O	Very red/warm

13. Are you troubled by shadowing on your work surface? *(Papers II, III, V)*

(4)	O	Yes, very
(3)	O	Yes, some
(2)	O	No, hardly
(1)	O	No, not at all
(0)	O	Not relevant

14. Are you troubled by too much light from the luminaires? *(Papers II, III, V)*

(5)	O	Very often
(4)	O	Too often
(3)	O	Sometimes
(2)	O	Very little
(1)	O	Never

15. Are you troubled by too much daylight from the windows? *(Papers II, III)*

	During the summer		During the winter	
Yes, very	(5)	O	(5)	O
Yes, some	(4)	O	(4)	O
No, hardly	(3)	O	(3)	O
No, not at all	(2)	O	(2)	O
Not relevant	(1)	O	(1)	O

16. What type of workplace lighting do you have? *(Papers II, III)*

Type: ____

(Fluorescent tube with HF ballasts/conventional ballasts, down-lights, up-lights, etc.)

Do not have any workplace lighting. O (continue to question 18)

17. How often do you use your workplace lighting? *(Papers II, III, IV)*

	In the summer		In the winter	
Very often	(1)	O	(1)	O
Fairly often	(2)	O	(2)	O
Sometimes	(3)	O	(3)	O
Very little	(4)	O	(4)	O
Hardly ever	(5)	O	(5)	O

18. What is your overall assessment of the general lighting in your workplace? *(Papers II, III, IV, V)*

	In the summer		In the winter	
Very good	(5)	O	(5)	O
Fairly good	(4)	O	(4)	O
Acceptable	(3)	O	(3)	O
Pretty bad	(2)	O	(2)	O
Very bad	(1)	O	(1)	O

19. What was your overall assessment of the **existing** general lighting in your workplace? *(Paper II after intervention)*

	In the summer		**In the winter**	
Very good	(5)	O	(5)	O
Fairly good	(4)	O	(4)	O
Acceptable	(3)	O	(3)	O
Pretty bad	(2)	O	(2)	O
Very bad	(1)	O	(1)	O

20. How do you experience your visual ability? *(Paper III)*

Very good	(5)	O
Fairly good	(4)	O
Acceptable	(3)	O
Pretty bad	(2)	O
Very bad	(1)	O

21. How did you experience your visual ability before you got new spectacles? *(Paper III)*

Very good	(5)	O
Fairly good	(4)	O
Acceptable	(3)	O
Pretty bad	(2)	O
Very bad	(1)	O

Questions added to the Visual Ergonomics Questionnaire

22. How do you feel today? *(Papers II, III, V)*

Very good	(5)	O
Fairly good	(4)	O
Acceptable	(3)	O
Pretty bad	(2)	O
Very bad	(1)	O

23. Do you experience much stress in your private life? *(Papers II, III)*

Yes, very much	(7)	O
Yes	(6)	O
Yes, some	(5)	O
Yes, a little	(4)	O
Sometimes	(3)	O
No	(2)	O
No, never	(1)	O

24. Do you feel well rested? (*Papers II, III, V)*

Yes, completely	(7)	O
Yes	(6)	O
Yes, some	(5)	O
OK	(4)	O
Somewhat tired	(3)	O
No	(2)	O
No, not at all	(1)	O

25. Do you like your work? *(Papers II, III)*

Yes, very much	(7)	O
Yes	(6)	O
Yes, some	(5)	O
OK	(4)	O
Somewhat	(3)	O
No	(2)	O
No, not at all	(1)	O

26. Do you experience your work as stressful? *(Papers II, III)*

Yes, very much	(7)	O
Yes	(6)	O
Yes, some	(5)	O
Sometimes	(4)	O
Rarely	(3)	O
No	(2)	O
No, not at all	(1)	O

27. Do you experience any trouble in performing all of your work tasks in time? *(Papers II, III)*

Yes, very much	(7)	O
Yes	(6)	O
Yes, some	(5)	O
Sometimes	(4)	O
Rarely	(3)	O
No	(2)	O
No, not at all	(1)	O

28. How do you experience letter sorting in terms of difficulty? *(Papers II, III)*

Very Hard	(7)	O
	(6)	O
	(5)	O
	(4)	O
	(3)	O
	(2)	O
Very easy	(1)	O

29. How do you experience letter sorting in terms of time? *(Papers II, III)*

Very time consuming	(7)	O
	(6)	O
	(5)	O
	(4)	O
	(3)	O
	(2)	O
Very quick	(1)	O

30. How do you experience the labelling of the sorting racks? *(Papers II, III)*

Very hard to read	(7)	O
	(6)	O
	(5)	O
	(4)	O
	(3)	O
	(2)	O
Very easy to read	(1)	O

31. How applicable are the following statements to your current workplace lighting? Graded on a scale of 1-5 (1= not at all; 5=very much) (Kansei Engineering) *(Paper II)*

	Not at all 1	2	3	4	Very much 5
Glare free light	O	O	O	O	O
Good light levels	O	O	O	O	O
Too strong light	O	O	O	O	O
No shadows on work task	O	O	O	O	O
Snuggly light	O	O	O	O	O
Strong light	O	O	O	O	O
Easy to read letters	O	O	O	O	O
Easy to read the labels	O	O	O	O	O
Good detectability (Easy to find names on the labels)	O	O	O	O	O
Well-planned light	O	O	O	O	O
Warm light	O	O	O	O	O
Congenial light	O	O	O	O	O
Professional light	O	O	O	O	O
Grey light	O	O	O	O	O
Weak light	O	O	O	O	O
Fresh light	O	O	O	O	O
Hard light	O	O	O	O	O
Soft light	O	O	O	O	O
Well-distributed light	O	O	O	O	O

32. Do you feel tired while in surgery? *(Paper V)*

Very often	(1)	O
Fairly often	(2)	O
Sometimes	(3)	O
Very little	(4)	O
Hardly ever	(5)	O

33. Do you experience the workload as static while in surgery? *(Paper V)*

Yes, very much	(5)	O
Yes	(4)	O
Sometimes	(3)	O
No	(2)	O
No, not at all	(1)	O
Not applicable	(0)	O

Thank you for participating!

11.2 Evaluation of the lighting during surgery questionnaire

(Used in Paper VI, similar questions were used in Paper V for the rating of the general lighting and operating light as in question 1)

Name:__________________________________ Year of birth:_____________

Date:____________ Op starting time:________ Op stop time: ____________

Profession: ____

Type of surgery: ____

Amount of light measured at the operating cavity: ________________________

Did you during this surgery use any of the following:

Ultrasound O

Lap/endoscopy O

Roentgen O

1 **How do you rate your experience of the general lighting in the room?**
(Rate on the scale below by marking with an ”x” or a bar on the line)

Extremely bad Very good

____

2 **What is your experience of the colour of the light from the general lighting?**

Too warm Too cool

____

3 **How did you experience your visual ability during surgery?**

Extremely bad Very good

____

4 **How tired do you feel now after surgery?**

Not at all Tired Very Tired

____

11.2 Evaluation of the lighting during surgery questionnaire

(Used in Paper VI, similar questions were used in Paper V for the rating of the general lighting and operating light as in question 1)

Name:______________________________________ Year of birth:______________

Date:_____________ Op starting time:_________ Op stop time: _____________

Profession: ____
Type of surgery: ____

Amount of light measured at the operating cavity: ___________________________

Did you during this surgery use any of the following:
Ultrasound O
Lap/endoscopy O
Roentgen O

1 **How do you rate your experience of the general lighting in the room?**
(Rate on the scale below by marking with an ”x” or a bar on the line)

Extremely bad Very good

____

2 **What is your experience of the colour of the light from the general lighting?**

Too warm Too cool

____

3 **How did you experience your visual ability during surgery?**

Extremely bad Very good

____

4 **How tired do you feel now after surgery?**

Not at all Tired Very Tired

____

Paper I

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Vision ergonomics at recycling centres

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ABSTRACT

All municipalities in Sweden offer their inhabitants a service for disposing of large-size and hazardous waste at local recycling centres. Opening hours at these centres include hours of darkness. The aims of this study were to 1) describe user and employee experiences of lighting and signs at Swedish recycling centres, 2) measure and assess the lighting system at the two recently built recycling centres in Linköping and to assess the legibility and visibility of the signs used and 3) propose recommendations regarding lighting and signs for recycling centres. Interviews and questionnaires were used to assess experiences of employees and users, and light measurements were performed. By observing users, activities with different visual demands at different areas within the recycling centres were identified. Based on the literature, standards and stakeholder experiences, recommendations regarding lighting systems and sign design, illuminance, luminance and uniformity are proposed for recycling centres.

1. Introduction

All municipalities in Sweden offer their inhabitants a service for disposing of large-sized and hazardous waste at local recycling centres. The waste is normally brought by car. Opening hours often include daytime and one or two evenings per week. In winter, many of the opening hours take place in darkness. A more detailed description of recycling centres and their function can be found in Engkvist et al. (2004, 2010) and in Engkvist (2010).

Since recycling centres represent a new line of activity within the recycling industry, little research has been performed – in particular, hardly any concerning visual ergonomics. Users normally make a few stops in the area for users, and walk carrying their waste to the containers for different waste fractions. Some users have pre-sorted their waste at home, but others sort at least some of their waste near the car or the containers. This means that there are pedestrians as well as car traffic in the area for users. This area and the traffic lanes are lit by lamp posts and sometimes line-suspended luminaires. Signs direct the users to the containers they are looking for. Visual conditions are crucial for both users and employees in many respects, and good light contributes to reduced risk of accident (Fothergill et al., 1995), more effective surveillance, more effective sorting, easier access to the required containers for different waste fractions and reduced risk of burglary. According to Boyce (2003), a study of the crime rate (robbery, sexual assault, threats etc.) was performed before and after changes in street lighting. Illuminance was changed from 0.6–4.5 lx to 6–25 lx, and the attachment was changed from low pressure sodium to high pressure sodium. During the 6-week study period, the crime rate sank from 22 to 3, measured as number of respondents experiencing crimes.

The respondents also experienced positive effects of the new lighting such as the feeling of increased safety, brighter lighting, improved look of area etc. There is a longer response time in peripheral vision using high-pressure sodium lights compared to metal halide lamps (Fotios et al., 2005; He et al., 1997). This can have an impact on detection of objects in the periphery, for example persons at the side of the road.

The present study was part of the multidisciplinary research programme "Recycling centres in Sweden – working conditions, environmental and system performance". The purpose of the programme was to form a basis for improving the function of recycling centres with respect to these three fields. Papers based on this research programme are collected and published in this special issue of Applied Ergonomics (2009, Volume xx, Issue xx).

Furthermore, there was collaboration with Tekniska Verken in Linköping, a municipally-owned company with responsibility for building and running recycling centres in Linköping. During the time this research programme was running, a second recycling centre was built in Linköping, and also a third was planned and built. The results from the research programme were presented and discussed with the persons responsible for the planning of the new

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recycling centres. Many aspects of the design were discussed, and several design recommendations resulting from the research programme were considered.

A few studies have been published on ergonomics at recycling centres, but no study specifically dealing with lighting has been found in the scientific literature. This paper focuses on lighting and signs at recycling centres, and in particular the lighting system at the two recently built recycling centres in Linköping.

The aims of this paper were to:

1) describe user and employee experiences of lighting and signs at Swedish recycling centres;
2) measure and assess the lighting system at the two recently built recycling centres in Linköping and to assess the legibility and visibility of the signs used;
3) propose recommendations regarding lighting and signs for recycling centres, based on vision ergonomics research and experiences from this study.

2. Frame of reference

2.1. Lighting

There are no recommendations of lighting specifically for recycling centres. There are, however recommendations for traffic roads and different outdoor workplaces. According to the recommendations for lighting given by CIE (CIE 031:1976), the illuminance level should be as even as possible in order to avoid dark areas. The measure of this value is uniformity (the quota between the minimum value and the mean value). Standards give recommendations of the minimum illuminance levels and uniformity for different tasks (CIE S 015:2005). The European Standard (CEN/TR 13201-1:2004) give recommendations for minimum luminance values and uniformity. The lighting should make it is easy to see where to go and to see containers, signs etc. To make this possible, some demands must be placed on luminance and illuminance and on their uniformity, adjusted to the reflection qualities of the different surfaces. The eye perceives luminance, which is the brightness of surfaces. Road surfaces differ with regard to the structure and material they consist of. Some are lighter than others and therefore need less light to fulfill the recommendations given (CIE 066:1984; CIE 144:2001). International and national rules for streets, roads and outdoor lighting at workplaces prescribe different demands and levels, for example, luminance and illuminance with regard to traffic load and speed (CIE 015:2005; SIS, 2003). Parts of these norms may be applied to recycling facilities. In order to facilitate orientation skills, it is important to use contrasts on the ground, e.g. white lines and arrows on the asphalt (CIE 144:2001).

Lighting should not cause glare. According to Boyce (2003), disability glare produces a measurable change in visibility because light scattered in the eye reduces luminance contrasts in the retinal image. There is a limit threshold increment in road lighting installations with regard to discomfort glare (CIE 115:1995), i.e. the difference in luminance contrast.

Several studies have been made on the colour of lighting, from the monochromatic yellow of low pressure lamps to the white of metal halide discharge lamps. Most of them were unable to reach any clear conclusions that white light is better, but their measurements were made on the in-axis objects. Boyce (2003) quotes a study made by He et al. (1997), where they looked at off-axis detection (detection of an object in the peripheral part of the retina) and change in reaction time when high pressure sodium lamps and metal halide lamps were compared. Their conclusion was that reaction time was quicker in the white light from the metal halide lamp. CIE standards recommend a colour rendering index of at least 0.2. However, for tasks that demand separating different objects, the requirements for colour rendering index must be higher.

2.2. Signs

Information is needed at the recycling centre for guiding the users. Therefore, the design and visibility of the signs are of crucial importance. Signs must have fulfilled certain criteria (Dewar, 1989). They must be visible to be acknowledged, readable at a far distance for sufficient reaction time and readable at a quick glance. The design of signs at recycling facilities has been based on local ambitions, resources and experience. There is a lack of detailed research-based knowledge of how signs should be designed in order to be visible and legible in an outdoor environment at different viewing distances and in different light conditions. Better design of signs contributes to improved quality of waste sorting and traffic safety, thus improving the environment and working conditions for both users and employees.

Visibility concerns sign position, shape and colour, and the complexity of the surroundings (O'Brien et al., 2002; Cole and Jenkins, 1982). Signs should be placed at a level high enough above the cars to be visible (Woodson and Conover, 1966). They should be well lit and not be placed in counter beam. Cole and Jenkins (1982) point to the importance of the edges of the signs for improving visibility. Visibility will be enhanced by a frame around the edges of the sign (Kuhn et al., 1997). The shape of the sign can also simplify the message. Instead of having a rectangular-shaped sign with an arrow pointing in the right direction, the sign should be shaped as an arrow (Bruyas et al., 1996). According to O'Brien et al. (2002), the sign that provided the best visibility had a negative polarity with a dark green background and white characters. Kuhn et al. (1997) found in a literature study that for green signs, the detection distance of the sign was improved when they were made of highly reflective material.

3. Materials and methods

Both of the two recycling centres studied consist of four major areas intended for users, namely 1) the area for large containers, 2) containers and cages for hazardous and electrical waste, 3) the recycling station for packaging and newsprint, and 4) the dump area for garden waste and excavated materials. The area for large containers includes containers for e.g. landfill, corrugated cardboard, combustible waste, metal scrap and wood. These containers are placed on a lower level than the users, see Fig. 1. On the other side is the environmental station for hazardous waste, containers for white goods and tires, see Fig. 2. Part of the area has a roof that shelters smaller containers for e.g. light bulbs, fluorescent tubes, batteries, chemicals, and cages for electric and electronic waste.

Within the area for the recycling station, there are containers for glass packaging, paper packaging, newsprint, metal packaging and plastic packaging. There are also containers for reusable products such as clothes, furniture, lamps, books, household utensils, see Fig. 3. A non-profit-making organization takes responsibility for the handling of products for reuse.

The fourth area is a dump for garden waste such as brush wood, leaves, grass, fruit waste, and also for excavated material such as stone, sand, and grit (Fig. 4).

The four areas are connected by paved roads that guide the traffic. In addition, a fifth area is intended only for employees, when handling the large containers. The layout of the recycling centre is seen in Fig. 5.

Fig. 1. The area for large containers at Malmen Recycling Centre.

In the first stage, data collection was performed at 16 recycling centres in Sweden, using questionnaires to 317 private and occupational users, as well as interviews with 77 private and occupational users. In addition, 163 users were observed during their visit, regarding their activities (e.g. driving, sorting, lifting, carrying, reading and throwing waste). An observation protocol was filled in by the researchers who avoided intruding on the users. The signs at the 16 recycling centres were also documented with photographs, and the type and size of the texts were noted. Further, a questionnaire was distributed to 122 employees at 42 recycling centres. The issues covered included the perception and experiences of lighting, injury risks related to light and improvement opportunities. Luminance and illuminance was measured at these 16 recycling centres during the data collection, with equipment as described below. For a more detailed description of the methods used, see Engkvist et al. (2010) in this issue.

In the second stage, data collection was performed at the two newly built recycling centres in Linköping, namely Malmen and Ullstämma. This included measurements of illuminance and luminance when they were artificially lit during hours of darkness. The intention was to include measurement points representing the whole range of luminance and illuminance levels. Measurements were performed on the ground in the areas described above, at container height, and at working height (75 cm over the ground); in addition, luminance from the vertical signs was measured. The illuminance of the different areas was measured at several places, alongside the containers. Every container had one measuring point at working height. There were 14 measuring points for the illuminance around the large container area for Ullstämma, and 19 for Malmen. The illuminances of the signs were measured vertically at 3 places: on the left side, in the middle and on the right side at the bottom on every sign. The reason for measuring at 3 places was to consider effects of shadows, although this did not have much of an impact on the result. The luminance on the ground was measured at approximately the same spots as the illuminance measuring points. The luminance was measured once on every sign, on the white part of the signs. The luminance from the luminaires was measured at a 45-degree angle from the line of vision. When deciding on the measuring points in order to obtain the highest and lowest values, a grid based on the positions of the luminaires were followed.

The measurements were performed in March, after sunset between 9.15 pm and 2 am. Illuminance (lx) and luminance (cd/m^2) were measured using a Hagner Universal Photometer, model S2. Furthermore, the signs at the recycling centres were documented with photographs, and the type and size of the texts were noted. Semi-structured interviews about their experience of the lighting in the different areas, colour rendering, difference dark/bright time of year, glare, the signs, size of the text, etc. were performed with the 5 employees at the two recycling centres, in order to assess their experiences and attitudes towards the lighting system and the signs at their workplaces, and also reactions from users.

Based on the observations from the 16 recycling centres, different tasks performed by the users were identified. With the help of CIE standards, these tasks were analyzed and compared with corresponding situations in the CIE Standards recommendations.

4. Results

4.1. User and employee experience of light and signs at Swedish recycling centres

Half of the employees (51%) from the 42 recycling centres did not consider that the lighting at their workplace was insufficient (too weak or causing glare), while the others (49%) reported that they perceived insufficient light at least 10% of their working time. The light measurements performed at the 16 recycling centres confirmed that illuminance and luminance varied considerably, partly since the measurements were performed during daylight or in darkness. Illuminance varied between 5 and 550 lx and luminance from 0 to 100 cd/m^2. The levels tended to be lower for hazardous waste and electrical waste, compared with the container areas. In many cases, the values were also considerably lower than applicable recommendations.

Fig. 2. Containers for bulky hazardous waste, cages for electric and electronic waste, and the area covered by a roof at Malmen Recycling Centre.

Fig. 3. The recycling station for packaging and newsprint at Malmen Recycling Centre.

The need for sufficient light was confirmed in different ways in the interviews and questionnaires. About half of the users considered that there were risks of injury at the recycling centre, and half of the employees had experienced a near accident during the last 12 months. Some of these risks were related to vision, e.g. treading on sharp-edged waste objects, tripping, falling and twisting an ankle due to uneven ground, waste objects on the ground or differences in levels. Several users and employees pointed out that there was a substantial risk that people could be hit by cars, especially when it was dark. About one third of the users looked in the containers in order to check if they were sorting and disposing of their waste in the correct container. For more than half of the users, the signs were of at least some importance when identifying and finding the correct container for their waste.

The possible improvements suggested by the users and employees included larger signs in 7 out of 27 proposals. In some of these cases it was particularly pointed out that better light was needed on the signs.

The user activities or tasks were described according to the observations. Based on these activities or tasks, lighting recommendations have been identified and related to each group of task, as shown in Table 1.

4.2. Lighting at Malmen recycling centre

Based on the 38 measurements, the mean luminance for the entire large container area (not including the area for hazardous waste under the roof) was 0.86 cd/m^2, with a uniformity of 0.58. The mean illuminance was 47 lx (39 measurements), with a uniformity of 0.42. The line-suspended luminaires gave considerable glare. They had a luminance of 50 000 cd/m^2, when measured at an approximately 45-degree angle from the line of vision.

Based on the measurements (5 times 2), the area where the employees handled the large containers had a mean luminance of 0.2 cd/m^2 and an illuminance of 10 lx (Table 2).

For a comparison with recommended values, see the recommendations at the end of this paper.

4.3. Signs at Malmen

Most of the signs at Malmen Recycling Centre had negative polarity, i.e. a dark background with light characters, in this case a dark blue background with white characters. The signs around the large container area had both positive and negative polarity, and had mean luminance of 6.1 cd/m^2. Luminance uniformity was 0.12. The mean illuminance was 26 lx, with a uniformity of 0.30 (Tables 3 and 4).

The biggest character was 16 cm high and the smallest was 7.5 cm high. The characters were written in lower case, see Fig. 6.

4.4. Lighting at Ullstämma recycling centre

Based on the 34 measurements, the mean luminance for the entire large container area (not including the area for hazardous waste under the roof) was 4.6 cd/m^2, with a uniformity of 0.65. The mean illuminance was 52 lx, with a uniformity of 0.29. The light source in the lamp posts at Ullstämma had a luminance of 20,000 cd/m^2, when measured at an approximately 45-degree angle from the line of vision. Based on the measurements (3 times 2), the area where the employees were handling the large containers had a mean luminance of 1.5 cd/m^2 with a uniformity of 0.91 and an illuminance of 25 lx, uniformity 0.8 (Table 5).

4.5. Signs at Ullstämma

Most of the signs at Ullstämma Recycling Centre had negative polarity with a blue background and white characters. The signs

Fig. 4. The dump area for garden waste and excavated materials at Malmen Recycling Centre.

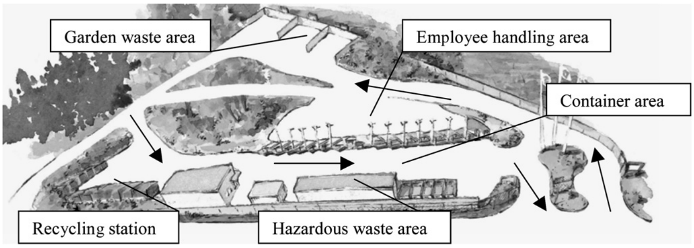

Fig. 5. An overview of the layout of Malmen Recycling Centre.

around the large container area had a mean luminance of 7.4 cd/m^2, measured on the white background. Uniformity was 0.33. The mean illuminance was 24 lx, with a uniformity of 0.41 (Table 6).

The biggest characters of those that were intended to be read at a distance, were 12 cm high, and the smallest were 7 cm high. The characters describing "Type of waste" were written in capital letters, and the remaining ones in lower case (Table 7).

Table 1
User tasks relating to area within the recycling centre and lighting recommendation.

Area	Task	Lighting recommendations	CIES015 2005 Ref no
Driving lanes	Driving	Em10 lx,Uo0.25	5.1.2
	Identifying other vehicles and pedestrians	Em 30 lx, Uo 0.4	5.1.4
	Visual search for signs	Em 30 lx, Uo 0.4	5.1.4
Area for employee handling of large containers	Driving work vehicles	Em 30 lx, Uo 0.4	5.1.4
	Identifying other vehicles and containers	Em 30 lx, Uo 0.4	5.1.4
User area near the large containers and recycling station	Driving	Em10 lx,Uo0.25	5.1.2
	Identifying other vehicles and pedestrians	Em 30 lx, Uo 0.4	5.1.4
	Visual search for signs	Em 30 lx, Uo 0.4	5.1.4
	Reading signs	Em 30 lx, Uo 0.4 (vertical)	5.1.4
	Identifying different types of waste in the containers	Em 100 lx, Uo 0.4	5.3.3
	Sorting different types of waste	Em 100 lx, Uo 0.4	5.3.3
	Carrying and disposing of waste	Em 30 lx, Uo 0.25	5.4.4
User area near the hazardous waste	Visual search for signs	Em 30 lx, Uo 0.4	5.1.4
	Reading signs	Em 30 lx, Uo 0.4 (vertical)	5.1.4
	Identifying different types of hazardous products	Em200 lx,Uo0.4	5.7.4
	Reading labels	Em200 lx,Uo0.4	5.7.4
	Sorting different types of waste	Em200 lx,Uo0.4	5.7.4
	Carrying and disposing of waste	Em 30 lx, Uo 0.25	5.4.4
Dump area for garden waste and excavated material	Driving	Em10 lx,Uo0.25	5.1.2
	Identifying other vehicles and pedestrians	Em 30 lx, Uo 0.4	5.1.4
	Visual search for signs	Em 30 lx, Uo 0.4	5.1.4
	Reading signs	Em 30 lx, Uo 0.4 (vertical)	5.1.4
	Identifying different types of waste in the dump area	Em 30 lx, Uo 0.25	5.4.4
	Carrying and disposing of waste	Em 30 lx, Uo 0.25	5.4.4

5. Discussion

The purpose of lighting is to create reduced risk of accidents, more effective surveillance, more effective sorting, reduced risk of burglary, and to aid identification and access to the intended containers for different waste fractions. A good visual environment also contributes to a positive image of the facility. Existing recommendations and standards of light provide a basis for the design of lighting systems. There is, however, no recommendation specifically for recycling centres. One aim of this paper is to propose recommendations for lighting and signs at recycling centres, based on vision ergonomics research, lighting recommendations in standards and experience from the present study.

There are no specific recommendations in Sweden or Europe regarding how lighting should be distributed over the recycling facilities. However, recycling facilities have motor traffic, which means several visual demands on reading signs. There is also some manual work involved in unloading material for recycling from the cars and throwing it into the containers. Therefore the European Standard (CEN) for street lighting should be valid. This standard is CEN/TR 13201-1 and is valid as Swedish Standard, SIS, SS-EN 13201-2. It is valid for all types of street lights and is divided into subcategories, everything from roads with a great deal of traffic to small low-traffic streets. Category MEW3 should be appropriate for a recycling facility, with motor traffic moving at less than 10 km/h. The classification of MEW3 means that the luminance on the ground should be a minimum of 1.0 cd/m^2 with a uniformity of minimum 0.4.

In this study, recommendations for illuminance for operations and work of this type are regarded as corresponding to those for the different type of work in the CIE recommendations (CIE 015:2005). The lighting was regarded as good at Malmen recycling centre. The total illuminance uniformity was 0.42 for the container area. Ullstämma had a total illuminance uniformity of 0.29 for the

Table 2
Mean illuminance and luminance measurements in the user areas at Malmen Recycling Centre.

Area	Luminance (cd/m^2)	Luminance uniformity	Illuminance (lx)	Illuminance uniformity
Large container area by the containers	1.1	0.45	65	0.61
The middle of the large container area	0.7	0.73	36	0.55
Area for bulky hazardous waste	0.8	0.63	41	0.73
Area for hazardous waste under the roof	7.1	0.91	233	0.86
Recycling station	4.8	0.85	52	0.77
Garden waste dump	4.0	1.0	11	0.71

Table 3
Mean illuminance and luminance measurements for the signs at Malmen Recycling Centre.

Sign location	Luminance (cd/m^2)	Luminance uniformity	Illuminance (lx)	Illuminance uniformity
By the large containers	6.8	0.29	33	0.45
By the bulky hazardous waste containers	3	0.24	15	0.52
By the hazardous waste containers under the roof	18	0.10	149	0.67
By the recycling station	4.7	0.75	52	0.77
By the garden waste dump	4.0	0.88	15	0.6

container area. For the container area, as pointed out earlier, 100 lx with a uniformity of 0.4, and a luminance of 1.0 cd/m^2, is recommended in areas where sorting takes place. For driving lanes and the different tasks carried out there, the garden waste dump, and the area for employee handling of large containers, the recommendations are 30 lx with a uniformity of 0.4. Regarding hazardous waste, the recommendations are slightly higher, due to the visual demands when sorting and reading labels, 200 lx with a uniformity of 0.4. There were no complaints about uneven lighting at Malmen, but the employees at Ullstämma considered the lighting somewhat uneven. A uniformity value of 0.4 is therefore considered sufficient.

Two of the employees at Ullstämma complained about the lighting, which they found uneven with too few light fittings. The light fittings cast sufficient light into 2 of the 12 containers. In reality, the uniformity value by the containers is lower, due to the fact that this value was calculated from measurements when the top covers of the containers were down. When the top covers of the containers are up, they cast shadows over the containers placed beside them. This is why only two out of twelve containers at Ulstämma have sufficient light according to the employees. At Ullstämma the staff also complained about their two lamp posts in the middle of the user area. The lamp posts take up considerable space and restrict the flow of traffic. The employees would prefer to have line-suspended luminaires.

At Malmen the employees were more positive about the lighting, especially the line-suspended luminaires. They did not experience any problems due to movements of the light fittings in windy weather conditions. The only complaint some of them had concerned the light source at the recycling station area. The lamp posts were attached with high pressure sodium, and the employees pointed out that this gave poor illumination. Sodium lamps are not recommended, due to the longer response time in peripheral vision, which is important since there are a great many pedestrians. Furthermore, sodium lamps give low colour rendering, and therefore make it harder to sort certain objects; for example, it is harder to tell the difference between plain wood and treated wood, which are supposed to go into different containers.

It was clearly demonstrated that many light sources in lines cast better light into the large containers at Malmen, while the few lamp posts at Ullstämma cast shadows from the container top covers.

Table 4
Size of the characters in the signs at Malmen Recycling Centre.

Size of the different characters in cm	Type of waste	Examples	Number	Information
By the large containers	7.5	5	13	3
By the bulky hazardous waste containers	12	6		
By the hazardous waste containers under the roof	12			
By the recycling station	mean 2.9			
By the garden waste dump	16	9		7

Fig. 6. An example of a sign by the large containers at Malmen Recycling Centre. The dark fields on the sign and the frame are dark blue and the light fields are white.

The mean illuminance by the containers, 41 and 65 lx, was not quite sufficient according to the recommendations. However, the uniformity of 0.44 was fairly close to the recommendations.

The light fittings installed at Malmen produced considerable glare, with a luminance of 50,000 cd/m^2. It would have been possible to avoid this, simply by choosing luminaires with the light source placed deeper and by adding louvres. The angle from the line of vision to the luminaire would then be larger, resulting in less glare.

The lack of light at the area where the employees handled the large containers, 10–25 lx, did not disturb the employees very much. The activities performed involve driving work vehicles, which are equipped with strong headlights. The only time it may become a problem, according to one employee, is when they stand and work close to the containers. Here, they do not always see exactly what they need, which may result in injuries.

Despite the fact that the illuminance was comparable between the two recycling centres, Malmen had considerably lower luminance from the ground. The reason was that the asphalt was new there, and therefore darker. After a couple of years it will become much lighter as at Ullstämma, which will create higher luminance values. The use of light stone materials in the asphalt would contribute further to higher luminance values. It should also be considered that rain decreases the luminance from the asphalt.

At the garden waste area, both at Malmen and Ullstämma, there is less need for illumination compared with the container areas, as there is no need to read or perform any detailed sorting work.

Table 5
Mean illuminance and luminance measurements in the user areas at Ullstämma Recycling Centre.

Area	Luminance (cd/m^2)	Luminance uniformity	Illuminance (lx)	Illuminance uniformity
Large container area by the containers	5.7	0.56	73	0.61
The middle of the large container area	3.8	0.78	37	0.41
Area for bulky hazardous waste	4.0	0.91	28	0.54
Area for hazardous waste under the roof	7.9	0.70	220	0.82
Recycling station	3.2	0.90	33	0.78
Garden waste dump	6.0	0.92	14	0.73

Table 6
Mean illuminance and luminance measurements for the signs at Ullstämma Recycling Centre.

Sign location	Luminance (cd/m^2)	Luminance uniformity	Illuminance (lx)	Illuminance uniformity
By the large containers	8.3	0.67	24	0.42
By the bulky hazardous waste containers	3.0	0.75	28	0.54
By the hazardous waste containers under the roof	7.2	0.97	178	0.84
By the recycling station	6.1	0.81	16	0.68
By the garden waste dump	5.6	0.93	10	0.82

The illuminance for most signs was not as high as the recommendations, either at Malmen or at Ullstämma. However, the luminance from the signs was sufficient in most places, given positive polarity.

The visibility of the signs was mentioned by many users as being important. According to the literature recommendations quoted above, the size of the characters is supposed to be 15–25 cm high, in order to be visible at a distance of 40–60 m. Hardly any of the signs had characters that complied with the recommended size.

The signs by the containers have negative polarity at the top and bottom, and positive polarity in the middle. At Malmen the employees noticed that when users parked by the containers and walked around to dispose of their waste, they often failed to read the top information about what type of waste to dispose of in the container. They only read the examples. One possible explanation for this might be that the information about the type of waste was mounted too high, since the bottom edge of the signs was placed 2.3 m above the ground. The users might have difficulty looking up to that height when walking and carrying waste close to the signs. This results in many unnecessary questions to the employees. One solution is to write the information about the type of waste twice on the sign: once at the top and then again at the bottom of the sign. When choosing the polarity of the signs, the opening hours and the type of background behind the signs should be taken into consideration. If the opening hours are mostly during daytime, positive polarity is preferred and vice versa. And if there are trees behind a sign (dark background) positive polarity is easier to spot (CIE S 137/E:2000).

Two studies (Dobas, 2005; Sjöblom, 2005) came to the conclusion that between 6 and 9% of Swedish drivers had inadequate visual acuity for passing the driving license limit of 0.5. This information is important when designing the signs, due to the fact that some of the users obviously need the large characters.

6. Conclusions and recommendations

This study has confirmed the importance of proper lighting at recycling centres in order to decrease risks of accidents and burglary, and to support users and employees in their sorting, sign reading and disposal activities. The legibility of signs has an important impact on the quality of user sorting activities. Many users would prefer bigger and clearer signs, and are concerned that insufficient light might increase the risk of being hit by a car when walking in the user areas of recycling centres. Few recycling centres comply with the recommendations in the literature and standards regarding lighting and sign design. The experience from two recently built recycling centres has contributed to a proposed recommendation regarding lighting and signs at recycling centres. These recommendations address the different areas within the recycling centre.

Table 7
Size of the characters on the signs at Ullstämma Recycling Centre.

Size of the different characters in cm	Type of waste	Examples	Number	Information
By the large containers	8	4		3
By the bulky hazardous waste containers	12	6		
By the hazardous waste containers under the roof	9			
By the recycling station	mean 2			
By the garden waste dump	7	5		3.5

7. Recommendations for lighting

General:

Luminaires should be line-suspended in order to avoid lamp posts in user areas. The luminaires should not be fitted with sodium lamps because of the low colour rendering and loss of peripheral detection ability.

The large container area:

Luminaires: Tiltable asymmetric beamer at a well-adjusted distance so that the light falls into the containers and that glare is avoided.

Illuminance 100 lx and luminance 1 cd/m^2, with a uniformity of minimum 0.4.

Driving lanes:

Luminaires: A symmetric luminaire with a deeply placed lamp and louvres. The light fittings close to the containers should be equipped with glare shields towards the driving area.

Illuminance 30 lx, with a uniformity of minimum 0.4.

The hazardous waste area under the roof:

Luminaires: Asymmetric fluorescent light fittings mounted directly inside the roof, with a light direction in under the roof. Above every sign there should be a fluorescent light fitting with a well-functioning glare shield.

Illuminance 200 lx and luminance 1 cd/m^2, with a uniformity of minimum 0.4. The luminaires should not be fitted with sodium lamps because of the low colour rendering and temperature. Inside the environmental station there should be symmetric fluorescent light fittings with a prismatic cover. The placing of the light fitting should be adjusted to the sorting table and shelves.

The area for employee handling of large containers:

Luminaires: A symmetric luminaire with a deeply placed lamp and louvers.

Illuminance 30 lx, with a uniformity of minimum 0.4.

Garden waste dump:

Luminaires: A symmetric luminaire with a deeply placed lamp and louvers.

Illuminance 100 lx and luminance 1 cd/m^2, with a uniformity of minimum 0.5.

7.1. Recommendations for signs

Signs and information boards should be well lit. Illuminance should be a minimum of 100 lx where work is performed. The mean luminance on the signs should be a minimum of 10 cd/m^2 (Vägverket, 2002).

There should be a consistent distinction between container signs and traffic information signs. A frame should be placed around the signs. A colour that differs from the surroundings should be chosen for the sign. Negative polarity (light characters with dark background) and a font without serifs should be chosen. A dark green background is preferred when there are no trees behind the sign. If the recycling centre is open mostly in daytime and lit by daylight, negative polarity will give the best conspicuity. If it is mostly open at night, positive polarity should be chosen.

The characters should be in lower case and 15–25 cm high for a reading distance of 40–80 m. The signs should be placed at a level high enough above the cars to be visible. A height of 2.3 meters is recommended.

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A visual ergonomics intervention in mail sorting facilities: Effects on eyes, muscles and productivity

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A B S T R A C T

Visual requirements are high when sorting mail. The purpose of this visual ergonomics intervention study was to evaluate the visual environment in mail sorting facilities and to explore opportunities for improving the work situation by reducing visual strain, improving the visual work environment and reducing mail sorting time. Twenty-seven postmen/women participated in a pre-intervention study, which included questionnaires on their experiences of light, visual ergonomics, health, and musculoskeletal symptoms. Measurements of lighting conditions and productivity were also performed along with eye examinations of the postmen/women. The results from the pre-intervention study showed that the postmen/women who suffered from eyestrain had a higher prevalence of musculoskeletal disorders (MSD) and sorted slower, than those without eyestrain.

Illuminance and illuminance uniformity improved as a result of the intervention. The two post-intervention follow-ups showed a higher prevalence of MSD among the postmen/women with eyestrain than among those without. The previous differences in sorting time for employees with and without eyestrain disappeared. After the intervention, the postmen/women felt better in general, experienced less work induced stress, and considered that the total general lighting had improved. The most pronounced decreases in eyestrain, MSD, and mail sorting time were seen among the younger participants of the group.

1. Introduction and background

A literature search for studies on longitudinal lighting interventions and eyestrain in a non-computer environment was performed but no internationally published peer reviewed articles were found. Aarås et al. (1998,2001) performed a large ergonomic intervention study of video display units (VDU) operators, which included lighting. They found that lighting and optometry are of crucial importance in reducing musculoskeletal disorders (MSD). Both mail sorting and VDU work is visually demanding, and a good visual environment is important for health and wellbeing.

1.1. Visual ergonomics and lighting

When vision is unsatisfactory, the body adapts to a posture aimed at improving it: "The eyes lead the body" (Anshel, 2005). The frequency of musculoskeletal pain among people with incorrect lenses in their glasses is higher than among those with correct lenses. A single vision lens or a work progressive lens is better for working with computers than a regular progressive lens (Horgen, 2003). People with eyestrain often also report musculoskeletal complaints (Knave et al., 1985). Studies show that an optic correction for near distance work affects the accommodation and vergence, which reduces muscle activity in the head, neck, and shoulder region (Lie and Watten, 1985, 1994; Richter, et al., 2010a,b). This means that a pair of working glasses adjusted for correct working posture and distances can reduce muscle strain. There are also differences in eyestrain within a working day: The amount usually increases when the same type of work is performed (Boyce et al., 2005).

The visual environment can change the mood of people, which can alter their behaviour (Boyce, 2004). Human performance can

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be affected by lighting via three routes, namely through the visual system, the circadian system, and the perceptual system (Boyce, 2003). Visual fatigue can be multifactorial, induced and/or supported by psychological factors, as well as the intensity and duration of the visual strain, the perceived situation and the physiopathological characteristics of the individual visual apparatus (Piccoli et al., 2003). An increase in illuminance within relevant ranges will often result in improved visual performance. According to Veitch (2001), a working area should have uniform illuminance while the surrounding areas should be non-uniform, but not causing glare. Glare can lower productivity as reported in a study by Horgen et al. (2007). A luminance contrast that is too high will cause visual fatigue due to continuous readaptation of the eyes; too low and it will result in a dull and non-stimulating working environment (CIE 2002). If a worker can change the level of illuminance at the workplace, productivity increases, environmental satisfaction improves, and energy savings are obtained (Boyce et al., 2006b; Juslén et al., 2007b).

There are many different mechanisms involved in enhancing human performance by light, visual comfort, visual ambience, interpersonal relationships, and the change process (Juslén and Tenner, 2005). According to Boyce et al (2006b) there are correlations between productivity and eye fatigue, and direct/indirect lighting systems can enhance motivation and attention during the working day. Based on present knowledge, the work related ocular/visual disorders and disturbances reported in the literature have a multifactorial origin, namely, task characteristics, environmental conditions and individual characteristics (Piccoli et al., 2003). To enhance productivity and wellbeing, and to reduce eyestrain, the visual environment has to be considered by providing good lighting conditions and good visibility of the tasks (Boyce et al., 2006a). Illuminance is one way to influence productivity. It may be an underlying cause of improved visual performance and have positive psycho-biological effects (Juslén et al., 2007a).

Akashi and Boyce (2006) showed that energy could be saved through an increase in colour temperature (from 3500 K to 6500 K) and a reduction of illuminance in offices from 500 to 360 lux from the general lighting for work tasks. This did not have any long-term impact on the visual performance, though. The workers did increase their use of task lighting at their desks, but this only had a little impact on the overall energy consumption.

Another visual ergonomics factor is the size of the printed text. Words written in lower case with an initial capital letter are easier to detect than words with only lower case or capital letters (Phillips et al., 1977; Phillips, 1979). Texts set in serif typeface, such as Times New Roman, are recommended because they are easy to read (MacLeod, 2000). In a study by Horgen et al. (2007), the size of the text also affects productivity in computer work. The recommended minimum size is 12 points, which represents a visual acuity of 20/60, depending on the screen size.

1.2. Kansei engineering

Kansei engineering is usually used when developing new products (Nagamachi, 1989; Schütte, 2005), such as cars, chairs, etc. To develop a new product within a specific area requires knowledge about what the customer wants and the feelings and experiences that are attractive to customers. Kansei words can be used to rate the importance of feelings and experiences. Kansei words are often adjectives where the participants grade the answer on a scale, usually from 1–7. The answer alternatives are, for example, between "I fully agree" and "I disagree completely".

1.3. Studies with postmen/women[2]

Postmen usually work in poorly lit facilities where they are exposed to glare, flicker from the luminaries, and poor ergonomics. The demands on sorting speed are high and so is static load on the upper body (Jennum et al., 1982; Jørgensen et al., 1989).

Wheatley (2002), focusing on muscle and skeletal symptoms among a limited group of postmen, found that four out of eight experienced some sort of eye discomfort. Analysis of data from the appendix of her report confirmed that postmen with eye discomfort often had a higher prevalence of muscular problems.

In another limited pilot study on postmen ($n = 6$), the impact of new lighting and labelling on productivity was investigated in two different districts (Kiviloog, 2003). This study included three categories of postmen, those sorting at a fixed district, those sorting at many different districts, and beginners/substitutes. After the introduction of new lighting, an average time improvement of 1–2 s/letter was found depending on the district. However, this was a small study and a Hawthorne effect may have been present.

1.4. The purpose of this study

The purpose of this visual ergonomics intervention study was to evaluate the visual environment in mail sorting facilities and to explore opportunities for improving the work situation by reducing visual strain, improving the visual work environment and reducing mail sorting time. The hypothesis was that incorrect lighting and incorrect power in lenses may cause eyestrain and affect workers' general wellbeing, and that visual problems may contribute to MSD, all of which may affect productivity. To improve the visual environment, the lighting should have a more uniform illuminance, higher illuminance and less glare in combination with better labelling.

2. Material and methods

2.1. Postmen's work

The work postmen carry out at the Swedish Post Office includes handling, sorting and delivery of mail. This study focuses on manual sorting of mail into sorting racks. From 2 to 4 h a day, the postmen sort several different types of letters. Every address/household has its own compartment. The number of sorting racks for each district varies between three and seven depending on its size (Fig. 1).

2.2. The locations – lighting conditions before the intervention

The participating postmen worked at five different locations in a middle-sized town in Sweden. Two of the post offices had naked fluorescent tubes as general lighting. The third and fourth had luminaries, the louvers of which were too few and too far apart. The fifth had luminaries with prismatic covers. All of the general lighting had the old type of conventional magnetic ballasts. At one of the offices, the daylight from windows facing south disturbed the postmen in their work when they were facing the windows.

2.3. The participants

The postmen were informed that participation was completely voluntary and would take place during working hours.

[2] Four postwomen were included in the study, two of whom dropped after the intervention. For the sake of brevity, the term "postmen" will be used in the rest of the article.

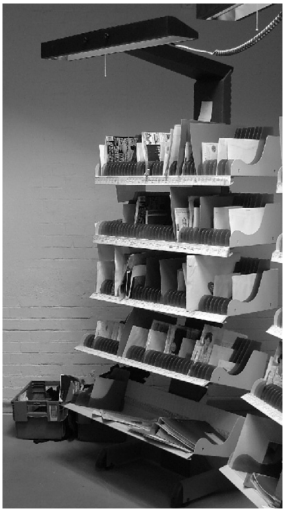

Fig. 1. The sorting racks with the new lighting.

The inclusion criteria were:

- Sorting mail by the postmen at their regular district before and after the intervention.
- Six postmen at each of the five offices.

Due to summer holidays, only 27 postmen were available to participate in the pre-intervention study in May–July 2004, 4 women and 23 men. Their ages varied between 24 and 63 years. Eleven were under 45 years of age. In the first post-intervention follow-up in May–June 2006, 25 of the original postmen took part: 2 women and 23 men. In the second post-intervention follow-up in December 2006–January 2007, 23 took part: 2 women and 21 men. There were two dropouts after the intervention (younger females due to sickness and pregnancy) and two additional drop-outs after the first follow-up (two males who had retired).

2.4. The intervention

New luminaries were specifically developed by a lighting manufacturer to be attached to the sorting racks in order to provide uniform light over the shelves. The primary criteria were a uniformity level of 0.7, a minimum illuminance of 300 lux on every shelf, an individual dimming function, and a minimum of glare for the postmen, see Fig. 1.

The general lighting was improved. Some of the old luminaries were turned off or moved if possible. All of the new luminaries were prepared for the attachment of indirect light. This involved a separate luminary on top of the new lighting fitting to improve general lighting when needed. The use of indirect light was determined by the shape of the room and placement of the sorting racks. This is because indirect light needs to have walls or a ceiling to reflect off in order to function as intended. A total of 20 indirect luminaries were added to some of the postmen's sorting stations.

The labelling strip lettering on the sorting racks was changed from 10 point capital letters to 12 point lower caps with an initial capital letter. The height of the labelling strip was increased by10 mm to accommodate the larger font. Each rack received one new holder for the labelling strip attached at a 15° angle from vertical, placed on the second shelf for better illuminance. Colour coding was introduced for the different streets, blocks of flats, etc.

2.5. Data collection before and after the intervention

The postmen's work environment was evaluated before the intervention from May to July 2004 on a normal working day, to minimize disturbances. This meant that only one or two people could take part in the study each day.

Before the lighting intervention took place, some of the districts had partially introduced the new labelling. Six districts had the old typeface with capital letters, and three had only the new typeface with lower case and an initial capital letter ($n = 27$). Five districts had only the old colour coding of the labelling. The remaining districts had only the new colour coding.

After the intervention, there were two follow-ups, the first in the summer of 2006 and the second in the winter of 2006–07. Most of the measurements of the pre-intervention study were repeated in the two post-intervention follow-ups, see also Table 1.

The second (winter) follow-up focused on eyestrain and general lighting. This was done to investigate how the seasons of the year affect eyestrain and how the postmen perceived their new lighting. A Kansei Engineering approach was used (Nagamachi, 1989; Schütte, 2005) to investigate how the postmen perceived the visual work environment using ratings of descriptive Kansei words. The words were rated from 1–5 on how much those questioned agreed on the following statements: glare free light, good level of light, too much light, no shadows, cosy light, biting light, easy-to-read letters, easy-to-read labelling, good detect ability, well planned light, warm light, comfortable light, professional light, grey light, weak light, fresh light, harsh light, soft light, and good light distribution.

Table 1
Overview of the methods used before and after the intervention.

	May–July 2004 Before the intervention ($n = 27$)	May–June 2006 After the intervention summer ($n = 25$)	Dec.–Jan. 2006–2007 After the intervention winter ($n = 23$)
Visual ergonomics questionnaire	•	•	•
Light evaluation	•	•	•
MSD evaluation	•	•	
Health questionnaire	•	•	
Kansei word rating questionnaire			•
Time study	•	•	
Measurements of illuminance/ illuminance uniformity	•	•	
Eye examination		•	
Impression of general lighting	•	•	

Table 2
The amount of eyestrain syndrome is obtained by multiplying occurrence by difficulty for the symptoms present and adding the values of the first eight symptoms. A sum of three or more indicates eyestrain that calls for attention.

			Occurrence				Difficulty		
			Few times	Every weekday	Every day		Negligible	Slight	Pronounced
	Yes	No	(1)	(2)	(3)	×	(1)	(2)	(3)
Smarting	O	O	O	O	O		O	O	O
Itching	O	O	O	O	O		O	O	O
Gritty feeling	O	O	O	O	O		O	O	O
Aching	O	O	O	O	O		O	O	O
Sensitivity to light	O	O	O	O	O		O	O	O
Redness	O	O	O	O	O		O	O	O
Teariness	O	O	O	O	O		O	O	O
Dryness	O	O	O	O	O		O	O	O
Eye fatigue	O	O	O	O	O		O	O	O
Headache	O	O	O	O	O		O	O	O

2.5.1. Work productivity – time study

A stopwatch was used to time the participants sorting 150 E5 letters, selected from the batch delivered to the postman's district. The study was performed in the morning as part of the ordinary sorting activity to assure that the postmen were adapted to the lighting conditions and present work situation.

2.5.2. The questionnaires

Three questionnaires were used (see Table 1). The visual ergonomics questionnaire was developed by Knave et al. (1985). It subjectively evaluates the visual working environment together with perceived problems and discomfort regarding the eyes, headaches, and musculoskeletal strain. Some questions about computer work were omitted because they were irrelevant to postmen's work. This questionnaire has been used in other studies, mainly in Sweden (see Håkansson, 2007). The health questionnaire deals with work related health and general wellbeing (e.g. tiredness, stress and the postmen's perception of the sorting work). This questionnaire was developed by the author and based on the validated questionnaires in Karltun's studies of work environment and organizational changes in the Swedish Post Office (Karltun, 2007). The last questionnaire involved the rating of Kansei words. Most of the postmen answered the questionnaires in the afternoon after their delivery rounds on the day they participated.

Eyestrain is a syndrome covering eight different symptoms: smarting, itching, gritty feeling, aches, sensitivity to light, redness, teariness, and dryness (Boyce et al., 2005). The amount of eyestrain was calculated. Eyestrain values for each symptom were calculated by multiplying the degree of occurrence by the degree of difficulty (maximum $3 \times 3 = 9$ points, Table 2). The sum of the values for the eight symptoms is the participant's eyestrain value. This value has a maximum of (9×8 symptoms) 72 points, and shows the participant's experience of eyestrain. An eyestrain index is defined as the average value for the participants in a study, also including those who experienced no problems. In this way, different groups of workers can easily be compared. Eye fatigue and headaches are other workplace related problems, but are not included in the eyestrain index (see Knave et al., 1985). Work-related eyestrain was defined as three or more symptoms points, according to Knave et al. (1985).

A similar index was calculated for the different MSDs from the upper body. The parts of the body included were divided into right and left hand, lower arm, elbow, upper arm, shoulder, neck, and back, for a total of 14 parts, with a maximum of 126 points (9×14).

2.5.3. Lighting data collection

The workplaces at each office were photographed and basic workplace dimension data collected. Assessments were made of the general lighting, the position of windows in relation to the sorting racks, and disturbing light sources. The illuminance (lux) was measured at three points on every shelf. The luminance was only measured in the first (summer) follow-up of 2006. Each sorting rack consisted of four shelves; 12 measurements were thus taken for each sorting rack, and the work stations/districts had between three and seven racks. The uniformity value for the illuminance was calculated as the average value divided by the highest value (CIE, 2002). Lighting was measured by a Hagner Universal Photometer S2 and a Hagner Screenmaster.

2.5.4. Eye examination

An optometrist performed optometric eye examinations on a Topcon VT-10 phoropter and a Topcon ACOP-6R/6EM visual acuity board. Most of the postmen participated over a 3-week period in May and June 2006, after the intervention. Three men dropped out of the eye examinations due to sickness and vacation. They did not have any eyestrain or problems with their eyes according to a visual examination in October 2007. The participants that needed new glasses according to the results of the visual examinations were given a pair of new ones after the study was performed.[3]

2.6. Data analysis

An expert assessment was performed of the risk for glare from luminaries and daylight based on the photos taken at the workplace visits: 1 = no risk for glare, 2 = some risk for glare, 3 = risk for glare. The workstation was assessed as having "risk for glare" if any direct counter beam sunlight was possible or if there were any luminaries without louvers mounted within the visual field. The workstation was assessed as having "some risk for glare" if it could have disturbing daylight, and if the postmen could see the lighting tubes directly in some viewing directions in spite of the louvers. A workstation with no disturbing daylight or artificial light was assessed as having "no risk for glare".

[3] The optometrist informed the participants that they needed new prescriptive lenses, but none got them on their own before the second (winter) follow-up, which is why they were provided with them at the end of the study. Their eyes have been examined with the new lenses, the results of which will be published in a future article.

The participants were divided into groups according to: a) age: a younger group < 45 years, and an older group ≥45 years; b) level of illuminance: group 1 < 500 lux (low), group 2500–750 lux (OK), group 3 > 750 lux (high); c) level of illuminance uniformity: group 1 < 0.60 (low), group 2 0.60 to 0.80 (OK), group 3 > 0.80 (high).

The participants that experienced eyestrain were placed in the "eyestrain" (ES) group and those without eyestrain were placed in the "no eyestrain" (NES) group. The postmen were divided into three groups based on the findings in the eye examinations: group 1, no requirement for any/new glasses; group 2, probable requirement for new glasses; group 3, requirement for new glasses.

The eyestrain values were compared to "Requirement of new glasses" and a new type of eyestrain was defined, "Assessed eyestrain". If the requirement for new glasses was high, it was probable that the assessed eyestrain was caused by the need for new glasses rather than by deficiencies in the working environment.

The MSD index was divided into total, torso, right and left side of the body.

The questions in the questionnaires were grouped into parameters, later used in the statistical analysis. For example, the general impression of light during the bright part of the year and during the dark part of the year were grouped under the total general impression of light (see Table 3), and the values for the separate questions were added together.

2.6.1. Group comparison statistics

The data collected was compiled in MS Excel for later statistical analysis, using the Statistical Package for the Social Sciences (SPSS Inc.) software. The material was analyzed with non-parametric methods, since most of the data (the questionnaires) were ordinal and subjective. The analysis methods used were: Wilcoxon matched pairs signed-ranks test, Mann–Whitney *U*-test, and Kolmogorov–Smirnoff two sample test, informed levels of significance $p < 0.05$, $p < 0.01$ and $p < 0.001$.

2.6.2. Correlations

The Spearman rank correlation coefficient was used for the correlation analysis, with levels of significance $* = p < 0.05$ and $** = p < 0.01$. Two-tailed analyses were made as the study was explorative. The correlation analysis was performed on data before and after the intervention. When comparing the Kansei ratings with some variables from the first (summer) follow-up after the intervention, one of the offices had changed locations, which resulted in six participants dropping out ($n = 17$) for the correlation analysis.

3. Results

3.1. Workplace lighting conditions before and after the intervention

Before the intervention almost half of the postmen had an old luminary to illuminate the sorting racks. The others had only general lighting from ceiling luminaries. After the intervention all of the postmen had both general lighting and the new lighting fittings on their sorting racks.

Illuminance before the intervention did not attain the recommended uniformity value of 0.7 for any of the participants. The mean uniformity value was 0.55. After the intervention the uniformity increased to 0.67 ($p < 0.01$).

The average illuminance increased from 556 lux with the old lighting to 947 lux with the new lighting ($p < 0.001$). The minimum changed from 253 to 537 ($p < 0.001$) and the maximum from 1086 to 1476 ($p < 0.01$).

The luminance on the labelling strip was only measured after the intervention, with an average 207 cd/m^2. The luminance from the general lighting varied from 4000 to 12000 cd/m^2.

The postmen did not use the individual dimming controls after initial adjustment, which usually was the highest possible. One postman did not use the new workplace lighting.

3.1.1. The postmen's experience of the workplace lighting and labelling

The general impression of the lighting improved after the intervention, both for the first (summer) follow-up (2.9–4.3 $p < 0.01$) and the second (winter) follow-up (2.8–4.2 $p < 0.01$). The "Total general impression of light" also improved (5.7–8.5

Table 3
Grouping of questions into parameters and response scores.

Parameter	Scale	Max
Total general impression of light		**10**
General impression of the light, bright part	1 = very bad 5 = very good	5
General impression of the light, dark part	1 = very bad 5 = very good	5
Light assessment		**9**
Level of illuminance: too high/low or "OK"	1 = much too high/low 3 = "OK"	3
Too much shadows or diffused light or "OK"	1 = to much shadows/diffused 3 = "OK"	3
Colour of light: too warm/cold or "OK"	1 = much too warm/cold 3 = "OK"	3
Inconvenience by light		**19**
Disturbed by shadows in reading material.	1 = not at all 4 = very much	4
Disturbed by too bright light.	1 = not at all 5 = very much	5
Daylight disturbance bright part of the year.	1 = not at all 5 = very much	5
Daylight disturbance dark part of the year.	1 = not at all 5 = very much	5
Wellbeing		**14**
How do you feel today?	1 = lousy 7 = excellent	7
Do you feel thoroughly rested?	1 = not at all 7 = yes, completely	7
Work induced stress		**14**
Do you experience your work as stressful?	1 = not at all 7 = yes, very much	7
Do you experience difficulty in keeping up with your work tasks?	1 = not at all 7 = yes, very much	7
How do you experience the labeling on the sorting racks?	1 = very easy to read 7 = very hard to read	**7**
How do you experience the sorting time?	1 = very fast 7 = very time consuming	**7**
Kansei statements of the lighting?	1 = no, not at all 5 = yes, to a high degree	**5**

$p < 0.01$), and in the second (winter) follow-up the new lighting was rated better compared to the old (7.6–5.5 $p < 0.01$).

Before the intervention, the eyestrain (ES) participants rated the lighting better than the no eyestrain (NES) participants (3.1–2.5 $p < 0.05$). However, this was not found after the intervention. In the second (winter) follow-up, the ES participants rated the lighting better than the NES participants, both for the new lighting (8.3–7.5 $p < 0.05$) and for the old lighting (6.2–4.8 $p < 0.01$).

"Light assessment" showed an improvement after the intervention (7.4–8.4 $p < 0.01$). Before the intervention, the ES participants were more disturbed by shadows in the reading material than the NES participants (3.4–2.8 $p < 0.05$), but after the intervention, there were hardly any differences.

The postmen experienced that the labelling on the sorting racks had improved after the intervention (3.6–2.8 $p < 0.05$). Before the intervention, the ES postmen experienced that sorting took longer than the NES postmen (3.1–2.7 $p < 0.05$).

3.2. Wellbeing and stress

The NES participants felt better than the ES participants both before and after the intervention (before: 4.5 to 5.7 $p < 0.05$; after: 4.4 to 5.9 $p < 0.01$). After the intervention the ES participants had a lower rating on "Wellbeing" than the NES participants (5.8–6.1 $p < 0.05$) see Fig. 2.

There was also more private life stress for the ES than for the NES participants (3.7–2.7 $p < 0.05$). Wellbeing improved for the older group. Work induced stress increased for the younger group and decreased for the older group after the intervention.

3.3. Eyestrain, eye fatigue and headache

Before the intervention 12 participants were defined as experiencing the eyestrain syndrome, with an eyestrain index of 3.9. After the intervention, eight participants experienced eyestrain, with an index of 3.7.

The most common symptoms before the intervention were sensitivity to light and gritty feeling. In addition, 12 participants suffered from eye fatigue and 6 had problems with headaches. After the intervention the most common symptoms were itching, gritty feeling and sensitivity to light. Nine experienced eye fatigue and three had problems with headaches. In the second (winter) follow-up, the most common symptoms were sensitivity to light, gritty feeling, itching and dryness. Eight persons experienced eye fatigue and three had problems with headaches.

Table 4
Number of postmen with eyestrain at the different offices and occasions.

Office	Before	After (summer)	After (winter)
1	2 ($n = 4$)	0 ($n = 3$)	0 ($n = 3$)
2	4 ($n = 6$)	4 ($n = 5$)	5 ($n = 5$)
3	1 ($n = 6$)	0 ($n = 6$)	1 ($n = 5$)
4	2 ($n = 5$)	3 ($n = 5$)	1 ($n = 4$)
5	3 ($n = 6$)	1 ($n = 6$)	4 ($n = 6$)

Eyestrain for those over 45 increased from 2.8 to 4.6 after the intervention. The younger group had a reduced amount of eyestrain. There was a higher percentage of ES participants at the two offices with naked fluorescent tubes (offices 1 and 2), than at the other offices (see Table 4). One of the other offices had a large increase in the amount of persons with ES after the intervention (office 5). This office had moved to a brighter location.

The second (winter) follow-up points to an increase of eyestrain: 11 out of 23 experienced eyestrain with an index of 5.6 compared with the first (summer) follow-up ($p = 0.102$).

Out of the eight ES postmen after the intervention, seven could be explained by the requirement of new power in their glasses ("Assessed eyestrain"). Out of the eleven ES postmen during the second (winter) follow-up ($n = 23$), only one could not be explained by "Assessed eyestrain".

3.3.1. Glare

There was a tendency towards a lower risk for glare after the intervention (2.04–1.76 $p = 0.09$). The number of participants in the high risk category was reduced from 7 to 4.

In the "high risk for glare" category, all except one participant had eyestrain before the intervention. After the intervention, there was only one ES person out of four in the highest risk category, see Table 5.

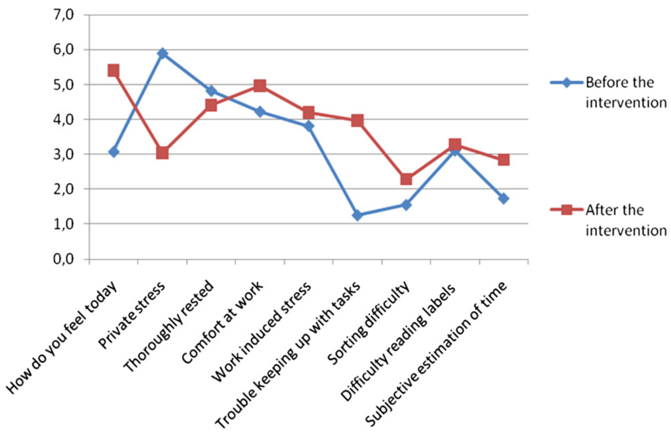

Fig. 2. The average scores on the Health questionnaire before and after the intervention (7 = best and 1 = worst).

Table 5
Total number of postmen in the different glare risk categories/number of postmen with eyestrain.

Assessment of glare		
Category	Before ($n = 27$)	After (summer) ($n = 25$)
1. No risk	6/3	10/4
2. Some risk	13/2	11/3
3. High risk	8/7	4/1

3.4. Musculoskeletal disorders (MSD)

The average MSD index after the intervention was almost unchanged (15.2–14.0, $p = 0.30$). Fourteen of the participants had an increased MSD index, nine had a decreased index and two had an unchanged index.

The MSDs were divided into different locations: upper body, left side, and right side. For the upper body there was a reduction of MSDs (10.7–8.2 $p < 0.05$). There was also a slight tendency towards a reduction from the left side (7.1–6.4, $p = 0.32$) and the right side (8.8–7.6, $p = 0.11$).

Before the intervention, the ES participants had almost three times as high MSD index as the NES participants (22.9–9.1, $p < 0.05$). After the intervention the difference was even higher (27.8–7.5 $p < 0.05$). When considering the different parts of the body, both the right and left sides showed significant differences (see Table 6).

After the intervention it was only the right side that showed significance between ES and NES (see Table 7).

The younger participants showed a tendency to decreased MSD index (15.4–9.2, $p = 0.18$), and the older participants were approximately on the same level before and after (16.4–16.9).

3.5. Work productivity

Before the intervention, the 12 ES postmen did not sort as rapidly as the 15 NES postmen, a difference of 0.31 s per letter.

After the intervention there was an improvement of 0.1 s per letter for the entire group. Eight ES postmen had an improvement of 0.28 s per letter while the remaining 17 had an improvement of 0.02 s per letter.

The younger postmen were 0.26 s per letter faster than the older before the intervention. Two years later, after the intervention, the younger group had a time improvement of 0.22 s per letter whereas the older had a slight improvement of 0.03 s per letter.

3.6. Visual examination

The eight ES persons in the first (summer) follow-up had a higher requirement for new power in their glasses than the NES persons (2.5–1.7, $p < 0.01$). The requirement for new glasses was also higher for ES participants during the second (winter) follow-up compared with the summer follow-up (2.6–1.3 $p < 0.01$). All of the participants received new glasses after the study if the visual examination showed that they were in need of it.

3.7. Correlations between variables included in the study

3.7.1. Before the intervention

Eighteen factors were found to be significantly correlated to at least one other factor (see Fig. 3 or Appendix 1). The objectively assessed factors are shown in bold with arrows indicating the direction of the correlation. *Eyestrain, MSD, Wellbeing* and *Work induced stress* are shown with double lines.

The objectively assessed variables affected *Eyestrain, Eye fatigue, Headache, Light assessment, Inconvenience by light, Wellbeing* and *Assessment labelling*. There was a positive correlation between *Eyestrain-Eye fatigue* and *Eyestrain*-MSD. *Eye fatigue* was also positively correlated to *Time/letter*. MSD had positive correlations to *Headache* and *Work induced stress*. *Wellbeing* had negative correlations to *Uniformity*, *Work induced stress* and *Headache*.

3.7.2. After the intervention

After the intervention, 19 factors were found to be significantly correlated to at least one other factor (see Fig. 4 or Appendix 2). The objectively assessed factors are shown in bold, namely *Uniformity value, Illuminance, Requirement for new glasses* and *Age*. The lighting factors (uniformity value and illuminance) are positively correlated to *Time/letter, and negatively correlated to Time difference*, *Comfort at work, General Impression of light* and *Level of difficulty sorting*. The *Requirement for new glasses* affects *Eyestrain* positively, and *Age* is negatively correlated to *Inconvenience by light*.

Eyestrain has positive correlations to MSD, Requirement for new glasses and Stress private, and a negative correlation to Time difference. Wellbeing correlates negatively to Eyestrain, MSD, Work induced stress, Subjective estimation of time and Headache. Eye fatigue correlates positively to Headache and Inconvenience by light. Headache has a positive correlation to MSD.

3.7.3. After the intervention – second (winter) follow-up

In the winter follow-up after the intervention, only six factors were found to be significantly correlated to at least one other factor (see Fig. 5). *Requirement of new glasses* correlates positively to *Eyestrain* and negatively to *General Impression of old lighting. Eyestrain* has a positive correlation to *Eye fatigue and General Impression of the old lighting,* and a negative correlation to *General impression of the new lighting. Eye fatigue* correlates positively to *Headache*.

In the second (winter) follow-up, there was a positive correlation for the Kansei word "Good detect ability" and *Time difference* after the intervention (0.558), and also for "Fresh light" and *Wellbeing* (0.546) ($n = 17$).

Table 6
Mean values for MSD index for left and right sides of the body before the intervention for ES and NES with significant differences *$p < 0.05$ and **$p < 0.01$.

2004 ($n = 27$)								
Left	Hand	Lower arm*	Elbow	Upper arm*	Shoulder*	Neck	Back	Total left side *
ES	1.4	1.4	0.7	1.1	2.9	2.1	2.8	12.3
NES	0.7	0	0.1	0	0.3	0.9	1.6	3.6
Right	Hand	Lower arm	Elbow	Upper arm*	Shoulder*	Neck	Back	Total right side *
ES	2.3	1.1	0.3	1.5	2.7	2	1.9	12.6
NES	0.7	0	0.5	0	1.0	1.8	1.5	5.5

Table 7
Mean values for MSD index for left and right sides of the body after the intervention for ES and NES, significant differences $*p < 0.05$ and $**p < 0.01$.

2006 (summer) ($n = 25$)								
Left	Hand	Lower arm	Elbow	Upper arm	Shoulder	Neck	Back	Total left side
ES	1.1	0.8	0.8	1.5	2.4	2.4	2	10.88
NES	0.5	0.3	0.8	0.1	0.9	0.8	0.9	4.29
Right	Hand**	Lower arm*	Elbow	Upper arm	Shoulder*	Neck*	Back	Total right side**
ES	4.5	2	0.5	1.5	3.6	2.8	2	16.9
NES	0.2	0.1	0.4	0.2	0.8	0.7	0.8	3.2

4. Discussion

4.1. Visual ergonomics, eyestrain and MSD

One of the hypotheses of this study was that eyestrain would decrease with improved lighting. There was only a small decrease in the percentage of persons with eyestrain. Before the intervention there were 12 participants with eyestrain (44%), but two of them dropped out, and after the intervention there were eight left (32%). The second (winter) follow-up points to an increase in the amount of eyestrain (48%), and an increased correlation to requirement for new glasses. According to a discussion with the Swedish Society of Occupational Optometry (2008), many optometrists have the experience that during the winter period the need for good correction in glasses is enhanced, although the mechanism behind this is unclear. A portion of the increased eyestrain could also be explained by environmental factors, such as dry air.

In a comparison with computer work, usually between 75 and 90% of these workers suffer from eyestrain (Anshel, 2005). The tasks for the postmen are similar to computer work. They have visually demanding work tasks but they do not have a lit screen to look at (most often also flickering in the past). The letter contrast is often good compared to that on a computer screen. Since no references were found in international peer reviewed eyestrain studies on lighting intervention in non-computer environments, relating the percentage with eyestrain among the postmen to similar working situations is not possible. In Wheatley's report (2002), eye discomfort was found among 50% of the postmen.

For the assessed ES, after the intervention, only one person out of eight could not be explained by the requirement for adjusted power in their glasses. Out of the 11 ES in the winter follow-up, only one could not be explained with the requirement for new power (the same person). The results also point to an increase in the amount of eyestrain from summer to winter.

The relationship between eye discomfort and MSD has been shown previously. This study confirms that eyestrain has a strong correlation with MSD. The amount of MSD among participants with eyestrain was three or four times as high. Before the intervention, there were significant differences on both right and left sides of the body, and after the intervention only the right side showed significance. This could be an indication that better lighting improves the overall body posture. All postmen in this study sorted with their right arm and those who had problems with their eyes had to adapt body postures and movements in order to read properly, hence straining the right side of the body. Postmen sorting with private glasses – progressive, bifocals or single

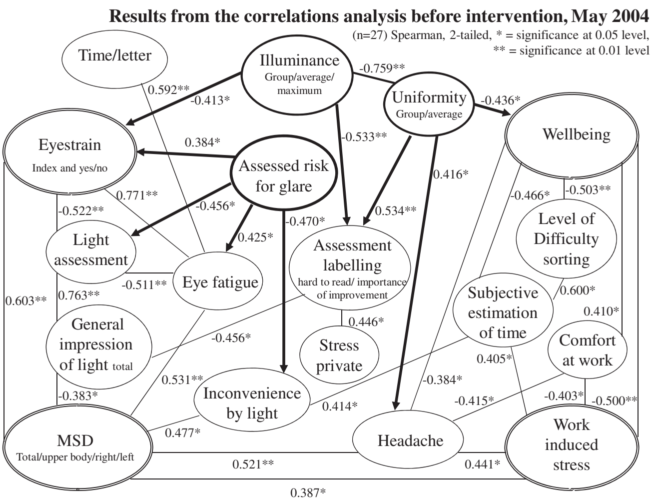

Fig. 3. Results from the correlation analysis before intervention ($n = 27$).

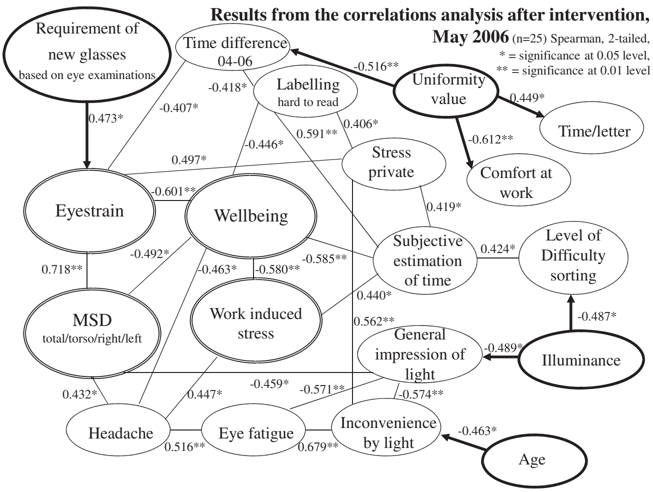

Fig. 4. Results from the correlation analysis after intervention – first (summer) follow-up ($n = 25$).

vision –may, due to the sorting distances, have improper body postures, such as "vulture-neck" – a rising of the chin in order to see the top shelf through the lower part of the lens – or bending down so see the bottom shelf.

The reading glasses that some of the postmen have do not function satisfactorily when sorting mail. Some type of progressive lenses for work needs to be developed for these cases. This would most certainly shorten the sorting time further. It is important for all postmen to have their eyes tested regularly, and that they be provided with the best possible lenses in order to reduce the sorting time. This also applies for younger postmen who suffer from

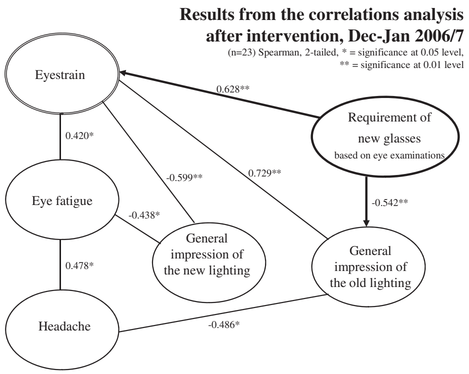

Fig. 5. Results from the correlation analysis after intervention – second (winter) follow-up ($n = 23$).

astigmatism or hyperopia. They may also experience difficulties reading.

There were differences between the two groups with and without eyestrain in, for example, wellbeing and private stress. Overall, the results show a better rating for participants without eyestrain. There was also an improvement in wellbeing after the intervention.

When grouping the participants by risk for glare, some interesting issues became clear. The risk for glare decreased with the new lighting, but unfortunately some risk was still present after the intervention. The general lighting could not be replaced so some of the participants experienced glare. Before the intervention, the risk for glare was positively correlated both with eyestrain and with the participants' impression of the lighting. After the intervention these correlations disappeared, which also indicates an effect of the reduced risk for glare.

The optometric examinations show that many in this group of postmen needed power adjustments of their glasses, as seen in the correlation analysis. Of the 25 postmen after the intervention, there were only 10 who did not require new glasses. Several of the postmen with eyestrain had an error of approximately 1 D in their lenses. It is very individual how the effects of the wrong power influence people. Some have great difficulty managing small differences in the requirement of new glasses, and others can work several years without complaining. There were three out of the 25 that had to be remitted further to ophthalmologists due to pathological problems, such as cataract.

4.2. Lighting, productivity and wellbeing

No correlation was found between eyestrain and the illuminance uniformity value before the intervention, but correlations for eyestrain were found with headache, wellbeing and the assessment of the labelling. After the intervention there were correlations between uniformity values and productivity, the higher the uniformity, the larger time difference after the intervention. Before the intervention, the productivity for those with eyestrain was lower than those without, but productivity did increase for those with eyestrain so that after the intervention there were no longer any differences between the groups. No time reductions were found in this study for those with NES. In Sweden today, there are 15,000 postmen that sort about 20 million mail items a day, half of which could be regular mail. If the new lighting decreases sorting time for those with eyestrain, this could result in a reduction of 62,000 h a year.

The Hawthorne effect (Pennock, 1929) must be taken into consideration as a possible contributing factor to the improvements identified after the intervention, even though there have been discussions lately about the interpretation of the Hawthorne studies. This present longitudinal study has been performed over 2.5 years, and the risk for a Hawthorne effect is therefore considered relatively low. A control group would have given stronger support to the results, but earlier studies have also identified that improved visual ergonomics results in decreased eye symptoms (Horgen, 2003; Horgen et al., 2007; Aarås et al., 1998, 2001). Previous studies also show that the relationship between changes in illuminance and task performance have been clearly established (Abdou, 1997), but no productivity studies have been found that include any kind of eye discomfort. The postmen's need for indoor light treatment with psycho-biological effects is not relevant, since the postmen work outdoors at least 2–3 h a day. This could explain the somewhat limited impact on productivity the lighting had in this study. In some studies, the increase in productivity could be up to 50% (Juslén et al., 2007a).

Work induced stress and wellbeing improved after the intervention for the older group (≥45 years). As age increases, more and more light is required to see properly. A 40 year old person needs twice as much light as a 20 year old (Anshel, 2005). The reduced stress and improvement of wellbeing could be a result of the new lighting.

Another impact on productivity is the change of labelling on the sorting racks. A previous pilot study found considerable improvement in time (Kiviloog, 2003), but she included postmen that had little experience from the district they sorted at. The postmen reported that when they have experience from a district, they do not look at the labelling as much. They know approximately were to put the letter (detectability), and only look at fewer than 10 different compartments to see where to put the letter. The correlation between detectability and sorting time supports these statements.

The change from capital letters to lower case may influence the sorting time. In this study, the full effects of the new labels could not be demonstrated since at some of the sorting racks the new labelling had already been partly implemented. This means that some of the time improvement could have taken place before this study started.

The general lighting at two of the offices was poor. This can result in problems with eyestrain and headaches. At offices with luminaries without louvers, eyestrain was more frequent than at the others. The office with the best lighting also had the lowest percentage of people with eyestrain. Office 3 had a high occurrence of eyestrain but the luminaries were hung low and the louvers were mounted far apart and often in the wrong place, which contributed to glare and counter beam. This may be one of the reasons for the higher occurrence of eyestrain in this office.

Illuminance varied greatly before the intervention within the different districts. This may lead to difficulties in reading text since it is difficult for the eyes to adapt to the different intensities of light. If the illuminance differs considerably and frequently, it takes longer for the eyes to adapt to the present illuminance to be able to read; thus the recommended illuminance uniformity of 0.7. After the intervention, the overall improvement in lighting was good and almost all of the requirements were met. The uniformity did not reach the intended level of 0.7 everywhere, but the reason for this lies in the general lighting in the room. In this study, the general lighting could not be replaced, although in some offices adjustments were possible, such as turning the luminaries off or moving them.

The lowest recommended value of illuminance for this kind of work is 500 lux (CIE, 2002). If the illuminance is not high enough it can lead to problems if the participant in question is over 40. Due to the normal ageing of the eye, these people will often need more light to improve their visual accuracy and to read better. The best condition is if the workplace lighting can be varied so that each postman can adjust it to his or her own personal preferences. If a person has a headache on a particular day, his or her tolerance to light might be lower than on other days. It is thus a great advantage if the light from luminaries can be varied.

There are relatively few participants in this study and a recommended visual environment was not obtained for all of the postmen. The results might have been different if all of the postmen included had achieved a good visual environment that fulfilled the recommendations in all respects.

The measurements, illuminance, luminance and the time study were also analyzed with parametric statistical methods, which gave almost the same significances as the non-parametric. This is why only the non-parametric analysis has been presented.

5. Conclusions

- To enhance productivity and wellbeing and to reduce eyestrain, three different areas in the visual environment have been considered: good lighting conditions, good visibility of the tasks and the person's visual ability. Functional eye glasses that are based on the person's visual environment have a potential to reduce eyestrain. There was a relationship between eyestrain and MSD: Those with eyestrain had three times as much MSD. Indications of decreased eyestrain are present in the study. The average sorting time was less for the group with eyestrain.
- The lighting intervention, including new workplace lighting and new labelling on the racks for mail sorting resulted in several improvements. After the intervention, the lighting improved and followed the recommendations for uniformity, illuminance and lower risk for glare. The subjective experience of the general lighting of the postmen's workplaces improved, a relationship between eyestrain and lighting no longer existed. Wellbeing increased after the intervention and the experience of level of difficulty when sorting and sorting time improved.
- In this study the young postmen with eyestrain had the greatest benefits from the lighting intervention, including decreased eyestrain, MSD and sorting time.

Acknowledgements

We would like to thank Svenska Posten AB, the Riegen's lighting manufacturer and especially light consultant Peder Wibom for support with the general lighting inspections and installations. Thanks to Synoptik who lent us the examination room and equipment for the optometric eye examinations. We would also like to thank Roger Wibom at Linköping University, and Per Nylén at the Swedish Work Environment Authority for all their help.

Appendix 1. Correlation before the intervention (2004) (Spearman's rho). * =correlation is significant at the 0.05 level; ** = correlation is significant at the 0.01 level; * = correlation is significant at the 0.001 level. Grey marking = tendency to significance (>0.05 < 0.07).**

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1 Private stress	1.00	−0.04	0.33	0.00	**0.45***	0.11	−0.24	0.19	0.23	−0.03	0.25	−0.24	0.03	−0.17	−0.25	−0.07	0.06	−0.09	0.04	0.25	−0.23	0.05	−0.29	0.02	0.36
2 Wellbeing at work		1.00	−0.06	−0.17	−0.10	−0.01	**0.41***	**−0.40***	0.09	**−0.42***	0.03	−0.09	0.13	0,02	0.03	−0.10	0.16	0.25	−0.24	−0.12	−0.03	−0.09	0.14	−0.18	−0.10
3 Level of difficulty sorting			1.00	**0.60****	0.32	0.21	**−0.50****	**0.30**	0.03	0.16	−0.04	0.05	−0.23	0.04	−0.07	−0.12	0.28	−0.32	−0.17	0.19	−0.31	−0.05	−0.25	−0.11	0.05
4 Subjective estimation of time				1.00	0.12	0.24	**−0.47***	**0.41***	0.36	0.38	0.30	0.24	0.04	0.14	0.10	−0.19	**0.41***	−0.29	0.07	0.13	−0.33	−0.33	−0.26	0.30	0.36
5 Subjective opinion of labelling					1.00	**0.59*****	−0.37	0.26	0.21	0.26	0.13	0.04	0.07	0.10	0.06	−0.32	0.10	**−0.46***	−0.15	**0.53****	**−0.40***	−0.11	**−0.53****	−0.14	0.20
6 Importance of labelling improvement						1.00	−0.37	0.06	0.35	0.08	0.16	−0.05	0.16	0.08	0.07	−0.34	0.10	−0.20	0.04	**0.47***	−0.29	−0.23	**−0.41***	0.12	0.24
7 Wellbeing							1.00	**−0.50****	−0.20	**−0.38***	−0.12	−0.25	−0.03	−0.27	−0.14	0.08	0.06	0.27	−0.31	**−0.44***	0.20	0.06	0.36	−0.19	−0.27
8 Work induced stress								1.00	0.11	**0.44***	0.10	**0.39***	0.20	0.27	0.24	0.03	0.21	−0.14	−0.05	0.12	−0.06	−0.03	−0.12	0.36	0.07
9 Eye fatigue									1.00	0.18	**0.77*****	0.21	**0.53****	0.22	0.26	**−0.51****	0.21	−0.24	**0.43***	0.27	−0.23	−0.20	−0.16	**0.59*****	**0.74*****
10 Headache										1.00	0.20	**0.41***	0.29	0.29	**0.52****	−0.10	0.28	−0.30	0.03	**0.42***	−0.164	−0.25	−0.30	0.37	0.24
11 Eyestrain											1.00	**0.42***	**0.60*****	**0.44***	0.30	**−0.52****	0.35	−0.29	**0.38***	0.25	−0.30	**−0.41***	−0.22	0.33	**0.90*****
12 MSD total												1.00	**0.74*****	**0.90*****	**0.80*****	−0.29	**0.39***	**−0.38***	0.08	−0.03	0.06	−0.07	0.12	0.15	0.36
13 MSD left side of body													1.00	**0.69*****	**0.77*****	−0.38	**0.43***	−0.24	0.17	0.02	0.05	−0.12	0.10	0.38	**0.53****
14 MSD right side of body														1.00	**0.79*****	−0.31	0.38	−0.33	0.01	0.13	−0.08	−0.18	−0.04	0.04	**0,41***
15 MSD upper body (back, neck, etc.)															1.00	−0.18	**0.48***	−0.21	−0.04	0.10	0.09	−0.08	0.04	0.26	0.28
16 Light assessment																1.00	−0.04	**0.76*****	**−0.46***	−0.22	0.22	0.08	0.18	0.01	−0.37
17 Inconvenience by light																	1.00	0.08	**−0.47***	−0.04	−0.13	−0.29	−0.03	0.10	0.34
18 General impression of the light																		1.00	0.19	−0.19	0.32	0.12	0.26	0.08	−0.23
19 Assessed risk for glare																			1.00	0.06	0.07	0.14	−0.02	0.21	0.34
20 Uniformity value																				1.00	**−0.57****	**−0.49****	**−0.76*****	0.07	0.25
21 Illuminance average																					1.00	**0.83*****	**0.90*****	0.14	−0.23
22 Illuminance average group																						1.00	**0.71*****	−0.04	−0.30
23 Illuminance max																							1.00	0.17	−0.22
24 Time/letter																								1.00	0.29
25 With or without eyestrain																									1.00

Appendix 2. Correlation after intervention (2006) (Spearman's rho). * = correlation is significant at the 0.05 level; ** = correlation is significant at the 0.01 level; * = correlation is significant at the 0.001 level. Grey marking = tendency to significance (>0.05 < 0.07).**

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1 Age	1.00	−0.03	0.05	−0.02	−0.08	0.11	0.03	−0.24	−0.36	−0.21	0.13	0.01	0.08	0.04	−0.02	0.32	**−0.46***	0.04	−0.12	−0.04	0.01	0.15	0.22	0.11	0.16
2 Private stress		1.00	0.10	0.33	**0.42***	**0.41***	−0.37	0.35	0.33	0.08	0.36	0.06	−0.10	0.31	0.08	−0.15	**0.56****	−0.20	−0.06	−0.13	−0.14	−0.19	0.12	0.26	**0.50***
3 Wellbeing at work			1.00	0.34	−0.16	−0.32	0.16	−0.22	−0.19	−0.28	−0.14	−0.13	0.01	−0.04	−0.09	0.20	0.06	**−0.61****	0.04	0.05	−0.30	0.35	−0.17	0.13	−0.13
4 Level of difficulty sorting				1.00	**0.42***	0.12	−0.18	0.31	0.04	0.00	0.05	−0.07	−0.05	0.08	−0.12	0.00	0.33	−0.25	**−0.49***	−0.31	−0.05	0.03	0.07	0.16	0.10
5 Subjective estimation of time					1.00	**0.59****	**0.59****	**0.44***	0.11	0.33	0.17	0.03	−0.10	0.17	−0.11	−0.16	0.22	0.22	−0.14	0.03	0.13	−0.25	0.32	0.14	0.17
6 Subjective opinion of labelling						1.00	**−0.45***	0.29	0.13	0.11	0.16	0.06	−0.10	0.11	−0.10	−0.12	0.24	0.37	−0.07	0.08	0.23	**−0.42***	0.21	0.27	0.10
7 Wellbeing							1.00	**−0.58****	−0.28	**−0.46***	**−0.60****	−0.33	0.01	**−0.49***	−0.23	0.36	−0.29	−0.16	−0.10	−0.16	0.01	0.17	−0.07	−0.26	**−0.52****
8 Work induced stress								1.00	0.12	**0.45***	0.32	0.16	−0.04	0.35	0.08	0.00	0.18	−0.13	−0.31	−0.30	−0.30	−0.28	0.01	−0.12	0.36
9 Eye fatigue									1.00	**0.52****	0.25	0.29	0.16	0.26	0.32	**−0.57****	**0.68*****	−0.05	0.19	0.03	0.11	0.02	0.27	0.33	0.18
10 Headache										1.00	0.36	0.37	0.29	0.38	**0.43***	−0.31	0.32	0.09	−0.19	−0.18	−0.10	−0.27	0.18	0.20	0.27
11 Eyestrain											1.00	**0.72*****	**0.41***	**0.71*****	**0.62****	−0.24	0.19	0.16	0.10	0.15	0.13	**−0.41***	0.01	**0.47***	**0.83*****
12 MSD total												1.00	**0.81*****	**0.81*****	**0.82*****	−0.37	0.32	0.04	0.25	0.26	−0.05	−0.25	−0.21	0.33	0.50*
13 MSD left side of body													1.00	0.44*	**0.77*****	−0.22	0.19	−0.09	0.16	0.23	−0.16	−0.13	−0.21	0.24	0.14
14 MSD right side of body														1.00	**0.68*****	−0.35	0.37	−0.01	0.14	0.13	−0.10	−0.31	−0.10	0.18	**0.64*****
15 MSD upper body (back, neck, etc.)															1.00	**−0.46***	0.28	0.08	0.25	0.29	0.00	−0.25	−0.14	0.10	0.35
16 General impression of the light																1.00	**0.57****	−0.21	**−0.42***	**−0.49***	−0.20	0.10	−0.09	0.04	0.00
17 Inconvenience by light																	1.00	−0.14	0.16	0.13	−0.08	−0.06	−0.04	0.36	0.23
18 Uniformity value																		1.00	−0.06	0.22	**0.82*****	**−0.52****	0.30	−0.03	0.04
19 Illuminance average																			1.00	**0.87*****	−0.04	0.15	−0.28	0.07	−0.08
20 Illuminance max																				1.00	0.19	−0.07	−0.18	0.08	−0.13
21 Uniformity value group																					1.00	−0.35	**0.45***	0.08	−0.04
22 Time study difference 2004–2006																						1.00	−0.02	−0.04	−0.29
23 Time/letter 2006																							1.00	−0.08	0.00
24 Requirement of new glasses																								1.00	**0.47***
25 With or without eyestrain																									1

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Paper III

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Optimal correction in spectacles – intervention effects on eyestrain and musculoskeletal discomfort among postal workers

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Abstract
Background: The static posture of postal workers when sorting mail can lead to musculoskeletal discomfort. Research has shown a connection between eyestrain and upper-body musculoskeletal discomfort in general, including postal workers. A previous study of postal workers found that most of those with eye strain were in need of a new correction in their existing spectacles.

Objective: Evaluate intervention effects on eyestrain and musculoskeletal discomfort with new spectacles for postal workers.

Methods: Postal workers subjectively reported eyestrain, musculoskeletal discomfort and their opinions of the visual environment via questionnaires pre- and post-intervention. After an eye examination the postal workers were divided into two groups: those who needed new spectacles and those who did not.

Results: Those who needed new spectacles showed a higher prevalence of eyestrain and musculoskeletal discomfort pre-intervention. Post-intervention, the postal workers rated their vision better and the average eyestrain and musculoskeletal discomfort decreased for both groups. These workers also experienced a decrease in discomfort on the left (static) side of the neck while sorting mail.

Conclusion: An intervention providing the optimal correction reduces eyestrain and decreases musculoskeletal discomfort, especially from the neck.

Keywords: mail, work posture, neck, static, dynamic, visual ergonomics, lenses, glasses

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1. Introduction

Anshel has stated that the eyes lead the body [1]. When there is a visual problem, the body adjusts its posture to make it easier to see.

Aarås et al. [2, 3] and Helland et al. [4] performed a large ergonomic intervention study of video display unit (VDU) operators that included lighting. They found that lighting and optometry are of crucial importance in reducing musculoskeletal disorders. Both mail sorting and VDU work is visually demanding, and a good visual environment is important for health and wellbeing.

Work tasks often involve repeated movements; this means a relatively low but static load on the worker. A relation has been documented between the position and movements of the arm and disorders in the neck and shoulder region due to neck/shoulder strain and demanding visual perception [4, 5].

The frequency of musculoskeletal pain among people with the wrong correction in their lenses is higher than among those with the optimal correction. A single vision lens or a work progressive lens/ computer lens is better for working at computers than a regular progressive lens [6]. A work progressive lens is adjusted in the different zones to function for working at a computer, with a wider midrange zone located higher up in the lens. This facilitates a less straining head posture. Niskanen et al. have also shown that companies benefit from providing their employees with specific working spectacles when working at a computer. The costs for the computer spectacles were offset by reduced sick-leave costs [7]. Studies show that individuals with eyestrain also report musculoskeletal discomfort to a higher degree than those without eyestrain [8, 9].

A relationship between the eyes and muscles has been found by some researchers [10, 11, 12], but the exact mechanism behind this needs more exploration. The hypothesis is that individuals with eye strain, in trying to see more clearly, may increase the muscle activity in their neck, shoulder, and scapula area.

To enhance productivity and wellbeing and to reduce eyestrain, three different areas in the visual environment have been considered: good lighting conditions, good visibility of the tasks and the person's visual ability [9].

Many different factors can cause eyestrain or blurred vision for the eyes: glare, too low illuminance, too high luminance contrast, the wrong correction in lenses, dirty lenses, presbyopia, eye diseases that reduce visual acuity (temporarily or permanently), atmospheric conditions, low clarity of the task, bad resolution on the computer screen, and too small details in the working material [1, 8, 13].

Lighting has an important role in determining the perceived visual attributes of objects. Objects can have different attributes: brightness (emitted light), lightness (reflection), hue (colour classification), saturation (of colour), transparency (colours behind or within an object) and glossiness. Aspects of lighting that can cause visual discomfort are: too little light, too much light, too much variation in illuminance between and across working surfaces, disability glare, discomfort glare, veiling reflections, shadows, and flicker. Disability glare disables the visual system making it harder to focus and is one of the causes of eye fatigue and eyestrain. When experiencing discomfort glare, the source of the glare is so bright that it causes an instinctive desire to look away [8].

Luminaires that are mounted in the wrong place, depending on where the light is needed, can cause shadows or reflected glare in the working material [14]. Insufficient illuminance levels or low uniformity levels can also affect the ability to work. This is why the uniformity value (minimum illuminance divided by the average illuminance of the task area) of the task illuminance should not be less than 0.7 [15]. According to Veitch [16], a working area should have uniform illuminance while the surrounding areas should be non-uniform, but not causing glare. The colour rendering index (CRI) and the correlated colour temperature (CCT) are important for a comfortable visual environment, but there seem to be cultural differences in CCT preferences according to Boyce [8].

There are about 7,000men and 4,500 women working as postal workers in Sweden. According to statistics from Arbetsmiljöverket (Swedish Work Environment Authority) [17], approximately 22 % of the men and 31 % of the women had work related musculoskeletal disorders in the 12 month period from January 2010 to December 2010. Out of these, 8.3 % for the men and 16.7 % for the women resulted in sick leave for one day or more; a quarter of the men and half of the women were on sick leave for more than five weeks. The percentages of postal workers that had problems with work related disorders in the following areas of the upper body were: 5.0/6.5 % (men/women) for back of the head and neck; 9.4/17.5 % for shoulder and arm; 1.6/6.3 % for hand, wrist and finger; and 11.3/18.1 % for back (except neck).

A lighting intervention was performed with postal workersby Hemphälä and Eklund [9]. The postal workers received new workplace lighting by their sorting racks, giving them a higher illuminance and a more uniform light. A relationship between eyestrain and musculoskeletal discomfort was found. Those with eyestrain had two or three times as much musculoskeletal discomfort, both before and after the lighting intervention. The average sorting time was lower for the group with eyestrain after the intervention. After the lighting intervention there were indications of decreased eyestrain. The lighting intervention, including new workplace lighting and new labelling on the racks for mail sorting, resulted in several improvements. After the intervention, the lighting improved and followed the recommendations for uniformity, illuminance, and lower risk for glare. The relationship between eyestrain and lighting no longer existed. In this lighting intervention study, the young postal workers with eyestrain had the greatest benefits from the lighting intervention, including decreased eyestrain, musculoskeletal discomfort and sorting time. It was also found that some of the postal workers in the study had the wrong correction in their spectacles or did not have spectacles at all, although they were in need of them.

1.2 The purpose of the study

The purpose of this visual ergonomics intervention study among postal workers was to examine the effects of new spectacles with optimal correction, especially the effects on the visual strain (eyestrain), musculoskeletal discomfort and how the postal workers rated their vision with their habitual spectacles and their new spectacles. The hypothesis was that the wrong correction and incorrect type of lenses can cause eyestrain and that visual problems can contribute to musculoskeletal discomfort.

2. Methods and Materials

2.1. Postal workers' work

The tasks of postal workers at the Swedish Post Office (Svenska Posten AB) include handling, sorting and mail delivery. They sort several types of letters from 2 to 4 hours a day. They start by manually sorting the letters into the different districts at the post office; after that they sort their own district into sorting racks. Every address/household has its own compartment (20 mm wide). The number of sorting racks for each district varies between three and seven depending on the district's size. Each sorting rack consists of five shelves (Figure 1). The postal workers sort letters on the top four shelves and the bottom shelf is only used for storage. The distances to the shelves range between approximately 40 cm to the top shelf and 80-90 cm to the fourth shelf. The distance to the letters in hand is approximately 40 cm.

Figure 1. The sorting rack. The top shelf should be at shoulder height for the postal workers. The bottom shelf is mainly used for storage.

2.2. The participants

The postal workers were informed that participation was completely voluntary and would take place during working hours. All of the postal workers in the study had participated in the previous study by Hemphälä and Eklund [9]. There were 17 male participants and one female in the study. They were between 26 and 62 years of age, with a mean of 47. The postal workers were divided into two age groups: under 45 years (1), and 45 years and above (2) (see Table 1).

2.3. The intervention

Visual examinations were carried out on all of the postal workers in the study and they were provided with the appropriate spectacle correction for their eye condition. All of the postal workers received new spectacles except for one individual who did not need them. The postal workers were given the type of lenses that they used or needed: progressive, bifocals or single vision (see Table 1). Progressive lenses have two main areas, distance and reading, and a corridor with including the powers in between. Bifocal lenses have two areas, distance and reading. Single vision or reading lenses have the same power in the entire lens, used either for distance or near, or just for reading. Some of the progressive lenses that the postal workers had used before the intervention were of a lower quality than the new progressive lenses.

Table 1. Type of lenses in spectacles before and after intervention, type of visual defect and if the postal workers needed new power.

No.	Type of lens before	Type of lens after	Type of visual defect	Need of new power	Age group
1	None	Single Vision	Hyperopia, Astigmatism	Yes	1
2	Progressive	Progressive	Hyperopia, Astigmatism	Yes	2
3	Progressive	Progressive	Myopia	No	2
4	Progressive	Progressive	Hyperopia, Astigmatism	No	2
5	Reading	Progressive	Hyperopia	Yes	2
6	None	None	None	No	1
7	None	Single Vision	Hyperopia, Astigmatism	Yes	1
8	Progressive	Bifocals	Myopia, Hyperopia, Astigmatism	Yes	2
9	Single vision	Single Vision	Myopia, Astigmatism	No	1
10	Reading	Progressive	Astigmatism	Yes	2
11	None	Progressive	Astigmatism	Yes	2
12	Single vision	Progressive	Myopia	No	2
13	Single vision	Single Vision	Myopia, Astigmatism	Unknown	1
14	Progressive	Progressive	Myopia, Astigmatism	No	2
15	Reading	Progressive	Hyperopia	Yes	2
16	Progressive	Progressive	Astigmatism	No	2
17	None	Single Vision	Myopia, Astigmatism	Yes	1
18	Single vision	Single Vision	Myopia	No	2

Age group 1=under 45 years; age group 2=45 years and above.

2.4. Eye examination

An optometrist performed the optometric eye examinations on a phoropter Topcon VT-10 and a visual acuity board Topcon ACOP-6R/6EM. The examinations were performed during two months in the autumn. All of the participants that needed new glasses according to the visual examinations were given a pair of new spectacles, except for one individual who did not need any. That person received sunglasses instead.

2.5. The questionnaires

The participants answered a questionnaire before and after they received their new spectacles. The second questionnaire was answered two to three months after they received their new spectacles. The postal workers evaluated their visual environment (such as too warm/cold light, too much light from luminaires, and shadows in the reading material), personal eyestrain and musculoskeletal discomfort. All questions are presented fully by Hemphälä [18, 19].

The questionnaire was divided into two parts. The visual ergonomics part was developed by Knave et al. [20]. It evaluated the visual working environment subjectively together with perceived problems and discomfort regarding the eyes, headaches, and musculoskeletal discomfort. This questionnaire was used in the previous postal workers study [9]. The postal workers also rated their vision on a scale from 1 (very bad) to 5 (very good).

2.5.1. Eyestrain and musculoskeletal discomfort

Eyestrain is a syndrome covering eight different symptoms: smarting, itching, gritty feeling, aches, sensitivity to light, redness, teariness, and dryness. The participants answered yes/no whether they experienced any of the symptoms. The amount of eyestrain was calculated. Eyestrain values for each symptom are calculated by multiplying the degree of occurrence (1=few times; 2=few days a week; 3=every day a week) by the degree of difficulty (1=negligible; 2=slight; 3=pronounced) (maximum 3 x 3=9 points). The sum of the values for the eight symptoms is the participant's eyestrain value. This value has its maximum at 72 points (9 x 8 symptoms) and shows the participant's experience of eyestrain. An eyestrain index is defined as the average value for the participants in the study, also including those who experience no problems. In this way, different groups of workers are easily compared. Eye fatigue and headaches are other workplace related problems but are not included in the eyestrain index; their values, though, are calculated in the same way. Work related eyestrain was defined as three or more symptom points, according to Knave et al. [20].
A similar index was calculated for different kinds of musculoskeletal discomfort from the upper body. In this index the parts of the body included were divided into right and left: hand, lower arm, elbow, upper arm, shoulder, neck, and back; a total of 14 parts, with a maximum of 126 points (9 x 14), but there was no limit defined for musculoskeletal discomfort (as for eyestrain) (Knave et al., 1985).

2.6. Data analysis

The data from the “before” and “after” questionnaires were compared and analysed. The participants were then divided into two groups: need of new spectacles (yes/no). An optometrist (one of the authors) divided the participants into the yes or no groups depending on the power in their new spectacles compared to their old ones or that they did not need glasses. If there was just a slight change (±0.25D) in the sphere or the cylinder, or no change, they were included in the “no need for new spectacles group”. If there was a greater change, or if they did not have any spectacles though in need of them, they were included in the “need for new spectacles group”. One of the participants had a minor improvement in visual acuity from 1.0- (missing one letter on the 1.0 level) to 1.0 (reading all letters on the 1.0 level) with the new spectacles, but the power of his old spectacles was unknown. He was thus placed in the “no need for new spectacles group” (individual no. 13, Table 1).

The data collected was compiled in MS Excel for later statistical analysis using the IBM SPSS statistics software version 20.0.0. The material was analysed with the non-parametric Wilcoxon matched pairs signed-ranks test, informed levels of significance $p<0.05$, $p<0.01$ and $p<0.001$.

3. Results

The postal workers in this study had all participated in a previous study (n=18). Before the intervention with the new spectacles in October-November 2007, half of the postal workers had eyestrain with an value ≥3. Fifteen of them (83 %) had musculoskeletal discomfort (see Table 2). Before the intervention seven of the postal workers reported that they experienced eye fatigue. Six of them had headaches. Nine of the postal workers had eyestrain. The group with eyestrain reported a slightly higher musculoskeletal discomfort, 14.1 compared to 11.7 for those without eyestrain.

Table 2. Average musculoskeletal discomfort for the entire group, before and after the intervention with new spectacles, divided into right and left side of the body.

Left	Hand	Lower arm	Elbow	Upper arm	Shoulder	Neck	Back	Musculoskeletal discomfort total
Before	0.72	0.22	0.17	0.78	1.72	1.89	1.94	7.44
After	0.17	0.50	0.22	0.11	1.11	1.17	1.17	4.44

Right	Hand	Lower arm	Elbow	Upper arm	Shoulder	Neck	Back	Musculoskeletal discomfort total
Before	0.33	0.11	0.06	0.06	1.83	1.11	1.94	5.44
After	0.39	0.11	0.11	0.00	0.94	0.94	1.17	3.67

Max for each body part is 9. Total max for each side is 63 and max for the upper body is 126.

The results show that after the intervention in February 2008, four of the postal workers experienced eye fatigue, and the average of that symptom changed from 1.0 to 0.28 ($p=0.041$). Three of the postal workers had headaches, 0.78 to 0.33 ($p=0.20$). Three of them had eyestrain, the index of which changed from 4.1 to 1.6 ($p=0.011$) (see Figure 2).

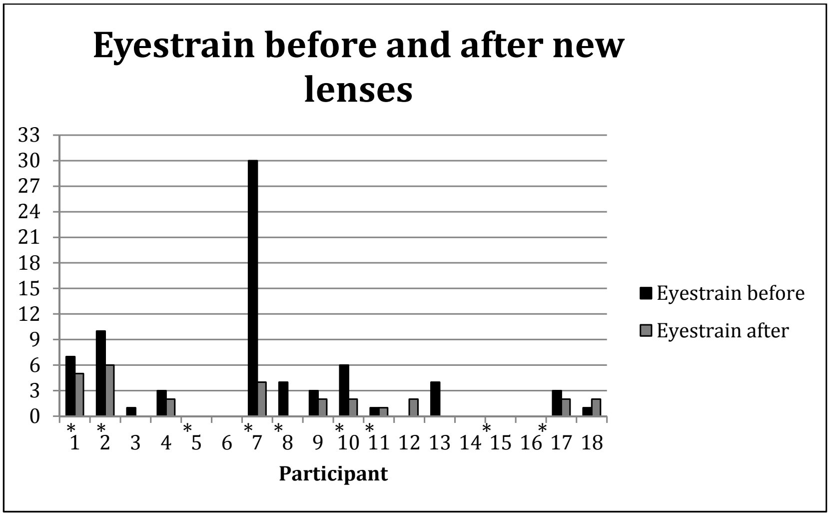

Figure 2. The amount of eyestrain (max 72) for each participant before and after the new spectacles (n=18). When the amount of eyestrain is ≥3, the eyestrain syndrome is present. (*=participants who needed new spectacles.)

The intervention also improved their vision. The rating of their overall vision improved from 3.4 to 4.5 (max 5) (p=0.011). Their vision especially improved while reading letters held in hand (p=0.023), reading at the top shelf (p=0.038), reading at the second shelf (p=0.038), and reading letters at the district sorting (p=0.038). No statistical significant differences were found before and after new spectacles concerning the visual environment.

The postal workers were also divided into two groups according to age. The eyestrain index for the younger group decreased after they received new spectacles, from 9.8 to 2.2 (p=0.068). The corresponding older group had a small decrease of 2.7 to 1.3 (p=0.17). The number with headaches in the younger group decreased significantly (p=0.034) from five individuals to one, an average of 1.7 to 0.2.

The musculoskeletal discomfort decreased after the intervention from an average of 12.9 to 8.1 (p=0.27), especially for upper arm, shoulder, neck, and back (see Figure 3 and Table 2).

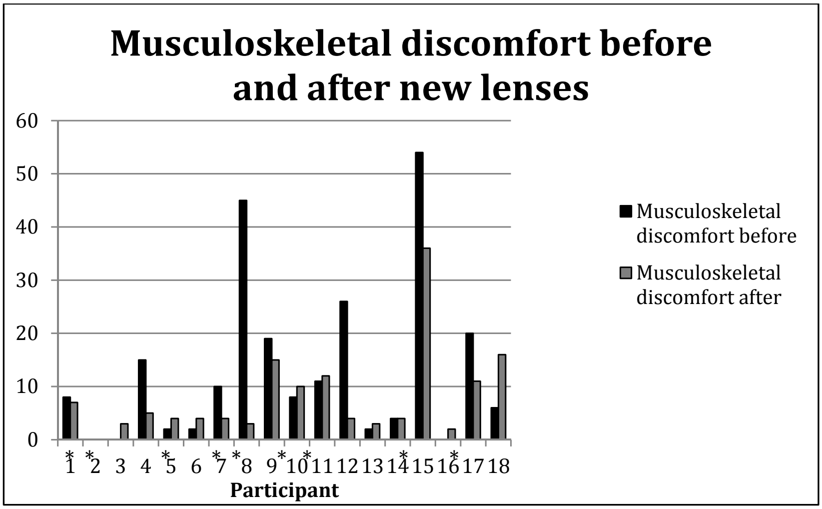

Figure 3. Musculoskeletal discomfort (max 126) before and after the intervention with new spectacles (*=participants who needed new spectacles).

3.1. Need/no need for new spectacles

The postal workers were divided into groups based on their need for new spectacles or not. After the intervention, the group that needed new spectacles (n=9) showed a decrease in the eyestrain index from 6.8 to 2.3 (p=0.027). The group that did not need new spectacles (n=9) also showed a decrease in the eyestrain index, though smaller, from 1.3 to 1.0 (p=0.34) (see Table 3).

Table 3. The average eyestrain and eyestrain index before and after the intervention divided into "need" and "no need" for new spectacles

	Burning	Itching	Gritty feeling	Ache	Light sensitivity	Redness	Teariness	Dryness	Eyestrain Index
Need									
Before	0.89	0.33	0.44	0.33	2.22	0.67	0.89	1.00	6.8
After	0.11	0.33	0.11	0.11	1.13	0.25	0.00	0.50	2.3*
No Need									
Before	0.11	0.11	0.00	0.22	0.00	0.22	0.67	0.00	1.3
After	0.11	0.11	0.00	0.00	0.11	0.11	0.56	0.00	1.00

* p=0.027

3.2. Eye fatigue

There were also decreases in both groups for eye fatigue: the need for new spectacles dropped from 1.7 to 0.4 (p=0.10), and no need for new spectacles from 0.3 to 0.1 (p=0.16). For headaches, there was a similar decrease: the need for new spectacles dropped from 0.6 to 0.4 (p=0.71), and no need for new spectacles from 1.0 to 0.2 (p=0.14).

Table 4. The average musculoskeletal discomfort for the right and left sides of the body, before and after the intervention, divided into "Need" and "No need" for new spectacles

Left	Hand	Lower arm	Elbow	Upper arm	Shoulder	Neck	Back	Musculoskeletal discomfort total
Need; *Before*	0.22	0.22	0.33	1.00	2.44	3.56	2.56	10.33
Need; *After*	0.22	0.89	0.33	0.11	1.56	1.67*	1.22	6.00
No Need; *Before*	1.22	0.22	0.00	0.56	1.00	0.22	1.33	4.56
No Need; *After*	0.11	0.11	0.11	0.11	0.67	0.67	1.11	2.89
Right	Hand	Lower arm	Elbow	Upper arm	Shoulder	Neck	Back	Musculoskeletal discomfort total
Need; *Before*	0.67	0.00	0.11	0.00	2.89	2.00	1.56	7.22
Need; *After*	0.33	0.00	0.22	0.00	1.11	1.11	1.11	3.89
No Need; *Before*	0.00	0.22	0.00	0.11	0.78	0.22	2.33	3.67
No Need; *After*	0.44	0.22	0.00	0.00	0.78	0.78	1.22	3.44

* p=0.027

3.3. Musculoskeletal discomfort

The musculoskeletal discomfort index was also reduced for both groups: those in need of new spectacles had a decrease from 17.6 to 9.7 (p=0.18), and those not in need only had a small decrease from 8.2 to 6.2 (p=0.83).

When looking at the neck, there was a significant decrease in discomfort on the left side from 3.6 to 1.7 (p=0.027) in seven of the postal workers who reported neck pain (n=9) in the group who needed new spectacles. For the group with no need of new spectacles, two of the postal workers reported neck pain from the left side before and after the intervention (n=9) with a small increase from 0.2 to 0.7.

The group that needed new spectacles had a decrease in neck pain from the right side: six of the postal workers before the intervention and five after, from 2.0 to 1.1 (p=0.063). The group with no need of new spectacles had a small increase of neck pain from the right side, from 0.2 to 0.8, two individuals before and three after (p=0.10) (see Table 4).

4. Discussion

The postal workers rated their vision better with the new spectacles than the old, especially at reading. This can be because reading was easier with the new spectacles, which provided them with extra power for reading.

The postal workers' eyestrain decreased with new personal spectacles. Only three of the original 18 still had eyestrain syndrome after they received new spectacles: one of them had cataract with sensitivity to light as a classic symptom. This left two younger postal workers with eyestrain that cannot be explained by the wrong correction (participants 1 and 7; see Figure 2). They did not have spectacles previously but received them for the first time due to hyperopia and astigmatism. It might be that they needed more time to get used to their new spectacles. But they did report a decrease in the amount of eyestrain. One other individual had a large decrease in eyestrain (participant 8; see Figure 2). He had progressive lenses before and changed to the optimal correction in a bifocal lens instead. The main advantage of a bifocal lens is that the reading area is higher up and wider. When the postal workers are sorting using ordinary progressive lenses, they have to extend their head backward to see the top shelf on the sorting rack clearly so that they can see through the reading area of the lenses. With bifocal lenses, participant 8 did not have to extend his head backward as much; this may have had a positive effect on the musculoskeletal discomfort as well.

There were two individuals among the "no need" for new power in spectacles group that reported eyestrain after the intervention. These two reported teariness that could be present because the postal workers were bicycling in the cold Nordic winter when they responded to the second questionnaire.

For eye fatigue there was a decrease both in the severity and the number of individuals with the symptom. A total of seven individuals reported eye fatigue before the intervention. Post intervention it was the same for two of them, the symptom had disappeared for three, and there was a decrease in the severity for the last two. So there appears to be a connection between the optimal correction and eye fatigue. The postal workers perceived an improvement of their overall vision. Since half of them needed new spectacles, this result is to be expected.

When the participants were divided into groups based on the need of new spectacles or not, some interesting results were found. As expected, the group with the need for new spectacles had a higher prevalence of eyestrain, headaches and eye fatigue as well as musculoskeletal discomfort. Having the wrong lens power can cause a straining of the eye (i.e. asthenopia or eyestrain). Research shows a correlation between straining of the eye and an increase of muscle activity in upper trapezius muscle [10, 11, 12]. As expected, the findings show an impact on the musculoskeletal discomfort with new spectacles. The results did show a non-significant decrease for most of the postal workers. The decreases were mainly located in the back, shoulders and neck, especially from the left side. Some of the postal workers also had an increase of musculoskeletal discomfort. These increases were mostly in the hands, lower arms, elbows, and upper arms. There were three individuals that had a large decrease of musculoskeletal discomfort, especially from the left side of the neck, shoulder, back, and upper arm.

The effect of this intervention was strong, in spite of the small group studied. It gave the postal workers better vision, so an improvement was expected. One interesting finding is connected to the way postal workers work, which is different from many other professions. When they sort mail they have a static side (the left side) and a dynamic side (the right side) when right handed. They hold a pack of letters in the left hand and sort them into the different compartments with the right. Earlier studies show that static work loads induce more musculoskeletal discomfort from the back and neck [2, 3, 4, 5]. This study found a significant decrease of neck pain from the static left side especially among those who needed new spectacles. Though there was a tendency toward a decrease on the right dynamic side as well, the decrease on the left side was statistically significant. The improvement was strongest for the postal workers that needed new spectacles. Those that did not need new spectacles sometimes also reported a decrease of musculoskeletal discomfort. One explanation for this finding might be a better and more upright work posture for the postal workers who were able to see better. Since the criteria for needing new spectacles was a change of more than ± 0.25 D, those individuals that had a power change of only 0.25 D were placed in the “no need” group. It is common knowledge among optometrists that there are individual variations in how sensitive people are to the wrong power; so some of the individuals could have had a positive response to this slight change. Five of the postal workers in the “no need” group had progressive lenses, some of which had a lower quality than the progressive lenses they were given in this study. This could also have effected both their perception of eyestrain and musculoskeletal discomfort.

There may be a disadvantage for the postal workers who sort with progressive addition lenses: they incline their heads backward in order to see the top shelf clearly. A specific type or sorting lens was tested, resulting in a decrease of the postal workers’ backward head inclination, which thus facilitated a better work posture [21]

This study was performed via questionnaires; thus, it is only the subjective reported eyestrain and musculoskeletal discomfort that were measured. The eyes were checked with an eye examination, but a thorough examination of their musculoskeletal discomfort would have been of interest as well. Two of the postal workers were regularly receiving physiotherapy for neck problems (participants 10 and 15; see Figure 3).

All of the postal workers had only used the new spectacles for about two months before the second evaluation. For this time frame, the results are surprisingly positive, especially considering the musculoskeletal discomfort.

In the Scandinavian countries it is common that the employer pays for a visual examination and pair of working spectacles, if needed, for employees working at a computer if the employees’ private spectacles are not adequate for the work task. This leads to the question of people in other professions that include static working postures and their need for personal spectacles, but due to financial reasons may not be able to purchase new ones as often as they need to. Another question is how sick leave is affected by this. The study by Niskanen et al. [7] shows that with specifically fitted computer spectacles it is possible to decrease sick leave due to upper back and neck musculoskeletal disorders. Is it possible to decrease company costs for sick leave among professions who have a static working posture but are not currently eligible for working spectacles by making them eligible? This question is of interest for further studies.

5. Conclusion

The postal workers rated their vision better after an intervention providing new spectacles. There was also a positive effect on eyestrain and musculoskeletal discomfort. Interventions consisting of the optimal correction of lens power decreased eyestrain and musculoskeletal discomfort including neck pain.

This study shows the importance of optimal correction and the positive effect this has on the eyes, musculoskeletal discomfort and headaches. Headaches, eyestrain or musculoskeletal discomfort from the neck or shoulders may signal the need of a visual examination.

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Paper IV

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Working spectacles for sorting mail

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Abstract

Background: Sorting mail into racks for postmen is visually demanding work. This results in a backward inclination of their heads, especially pronounced for those who use progressive addition lenses.

Objective: Evaluate the effects on physical workload of customized working spectacles.

Methods: Twelve male postmen sorted mail on two occasions: once using their private progressive spectacles and once using customized sorting spectacles with inverted progressive lenses. Postures and movements of head, upper back, neck, and upper arms were measured by inclinometry and muscular load of the trapezius by electromyography.

Results: With the sorting spectacles, both the backward inclination of the head and backward flexion of the neck were, as intended, reduced (3°), and the muscular load of the right upper trapezius was reduced, compared to sorting with private spectacles. However, with the sorting spectacles, there was an unfavorable tendency of increased neck forward flexion (2°), and increased sorting time (13%).

Conclusion: The reduction in load may reduce the risk for developing work-related musculoskeletal disorder. However, the size of the possible reduction is difficult to predict, especially since quantitative data on exposure-response relationships are unknown. Alternative working spectacles with inverted near progressive lenses ought to be evaluated.

Keywords: postmen, EMG, inclinometry, progressive lenses, work progressive spectacles

1 Introduction

Work-related musculoskeletal disorders (WMSD) are the dominating factor behind reported long term sick leave in Sweden [1]. According to statistics from 2010, 17% of the male and 23% of the female employees in Sweden reported WMSD in the last 12 months, and among the approximately 7,000 men and 4,500 women working as postmen in Sweden, 22% of the men and 31% of the women reported WMSD [2]. The percentages of the working population in Sweden that reported WMSD in the shoulder and arm were 4/7% (men/women) and in the back of the head and neck, 2/4%. The percentages of postmen that reported WMSD in the shoulder and arm were 9/18% (compared to 6/9% among general office and customer service work) and in the back of the head and neck, 5/7% (3/6%). So the prevalence of WMSD of postmen is higher than the general population and among general office and customer service work.

A relationship has been documented between repetitive movements of the arm and pain in the neck and shoulder region [3]. Work tasks that involve repeated movements often lead to a relatively low but sustained muscular activity in the shoulder muscles [4]. Another concern is awkward neck postures. Studies show increased neck pain when the working posture results in a forward inclination of the head [5, 6]. There is also an increased risk of neck pain with a backward inclination of the head while working [7].

In addition, a relationship has been shown between demanding visual tasks and disorders in the neck and shoulder region [8, 9]. Individuals with eyestrain also report musculoskeletal discomfort to a higher degree than those without eyestrain [10, 11]. Straining of the eyes, which can occur due to the wrong power in spectacles, glare from light sources, and visually demanding work, may cause an increased activity in the upper trapezius muscle [12, 13, 14]. A risk factor contributing to the correlation between eye-neck/scapular area symptoms can be near work. Correction with appropriate spectacles might therefore be considerably cost-effective interventions in health care [15].

The job tasks of postmen at the Swedish Post Office (Svenska Posten AB) include handling, sorting and delivery of mail. For about 2-4 hours a day, the postmen sort several different types of letters. They start by sorting the letters into the different districts the post office serves and after that, they sort their own district. They use specific sorting racks at their district. While sorting, postmen have a dynamic side and a static side. The right side is the dynamic side for right-handed postmen who take letters from their left hand and sort them into the sorting racks. The static side is the left side where they grip a pile of letters with their left hand. Sometimes they rest the pile of letters on their arm, and hold the letters at reading distance. The sorting is visually demanding, since the postmen have to read both the name and the address on the letters, and the labeling on the shelves. In a previous intervention study regarding new lighting and labeling of the sorting racks, the lighting was upgraded to the recommended uniformity and illuminance levels, and the risk for glare was decreased [11]. In conjunction with the study, the new lighting was installed in all post offices at Svenska Posten AB in Sweden. An intervention study, where a group of postmen were given new private spectacles with the type of lens that they needed (progressive, bifocals or single vision) [16], showed that correct power in lenses reduced self-reported eyestrain and discomfort from the neck.

People enter into the presbyopic age around 45 years and the need for extra reading power (addition) becomes notable [17]. Postmen using spectacles with progressive addition lenses

(PAL) need to incline their heads backward when reading on the top shelf in order to see through the reading part of their glasses to get sharp vision, since the shelf is only 40 cm away (Figure 1). The bottom shelf, on the other hand, is at distance of 90 cm, which is why they need to incline their heads forward to avoid the reading part of the glasses.

Figure 1. The sorting rack. The bottom shelf is mainly for storage.

The aim of the present study was to investigate the effects of customized mail sorting spectacles, with reversed reading and distance zones, on the working posture and muscular load of presbyopic postmen while sorting mail. The hypothesis was that the new customized sorting spectacles would reduce the backward inclination of the head and the muscular load of the shoulders.

2 Materials and Methods

The postmen sorted the letters (see section 2.2) into three or four sorting racks, individually adjusted so that the highest shelf was at shoulder height (Figure 1). The top four shelves were used for sorting; the bottom shelf was only used for storage. Every address/household has its own compartment that was 20 mm wide. The distance from the eye to the top shelf was approximately 40 cm, to the fourth shelf 90 cm, and to the letters held at reading distance approximately 40 cm.

2.1 Participants

Twelve right-handed male postmen with progressive spectacles (PAL) participated. Their mean age was 59 years (range 48-64), height 179.5 cm (range 172-194), weight 79.5 kg (66-100) and addition on their spectacles +2.00 diopters (+1.75 - +2.50). All of them had worked as postmen for at least 30 years. Nine of the postmen were participants in previous studies by Hemphälä and Eklund [11] and Hemphälä et al. [16]. Three of the postmen had eyestrain syndrome [18, 11]. All of them reported some degree of musculoskeletal discomfort. Participation was voluntary and the measurements took place during working hours.

2.2 Intervention

Eye examinations were carried out on the postmen in August 2010 by an optometrist using a phoropter Topcon VT-10 and a visual acuity board Topcon ACOP-6R/6EM (Topcon Scandinavia AB, Mölndal, Sweden). Those who needed were provided with new private spectacles so that all participants had private progressive addition lenses (PAL) with correct power (private spectacles). In addition, the postmen received a new pair of specifically customized sorting spectacles for work in September 2010. The sorting spectacles had double frames and flip-up spectacles (Optergo "DP" Frame by Optergo/Multilens, Mölnlycke, Sweden) (Figure 2). The posterior frame had a single vision lens with the correct power for each postman's distant vision. The anterior flip-up frame contained a pair of room progressive lenses (Gradal RD by Zeiss Vision, Stockholm, Sweden) that have three different zones (room distance 1.5-3.5 m, intermediate distance 70-90 cm and reading distance 40-50 cm). The lenses were mounted upside down and lower, so that when looking straight ahead, the postmen used the reading distance zone, when looking somewhat downward they used the intermediate distance, and when looking further down, the room distance zone. Both the distance power and the addition were the same for their private and the sorting spectacles.

Figure 2. The sorting spectacles with double frames. The anterior frame is a flip-up frame with room progressive lenses mounted upside down. The posterior frame has single vision lenses.

The intention was that the postmen by using the new sorting spectacles would not have to incline their heads backward when looking at the top shelf. During the measurements, the postmen sorted letters looking through the anterior frame with the room progressive lenses. When not sorting mail and looking at a distance, they could just flip up the anterior frame and look through the posterior frame. The postmen received the sorting spectacles more than six months before the study was performed and their private progressive spectacles before that. They were asked to use the sorting spectacles as much as possible. In May 2011, they sorted a specific number of C5 letters (23 x 16 cm), the same number for all of the postmen, with both their private and sorting spectacles. The same letters were sorted twice in random order (i.e. not the same order between the first and the second trial). A stopwatch was used to time the two letter sorting trials. The letters were sorted into empty sorting racks. Half of the participants started sorting with the sorting spectacles and the other half started with the private spectacles. A requirement from the unions in Sweden was that the number of letters sorted in the time study would not be revealed, since there was no wish for their members to participate in productivity studies.

2.3 Work postures and muscular activity

Inclinometers, based on triaxial accelerometers (Logger Teknologi HB, Åkarp, Sweden), were used to record the inclination relative to the line of gravity for head, upper back and both upper arms [19, 20]. The inclinometers were fixed with double-sided adhesive tape to the forehead, to the right of the spine at the level of C7 and to the lateral parts of both upper arms with their proximal portion just distal to the insertions of the deltoid muscles. The reference positions (0° of forward/backward) of the head and upper back were recorded with the subject standing upright and looking straight ahead. The reference positions for the upper arms were recorded with the subject seated, with the side of the body leaning towards the armrest of a chair and the arm hanging perpendicular over the armrest with a 2 kilo dumbbell in the hand. The neck angles were calculated as head angles minus upper back angles. The 1^{st}, 10^{th}, 50^{th}, 90^{th} and 99^{th} percentiles of the angular distributions of head and upper back inclination and neck flexion, and the 50^{th} and 99^{th} percentiles of the angular distributions of arm elevation were used as measures of posture. The angular distributions of the lateral inclination of head and upper back as well as the lateral flexion of neck at the 50^{th} percentile were also derived. Further, the 50^{th} percentile of the angular velocity distributions of head and upper back inclination, neck flexion and arm elevation were used as measures of movements. For head and upper back, positive values denoted forward inclination and negative values denoted backward inclination. For neck, positive values denoted forward flexion while negative values denoted backward flexion.
Surface electromyography (EMG) was recorded bilaterally from the upper trapezius muscle, using Ag/AgCl electrodes (AmbuNeuroline 720, Ballerup, Denmark) with a centre-to-centre distance of 20 mm. Electrodes were placed over the upper trapezius, two centimetres lateral to the midpoint on the line between the seventh cervical vertebra and the lateral edge of the acromion. The sampling rate was 1024 Hz, and the signal was band-pass filtered (30 – 400 Hz). The root mean square value (RMS) was calculated for epochs of 0.125 s, and the noise was subtracted in a power sense. Data were normalized to the EMG activity derived during three maximal voluntary contractions (MVC). The MVCs were performed before sorting as arm abductions against resistance proximal to the elbow with the arms raised to 90° in the scapular plane [21, 22]. The highest registered EMG level was then selected as the maximal voluntary electrical activity (MVE). The activity registered during work was reported as % MVE. Muscular rest, defined as fraction of time with an activity <0.5% MVE, and the 10^{th}, 50^{th}, 90^{th} and the 99^{th} percentiles of the amplitude distributions, were used to describe the muscular activity. For details, see Hansson et al. [23, 24, 25, 26], and Nordander et al. [27, 28].

2.4 Data analysis

Data was statistically analyzed in SPSS 18.0 (SPSS Inc., Chicago, IL, USA). For comparisons of technical measurements of physical workload between tasks using private spectacles and using sorting spectacles, paired sample t-tests were performed; 95% confidence intervals as well as p-values were derived. A p-value below 0.05 was considered statistically significant. For all estimates of workload, where p-values for difference between types of spectacles were below 0.1, the effect of sorting time on workload was estimated using linear mixed models where sorting order was used to define repeated measures, type of spectacles and sorting time were fixed factors.

3 Results

Letter sorting with private spectacles was performed with a backward inclination of the head of 4.5° at the 1^{st} percentile of the amplitude distribution (group mean, Table 1). This backward inclination was reduced by 2.7° with the sorting spectacles. Consistently for the 10th percentile, the slight forward inclination of 9.8° recorded with the private spectacles, was increased by 2.8° with the sorting ones. These differences were accomplished by a change in neck postures, as neck flexion showed similar differences while no significant differences were recorded in upper back postures. Regarding the 50th, 90th, and 99th percentiles, the head and upper back showed no significant differences, while the neck showed a tendency for a higher forward flexion (about 2°) when using the sorting spectacles. For lateral inclination, the 50th percentile showed that mail sorting was performed with a slight inclination to the right (private spectacles head lateral inclination p10 -6.5°, p50 3.9°, p90 15.4°). No differences were found between the two types of spectacles (not shown in table). Upper arm elevation did not differ between the spectacles. The velocity of the upper right arm was 3.7°/s lower with the sorting spectacles.

The elevation in the 99th percentile for the upper right arm with the private spectacles was almost twice as high (73.7°) compared to the upper left (38.3°) and the velocity for the upper right arm was also about twice as high (54.8°/s) compared to the upper left (27.8 °/s), consistent with the concept of a dynamic and a static side (Table 1).

When using the sorting spectacles, the load of the right trapezius muscle for the 10th, 50th, and 90th percentiles was 7-15% lower compared to the private spectacles (Table 2). No differences were registered on the left side. With the private spectacles there was lower muscular rest, and higher load for the 50th, 90th, and 99th percentiles on the right side, as compared to the left.

Table 2. Muscular load for twelve men during mail sorting with sorting spectacles (Sorting) and private progressive spectacles (Private) shown as mean values and standard deviations (SD) within brackets. The differences between sorting and private spectacles (Sorting – Private) are shown as mean values (SD), 95 percent confidence intervals (95% CI) and p-values. The percentile values are normalized to the maximal voluntary EMG activity (% MVE).

Muscle / Side / Measure		Sorting	Private	Sorting – Private		
		Mean (SD)	Mean (SD)	Mean (SD)	95% CI	p-value
Trapezius						
Right						
Muscular rest (% time)		8.9 (12.8)	6.3 (9.6)	2.6 (6.1)	1.2 – 6.4	0.164
Percentile (% MVE)	10th	1.1 (0.9)	1.3 (1.2)	-0.3 (0.4)	-0.5 – -0.0	0.045
	50th	3.9 (2.9)	4.3 (2.9)	-0.5 (0.7)	-0.9 – -0.0	0.045
	90th	9.2 (5.0)	9.9 (4.7)	-0.7 (0.9)	-1.3 – -0.1	0.029
	99th	16.1 (6.9)	16.3 (6.4)	-0.1 (1.5)	-1.1 – 0.8	0.758
Left						
Muscular rest (% time)		29.2 (28.1)	28.8 (29.7)	0.3 (7.4)	-4.4 – 5.1	0.877
Percentile (% MVE)	10th	1.2 (1.7)	1.6 (2.0)	-0.3 (0.8)	-0.8 – 0.1	0.158
	50th	2.8 (3.1)	3.1 (3.6)	-0.3 (0.9)	-0.9 – 0.2	0.214
	90th	4.7 (4.6)	5.1 (5.0)	-0.4 (1.1)	-1.0 – 0.3	0.264
	99th	7.6 (6.5)	7.4 (6.4)	0.2 (2.0)	-1.1 – 1.4	0.794

Table 1. Head, upper back, neck and upper arms postures and movements for twelve men during mail sorting with sorting spectacles (Sorting) and private progressive spectacles (Private) shown as mean values and standard deviations (SD) within brackets. The differences between sorting and private glasses (Sorting – Private) are shown as mean values (SD), 95 percent confidence intervals (95% CI) and p-values. For inclination and flexion, positive values denote forward.

Region / Postures/movements / Measure		Sorting Mean (SD)	Private Mean (SD)	Sorting – Private Mean (SD)	95% CI	p-value
Head						
Inclination (°)						
Percentile	1st	-1.8 (6.6)	-4.5 (6.8)	2.7 (3.7)	0.3 – 5.1	0.028
	10th	12.7 (8.3)	9.8 (8.5)	2.8 (4.1)	0.2 – 5.5	0.035
	50th	37.0 (8.2)	35.3 (6.0)	1.7 (6.4)	-2.3 – 5.8	0.371
	90th	58.2 (6.6)	57.7 (4.7)	0.5 (5.5)	-3.0 – 4.0	0.749
	99th	68.8 (5.5)	67.8 (4.0)	0.9 (4.5)	-2.0 – 3.8	0.492
Velocity (°/s)						
Percentile	50th	18.2 (3.6)	18.0 (3.1)	0.1 (1.9)	-1.0 – 1.3	0.794
Upper Back						
Inclination (°)						
Percentile	1st	-4.0 (3.1)	-3.3 (3.5)	-0.6 (1.4)	-1.5 – 0.3	0.151
	10th	0.7 (3.2)	1.2 (3.6)	-0.5 (2.0)	-1.7 – 0.8	0.405
	50th	7.8 (4.0)	8.3 (4.1)	-0.6 (2.4)	-2.1 – 0.9	0.425
	90th	26.2 (8.3)	27.3 (9.1)	-1.2 (3.2)	-3.2 – 0.9	0.243
	99th	39.6 (10.8)	40.2 (10.5)	-0.6 (3.9)	-3.1 – 1.9	0.603
Velocity (°/s)						
Percentile	50th	13.8 (3.3)	14.0 (2.9)	-0.2 (1.4)	-1.1 – 0.7	0.643
Neck						
Flexion (°)						
Percentile	1st	-4.9 (7.9)	-8.0 (7.2)	3.1 (2.9)	1.3 – 4.9	0.004
	10th	8.7 (8.8)	5.8 (8.2)	2.9 (3.3)	0.9 – 5.0	0.010
	50th	28.3 (8.9)	26.2 (7.5)	2.1 (3.7)	-0.2 – 4.5	0.072
	90th	37.3 (8.8)	34.9 (8.0)	2.4 (3.9)	-0.1 – 4.9	0.060
	99th	43.7 (10.3)	41.7 (9.6)	2.0 (3.6)	-0.3 – 4.2	0.080
Velocity (°/s)						
Percentile	50th	13.7 (2.7)	13.8 (2.4)	-0.2 (1.8)	-1.3 – 1.0	0.770
Upper arm, right						
Elevation (°)						
Percentile	50th	25.2 (3.8)	25.5 (3.9)	-0.3 (3.1)	-2.3 – 1.7	0.722
	99th	72.2 (9.0)	73.7 (8.0)	-1.5 (3.3)	-3.5 – 0.6	0.146
Velocity (°/s)						
Percentile	50th	51.1 (12.9)	54.8 (14.7)	-3.7 (5.6)	-7.3 – -0.1	0.044
Upper arm, left						
Elevation (°)						
Percentile	50th	18.8 (3.7)	18.6 (3.9)	0.2 (0.9)	-0.4 – 0.8	0.424
	99th	40.6 (9.7)	38.3 (5.9)	2.3 (6.5)	-1.8 – 6.5	0.242
Velocity (°/s)						
Percentile	50th	28.6 (7.4)	27.8 (6.5)	0.8 (3.0)	-1.1 – 2.6	0.395

[It took on average 1.2 minutes longer to sort the letters with the sorting spectacles (10.3 minutes) than with the private spectacles (9.1 minutes), and 1.0 minutes shorter to sort the letters the second time (9.2 minutes) than the first time (10.2 minutes). Consistently, those who started sorting with the private spectacles sorted on average 0.2 minutes faster with these than with the sorting ones, and those who started with the sorting spectacles sorted on average 2.1 minutes slower with these than with the private ones. Thus, the effects of type of spectacles and sorting order were additive.

The time used for sorting the letters with the different spectacles did not influence the head inclination (1st percentile p=0.5; 10th p=0.13). For all percentiles of neck, except the 99th, no influence of sorting time was shown (1st p=0.7; 10th p=0.4; 50th p=0.4; 90th p=0.08; 99th p=0.049). When sorting time was included in the model for the 99th percentile, there was no longer any difference between the spectacles (p=0.9). For the right upper arm velocity, sorting time had an influence (50th percentile p=0.002), and no effect of type of spectacles remained (p=1.0). Within individuals, this difference in upper arm velocity correlated well with the time used to sort the letters (Figure 3). No influence of sorting time was shown for the muscular activity in the right trapezius (10th percentile p=0.5; 50th p=0.3; 90th p=0.6).

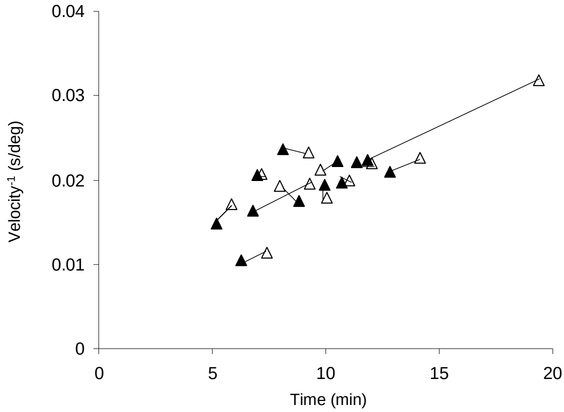

Figure 3. Velocity^{-1} (s/°) at the 50th percentile for right upper arm and the time required for sorting letters in twelve males using private spectacles (filled triangles) and sorting spectacles (open triangles).

4 Discussion

With the private progressive spectacles, the postmen inclined their heads and flexed their necks backward when sorting mail. Concerning that aspect, the sorting spectacles resulted in a slightly less backward inclination of the head and flexion of the neck of 3° in both. However, there was a tendency to an increased neck forward flexion of 2°. The major reason for this could be that the postmen flexed their necks forward more with the sorting spectacles when reading the envelopes in their hands because the reading zone was mounted higher in the lens.

If they had used a near progressive lens (with two zones, half of the lens for reading distance and the other half for intermediate distance) instead of the room progressive lens (with three different zones), the results might have been better. The backward inclination of the head and the backward flexion of the neck when looking at the upper shelf would still probably have been reduced, but the forward flexion of the neck would have been smaller. If they had used a near progressive lens, the reading zone would be larger, making it easier to read the envelopes and resulting in a smaller forward inclination of the head. Some of the postmen reported some dizziness when using the sorting spectacles; this may have been caused by the room progressive lenses. The dizziness should decrease with a near progressive lens, because the two zones are larger resulting in less distortion of the picture in each zone. Near progressive lenses might also be easier to get used to, so that the postmen would use the sorting spectacles more often. This could also affect the sorting time, making sorting spectacles as efficient as the private ones. Thus, the evaluation of a near progressive lens for sorting spectacles for postmen is recommended. Such a study should be more extensive and include more subjective ratings of the spectacles, analyses of the function of the lenses, and a more thorough control of participant compliance. There have been successful fittings of inverted presbyopic lenses, but no references have been found. One example is inverted progressive lenses for personnel working in cranes in Gothenburg, Sweden. The work-cabins are very high up, and the worker needs to look at a computer screen mounted straight ahead and also look through a glass floor, at the ground, 30 meters down.

There are also other types of lenses that might be possible to use. Unfortunately the range of different lens types have decreased since the progressive lenses arrived. One example might be a type of trifocal lens with an inverted intermediate and reading zone. This type of lens is not produced today. This could be another solution to the problem, if the inverted trifocal lenses are mounted a bit higher up than pupil height.

The postmen rated their vision with the sorting spectacles a little bit lower on average than with the private progressive spectacles. One of the factors causing this could be that it takes some time to become accustomed to a new type of lens that is mounted up-side down. Getting accustomed to a new pair of progressive lenses can take anything between a few days to several months; the sorting spectacles are probably more difficult. Most of the postmen sorted slower with the new, customized sorting spectacles. They were given the spectacles six months before the study, and were told to use them as much as possible. It is common that it takes about two months for a person to become accustomed to a new type of lens. Since the postmen only used them a few hours at every daily occasion, it might have taken them longer. But not all of the postmen had used them as often as they were told, which might explain why it took them longer to sort with the sorting spectacles. The postmen's opinion about the sorting spectacles is not known since no thorough subjective feedback was recorded from the postmen when using the spectacles. During the time study the participants were asked about how the new glasses worked, two of the postmen complained verbally about dizziness, rest of them did not complain.

The postmen have to be really motivated to use the new sorting spectacles; they have to be informed about the positive effects and encouraged to use them every day. This might be hard if they do not have any clear neck problems, or if they consider the sorting spectacles to be more uncomfortable than their private spectacles. The slower sorting resulted in a lower velocity. The muscle activity was also reduced with the sorting spectacles. This reduction could not be explained by the longer sorting time.

According to Swedish statistics for the shoulder/arm and neck, the percentage of postmen that reported WMSD was, for both men and women, more than twice as high as among the working population in general.[Please see above comments in the Introduction section.] Handling post is heavy and repetitive work with strenuous working postures that can cause MSD. The postmen's work task evaluated in this study is only performed for less than half of their working day and is not representative of a full working day. The other work tasks, such as the delivery of the post, have not been analyzed in this study.

Only male postal workers were measured in this study. Studies show that there are no differences in body postures and movements between men and women, although the relative musculoskeletal load in percentage of the MVE is higher for women than men during the same work load [29].

Dentists have a large head forward inclination and a large neck flexion while working which leads to neck strain. In a study by Lindegård et al. [30], a decrease in the forward head inclination as well as forward neck flexion of 5° was achieved by using specifically designed prismatic spectacles, allowing the dentists a more natural working posture. The postmen also showed a high head forward inclination for the high percentiles. The present intervention did not intend to affect this; in fact a small increase was noted, as discussed above.

In comparison with other occupations, the head backward inclination was not remarkably high. For other occupations, such as electricians in construction work with more pronounced head backward inclination [31], the effect of a spectacle intervention might have a larger preventive effect.

5 Conclusion

Head backward inclination and neck backward flexion were both reduced by 3°, and muscular load in the right upper trapezius decreased for the 10^{th}, 50^{th}, and 90^{th} percentiles by on average 11% when using sorting spectacles with inverted work progressive spectacles while sorting mail. This reduction in load may reduce the risk for developing WMSD from the neck and shoulder areas. However, the size of the possible risk reduction is difficult to predict, especially since quantitative data on exposure-response relationships are unknown. The evaluation of near progressive lenses in sorting spectacles for postmen is recommended.

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Paper V

Submitted to Lighting Research and Technology

Towards lighting recommendations for operating theatres

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Abstract
Surgery is visually demanding and requires a good visual environment with efficient illuminance and minimal glare. High luminance contrasts, which can cause eyestrain and problems seeing clearly, are common in operating theatres due to high illuminance levels from surgical luminaires and low illuminance in surrounding areas. The purpose of this study was to see how an altered general lighting with an increased illuminance and higher correlated colour temperature (CCT) in an operating theatre affects the operating personnel's visual performance and subjective experiences of the lighting. A second purpose was to analyse the effects of glare on the personnel from three different illuminance levels from the surgical luminaire, together with different general lighting situations. The lighting recommendations that exist for operating theatres are often only for the general lighting. No previous studies have been found that support these recommendations. In this laboratory study, performed in an operating theatre, four different lighting situations were compared at three different operating light levels. The lighting situation using the existing installation resulted in a CCT of 3000 K and a general lighting of 1000 lx. Of the three test lighting situations, the one with the highest CCT and illuminance had a CCT of 4300 K and a general lighting of 2000 lx, 3800 lx around the operating table and 5700 lx at the operating table. The contrast vision of the medical personnel was tested while being exposed to glare in twelve different lighting situations. Compared to the existing lighting, the test lighting situation with the highest illuminance and CCT was rated better, but the results of the personnel's visual tests showed no significant difference between the two.

1 Introduction

The requirements for the visual environment in an operating theatre are high. Surgery requires a high level of intellectual preparation, an efficient and controlled workspace, fine motor skills, physical endurance, problem-solving skills, and emergency response skills (Berguer, 1999). Surgeons or assistants who have any visual problems can make serious treatment mistakes. Surgeons mainly focus their vision in the highly illuminated operating cavity. Being fully adjusted to that luminance can cause problems when they look up into darker areas and need to adjust to lower luminances. Scrub nurses also have very visually demanding work that involves focussing on the surgeons' performance in the operating cavity as well as handing the surgeons instruments from the instrument table. This means that their vision needs to adjust to very different levels of luminance throughout the operation. The main work tasks of the anaesthetist nurse are to look at the monitors for information, check patients' vital signs, and administer medications. The circulating nurse assists the other personnel, which sometimes involves very visually demanding work tasks. How should the general lighting in an operating theatre be designed to provide the best basis for the visual ability of the operating staff? What factors affect the operating personnel's visual ability?

Surgery is visually demanding and requires a good visual environment with efficient illuminance and no glare. It is desirable to have a uniform illuminance over the working area. The operating light should have a light beam that provides parallel light with a high illuminance to produce sharp shadows and facilitate depth perception (Knulst et al., 2011). Operating light usually provides very high amounts of illuminance and high luminance contrast between the operating field, the direct surrounding areas and the outskirts of the room. Luminance contrasts that are too high will result in glare and cause visual fatigue due to the continuous readaptation of the eyes and can result in lower productivity (SS-EN 12464-1 Boyce et al., 2006).

The high luminance contrast in the operating theatre between the operating light and the surrounding area causes glare for the operating personnel. One study found that the luminance contrast within the visual field was 140:9:1 (operating light: immediate surrounding areas: outskirts of the room) (Hemphälä et al., 2011). The luminance contrast for visually demanding work, such as computer work, should be within 10:3:1 (ANSI/IESNA, 2004).

With age comes an increased need for light and a higher sensitivity to glare. Due to a decreased ability to adjust quickly to lower luminances, an ageing surgeon may be negatively affected by the high luminance contrast. However, such effects may be offset by increased competence and operative skills that can positively affect patient outcomes (Waljee & Greenfield, 2007). According to Veitch (2001), an increase in illuminance within relevant ranges will often result in improved visual performance. Surgeons often use headlamps to enhance the illuminance in the visual field (Hemphälä et al., 2011). However, this can lead to an increased risk for musculoskeletal strain (due to the extra weight) and deterioration of the visual situation for the assistants when the surgeons move their heads.

Glare affects visual ability, and adaptation glare or a discomfort glare will deteriorate one's contrast visual acuity when adapting to lower luminances (Boyce et al., 2003). The exact mechanisms behind retinal adaptation to luminance and contrast are still uncertain (Jarsky et al., 2011). Adaptation to contrast seems to go through the photoreceptor inputs and the ganglion cells (Rieke, 2001; Baccus and Meister, 2002). Laming states that the fast onset of contrast adaptation is mainly observed in the ganglion cells that have a higher sensitivity to cooler light. With higher illuminances, the rhodopsin of the photoreceptors on the retina will be bleached. When they are saturated, the neural response decreases and through differential coupling, the signals will still go through but with a decreased sensitivity (i.e. an adaptation to that luminance) (Laming, 2013).

The amount of illuminance needed in the operation cavity for different types of surgical procedures depends on the procedure as well as the amount of illuminance in the entire room. The first reaction when the light is perceived as inadequate seems to be to increase the illuminance levels: "The more – the better" (Weston, 1962). However, many operating lamps provide too much illuminance, usually between 100000 and 160000 lx, with a minimum of 40000 lx (SS-EN 60601-2-41; Hemphälä et al., 2011). Neither of the standards with recommendations for lighting of the operating cavity (SS-EN 12464-1 and ANSI/IESNA, 2006) seems to base the values on any research results.

The international standardised recommendations, SS-EN 12464-1 for the illuminance in operating theatres, recommends a minimum of 1000 lx for the general lighting. For the operating area (operating cavity) there is only a comment: 10000 to 100000 lx from the operating lamp. If this recommendation for the general lighting is followed together with the recommendations for operating light, the luminance contrast between the operating light (minimum 40000 lx) and the general lighting (1000 lx) will be high.

According to the Illuminating Engineering Society of North America (IESNA), lighting recommendations for hospitals and healthcare facilities (ANSI/IESNA, 2006), the luminance ratios should not be greater than 3:1 between the operating cavity and the surrounding operating field, and no greater than 5:1 between the operating cavity and the instrument table. The light output from the operating lamp should provide at least 25 000 lx (it also mentions 27000 lx in the text) directed as a light beam, a 20 cm circular pattern on the operating table. The operating lamps should have a colour temperature between 3500 K and 6700 K, and the general lighting should be kept as close as possible to this colour temperature. In *The Lighting Handbook* (IES, 2011) there are lighting recommendations for different age groups. The general lighting in an operating theatre for an individual under 25 years should be 1000 lx, for an individual 25-65 years, 2000 lx, and for an individual over 65 years, 4000 lx. The operating table should be 1500 lx for an individual younger than 25, 3000 lx for an individual 25-65 years and 6000 lx for an individual over 65 years. A German standard (DIN 5035-3, 2006) states that the surrounding areas around the operating table, 3 x 3 m, should be higher than the general lighting. No references have been found supporting these recommendations.

When choosing the different lighting situations for this study, the effect of colour temperature on alertness was considered. It is known that the human circadian system (sleep-wake cycle) is affected by an increase in alertness when exposed to cooler light with a higher correlated colour temperature (CCT) via the photosensitive retinal ganglion cells on the retina (Brainard et al., 2001). Cooler light can positively affect our alertness and performance (Rea, 2011).

The main purpose of this study was to see how an altered general lighting with an increased illuminance and higher CCT in an operating theatre affects the operating personnel's visual performance and their subjective experiences of the lighting. A second purpose was to analyse the effects of glare from three different illuminance levels from the surgical luminaire (low, medium, and high illuminance) together with different general lighting situations. Based on the theories referred to in this section, it was hypothesised that a lower luminance contrast ratio together with a cooler light would have a positive effect on visual performance in operating theatres.

2 Method

2.1 Overview

The study was performed with 29 subjects in an operating theatre with 12 different lighting situations. In a randomised order of the lighting situations, each subject performed visual performance tests and rated the lighting for all 12 lighting situations.

An application for ethical vetting regarding this study was approved by the Central Ethical Review Board in Lund.

2.2 The laboratory setting

This study was performed in an operating theatre with no access to daylight. The operating theatre was 6.2 x 6.2 m with a height of 3.05 m and was used for general surgery (urology and gynaecology procedures) during weekdays and as a laboratory during evenings and weekends.

The general lighting in the operating theatre consisted of two different sets of luminaires. The existing general lighting consisted of twelve fluorescent luminaires mounted directly onto the ceiling and fitted with T5 fluorescent lighting tubes (OSRAM 28 W 830 [CCT 3000K]) with high frequency electronic ballasts. The test general lighting mounted in the operating theatre consisted of twelve luminaires, tiles, (0.6 x 0.6m) with WW 940 (CCT 4000K) and 965 (CCT 6500K) fluorescent tubes centred in the middle around the operating table and eight luminaires with fluorescent tubes W840 (CCT 4000K) + RGB (Red, Green and Blue). All of the test luminaires could be dimmed and programmed to certain illuminance levels, and the eight luminaries along the walls could also be programmed to different colour temperatures. The two operating lamps were X6 marLux from KLS Martin Group fitted with halogen and metal halide, giving a maximum of 150000 lx and having a CCT of 4300 K. They were mounted in the ceiling in the middle of the room (see Figure 1).

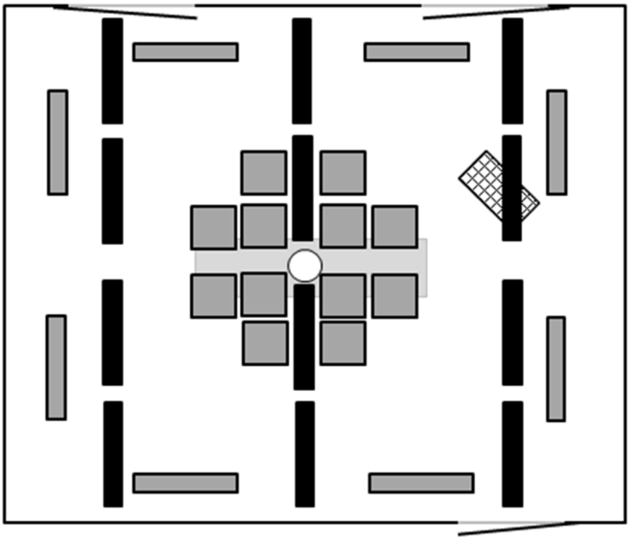


Figure 1. The approximate placement of the general lighting: existing (shown in black), test (grey with black edges), operating lamps (round circle), operating table (light grey), anaesthesia equipment (checked rectangle).

The test luminaires were programmed to three different illuminance levels. Together with the existing luminaires in the operating room this resulted in four different general lighting situations: 3 test and 1 existing. Each of these was combined with three different illuminance levels from the operating lamps: low (L) = 35000 lx; medium (M) = 65000 lx; high (H) =100000 lx. This resulted in 12 different lighting situations. For more information about the lighting, see Table 1.

Table 1. Average general lighting with the operating light: Amount of light from the operating light: 35000 lx=low (L), 65000 lx=medium (M), 100000 lx=high (H). Existing luminaire; T1: test luminaire with lowest illuminance; T2: test luminaire with medium illuminance; T3: test luminaire with high illuminance. Amount of illuminance 1 m around the operating table. Average amount of illuminance on the operating table (outside of the operating light area [OLA]). OLA: amount of illuminance where the subjects let their eyes adapt between tests. CVA: amount of illuminance on the contrast visual acuity chart. The operating lamp was on while measuring the different general lighting situations, but it only affected the light on the operating table and on the OLA. CCT (correlated colour temperature) for the different general lighting situations (see Figure 2 for more information).

Operating light	Type of general lighting	General lighting (lx)	1 m around the operating table(lx)	Operating table (lx)	OLA (lx)	CVA (lx)	CCT (K)
Low (L)	Existing	1100 (750-1300)	1200	**1700**	16800	1260	3000
	T1	1200 (500-2150)	1500	**2500**	17400	950	3900
	T2	1650 (850-2900)	2100	**3500**	21000	1340	4100
	T3	2950 (1500-5100)	3800	**6700**	23500	2400	4300
Medium (M)	Existing	1100 (750-1300)	1200	**2500**	31700	1260	3000
	T1	1200 (500-2150)	1500	**3400**	31300	950	3900
	T2	1650 (850-2900)	2100	**4300**	31850	1340	4100
	T3	2950 (1500-5100)	3800	**6900**	36450	2400	4300
High (H)	Existing	1100 (750-1300)	1200	**2700**	40600	1260	3000
	T1	1200 (500-2150)	1500	**3600**	38550	950	3900
	T2	1650 (850-2900)	2100	**4700**	44750	1340	4100
	T3	2950 (1500-5100)	3800	**7100**	49500	2400	4300

The illuminance and luminance were measured with a Hagner Universal Photometer S1 and a Hagner Screenmaster. When measuring the general lighting, the room was divided into a grid with 23 measuring points (5 x 5 measuring points, minus two above the operating table), with the measuring points about one meter apart, starting and ending about one meter from the walls, measured at working height horizontally or vertically, when needed. The luminance for the general lighting was measured at a 45° angle directed at a horizontal white paper at working height, or vertically towards the walls. There was no noticeable impact on the general lighting from the different illuminance levels of the operating lamp outside of the operating table (see Tables 1 and 2 for more information). The luminance contrast ratios between the visual task areas were also calculated (see Table 2 for more information).

The illuminance level for the general lighting was calculated as the average illuminance from the 23 measuring points. The illuminance level for the “1 m around the operating table” was calculated as the average illuminance of the eight measuring points surrounding the operating table (out of the 23). The illuminance level for the operating table is the average illuminance level for the fifteen measuring points on the operating table out of which eight were around the OLA (operating light area, see Figure 2), four on the instrument table and the rest on the operating table. There were an additional nine measuring points on the OLA reading chart (15 x 24 cm). The average illuminance is shown in Table 1.

The luminance was measured directed at the laboratory setup (green operating drapes, the OLA) for the different lighting situations. The diameter of the light beam (OLA) was adjusted so it more or less covered the width of a standardised reading test to which the subjects were adapting their eyes (about 15-20 cm in diameter depending on the amount of lx: the higher the amount of lx, the smaller the diameter). The operating lamp was adjusted to three different illuminance levels: low (L) = 35000lx, medium (M) = 65000lx and high (H) = 100000lx (see Tables 1 and 2 for more information).

Table 2. Luminance contrast ratios between OLA (operating light area where the subjects let their eyes adapt) and the CVA (contrast visual acuity) chart. Luminance ratios between OLA and the operating table (OR table with green operating drapes).

Luminance ratios			
Operating light	Type of general lighting	OLA:CVA	OLA:OR table
Low (L)	Existing	15:1	27:1
	T1	19:1	19:1
	T2	16:1	17:1
	T3	9:1	12:1
Medium (M)	Existing	25:1	40:1
	T1	28:1	29:1
	T2	21:1	22:1
	T3	15:1	18:1
High (H)	Existing	43:1	51:1
	T1	49:1	37:1
	T2	40:1	32:1
	T3	24:1	22:1

2.3 The laboratory experiment

The experiment procedure took about two hours to perform with each subject and was video filmed as a backup. An operating table was covered with green operating drapes. An instrument table was positioned across the operating table to the left of the participant who was standing by the operating table (see Figure 2).

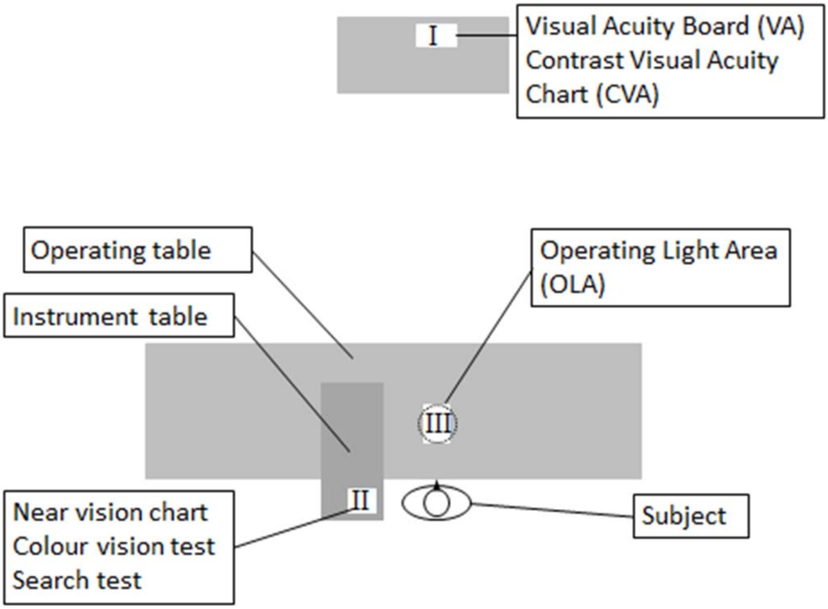


Figure 2. Laboratory setup in the operating theatre. The subject stands next to the operating table. I: placement of the visual acuity and contrast visual acuity charts; II: placement of the near vision chart,colour vision test and the search test; III: operating light area (OLA) where the subjects let their eyes adapt to the luminance from the operating light.

The operating table height and distance to the operating light was standardised by setting the operating table at elbow height and then placing the operating lamp at approximately the same distance to the operating table. The reading distance was also measured and was an average of 57 cm. The subjects' visual ability was analysed with the following tests once, before the study started in the existing lighting situation (see Tables 1, 2 and Figure 2):

- Visual acuity at 3 m distance (I in Figure 2), monocular/binocular (3 Meter Logarithmic SLOAN Visual Acuity Test, Precision Vision, La Salle, IL, USA). See Figure 3.
- Contrast visual acuity (CVA) at 3 m distance (I in Figure 2), binocular (Translucent Contrast Chart with 1.25% contrast, Precision Vision, La Salle, IL, USA), placed on a 1.2 m high table covered with a green operating drape. The CVAs for first nine rows on the test were (in order from the top) 0.16, 0.20, 0.25, 0.32, 0.40, 0.50, 0.63, 0.80, and 1.0. See Figure 3.

- Visual acuity at near range (II in Figure 2), near vision reading chart (minimum 5p), (standardised reading charts "Svenska Stilskalor" (developed by Anders Hedin, 1982), 17 x 24 cm, Henry Eriksson AB, Bandhagen, Sweden). See Figure 3.
- Colour vision (II) (Ishihara Colour Vision Test, 38 plates edition, 2010, Kanehara Trading Inc., Tokyo, Japan).

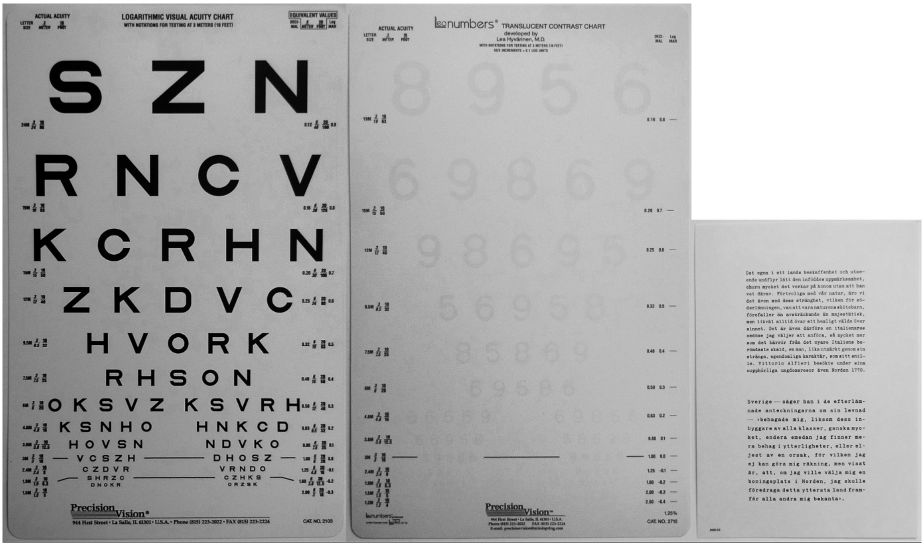


Figure 3. The Precision Vision 3 m visual acuity (VA) test and the Precision Vision 3 m contrast visual acuity (CVA) chart together with the standardised reading chart used in the operating light area (OLA).

The operating light was set according to a randomised schedule (low, medium or high) focused on a standardised reading chart on the operating table placed in front of the subject, in the operating light area (OLA) (III in Figure 2). The operating light took some time to set to the correct illuminance level; it was easier to change the general lighting. The subject was asked to close his/her eyes for about 30 seconds while the general lighting was changed to the first lighting situation according to a randomised schedule consisting of: existing, test 1 (T1), test 2 (T2) or test 3 (T3).

When the first of the twelve lighting situations was on, the individual was told to:
(see Figure 2)

- Open his/her eyes and look at the OLA (III) and adjust his/her eyes for 30 seconds to the luminance level.

- Look at the contrast test placed 3 m in front of him/her (I). For 2 minutes the subject tried to see the different visual acuity levels on the contrast visual acuity chart, each level timed and recorded. After 2 minutes he/she were stopped and the contrast visual acuity (CVA) was recorded.
- Rate the general lighting by placing a mark on a visual analogue scale (VAS), a ten cm long line (from very bad to very good).
- Rate the operating light by placing a mark on a VAS, a ten cm long line (from very bad to very good).
- Close his/her eyes while the general lighting was changed to the next situation (minimum of 30 seconds).

After testing the subject's visual abilities in the four general lighting situations for the first operating light situation, the existing lighting situation was turned on and the operating light was changed to the next situation. Then the general lighting was set according to the randomised schedule. This happened for all of the three operating light situations.

The contrast visual acuity (CVA) was recorded and if needed, a + or – was put after the visual acuity if the subject could read more or less than the actual visual acuity row. This was then translated into a number based on the size of the difference between the rows and the number of letters on each row.

When a subject had completed the tests in the twelve lighting situations, he/she was asked to perform the first situation again, so that it was possible to analyse any learning effect of the tests.

2.4 Subjects

Due to the specific surroundings in the operating department, the subjects were invited from the personnel in that department or medical students who were accustomed to the atmosphere in an operating room. Fifteen of the subjects were students. There were 29 subjects: 22 females and 7 males. The average age was 39 years for the entire group, 52 years (36-65) for the operating staff, and 25 years (23-32) for the medical students.

2.4.1 Visual function, eyestrain and musculoskeletal discomfort

All the subjects had a minimum binocular visual acuity of 1.0 (1.0-1.6) with correction if needed, and could read the smallest text on the reading chart (J1-2, 5p) with correction if needed. Only one of the male students had problems with the colour vision test due to a colour deficiency. One subject originally recruited for the study could not read anything on the contrast visual acuity test and was therefore excluded from the study, resulting in a total of 29 subjects.

A visual ergonomics questionnaire including subjective ratings of eyestrain and musculoskeletal strain developed by Knave et al. (1985) was used. The questionnaire was modified to match the operating personnel's work (see Hemphälä et al., 2014 for the full questionnaire). According to Knave et al. (1985), eyestrain is a syndrome comprising eight different symptoms: smarting, itching, gritty feeling, aching, sensitivity to light, redness, teariness, and dryness. Work-related eyestrain was defined as the reporting of three symptoms or more (Knave et al., 1985 and Hemphälä et al., 2012).

The results from questionnaire showed that 17 (7 of them over 45) out of 29 subjects reported eyestrain and individuals with eyestrain reported four times more musculoskeletal discomfort from neck and shoulder.

2.5 Statistical analysis

A repeated measures analysis of variance was carried out by using a generalised estimating equation (GEE), since each subject went through the tests 12 times. Subject identification and the twelve lighting situation scenarios were used to indicate the repeated measurements.

The effects of different lighting situations on the CVA index (time needed to see the first row of the CVA chart and CVA reading after two minutes), and the subjective ratings (perceived experience of general light, experience of operating light) were analysed using a linear model type of the GEE. To exclude confounding variables (e.g. learning effect and tiredness) associated with performing 12 repeated CVA tests in a relatively short time, an unadjusted version was first analysed and then an adjusted model with test sequence included. However, results from the test sequence for adjustment did not modify the main effect of the lighting situation meaningfully. We also repeated all statistical analyses using the logarithm of the CVA index and ratings as a sensitivity analysis. However, results using the log-transformed CVA index or ratings did not show any meaningful differences from the results using the original data. Thus, results reported in this paper are based on the original data with the unadjusted model. All analyses were carried out by SPSS 20.0 (IBM Corp., Armonk, NY, USA).

3 Results

Overall, the existing and T3 (test lighting with the highest CCT and illuminance), rendered similar results on the tests, but the T3 lighting situation received better ratings, especially for the higher levels of operating light. The T1 and T2 lighting situations in most cases rendered lower results and lower ratings than existing and T3 (see Figures 3 and 4).

There was a tendency indicating that the T3 lighting situation was better in a shorter time frame (time to read first CVA row). The CVA was similar after two minutes for the existing and the T3 lighting situations, with a tendency for the existing lighting situation resulting in a higher CVA. For the higher levels of operating light, the T3 general lighting received significantly better ratings. The ratings of the operating light were similar in the different general lighting situations (see Table 3 and Figure 4).

Table 3. Results, divided into amount of operating light from the contrast visual acuity (CVA) test after adjusting the eyes to the illuminance levels in the operating light: time to read the first CVA row; CVA after 2 minutes. Ratings of the general lighting and the operating light in different operating light settings. The significance is calculated compared to the existing general lighting situation in each operating light level (n=29).

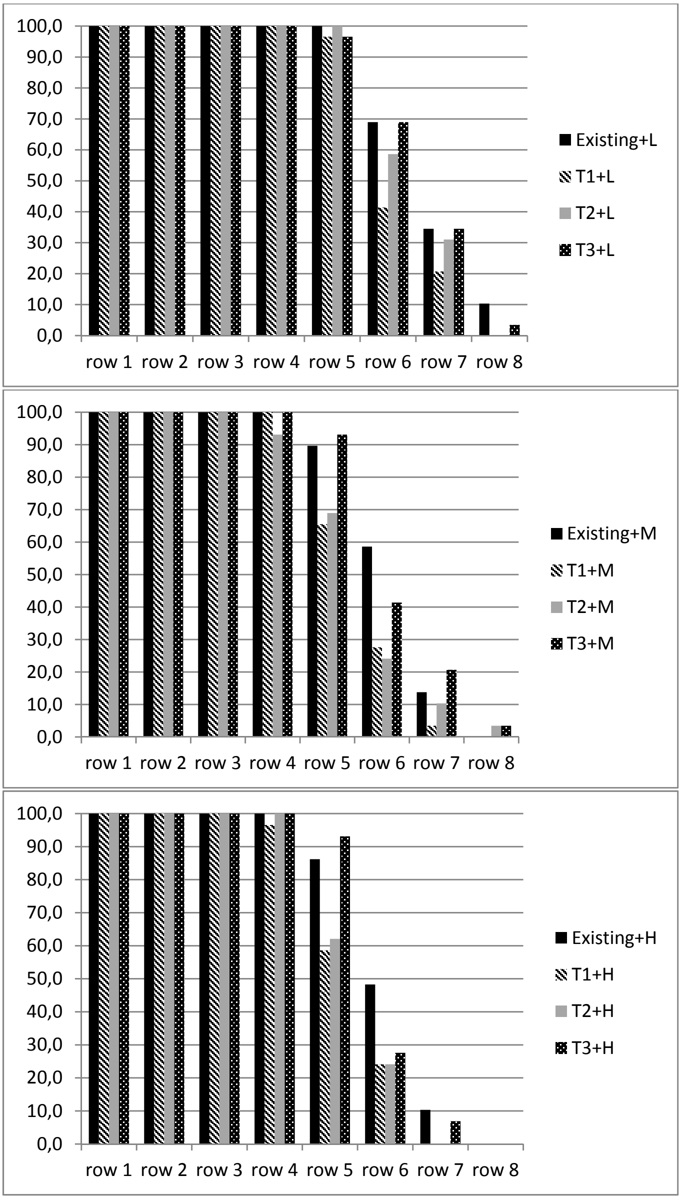
Operating light	General light	Time to read first CVA row (s)*	CVA after 2 minutes*	Rating score of general light*	Rating score of operating light*
Low (L)	Existing	8.6±5.4	0.54 ±0.13	6.4±2.5	6.6±2.0
	T1	11.2±7.1***	0.46 ±0.10***	5.8±2.1	6.2±2.1
	T2	8.6±4.2	0.51 ±0.11**	6.1±2.0	6.4±2.2
	T3	7.3±2.7	0.52 ±0.11	6.6±2.1	6.3±2.1
Medium (M)	Existing	13.9±7.1	0.48 ±0.09	6.2±2.4	6.3±2.3
	T1	21.3±10.8***	0.39±0.11***	5.0±2.3 ***	5.7±2.4*
	T2	17.9±10.8**	0.42±0.12***	6.1±2.3	6.6±2.3
	T3	12.6±7.5	0.46±0.11	7.0±2.1	6.4±2.3
High (H)	Existing	18.4±7.7	0.45±0.09	5.6±2.5	5.6±2.6
	T1	25.7±9.4***	0.38±0.07***	4.9±2.4	5.5±2.5
	T2	22.8±10.4***	0.39±0.07***	5.8±2.7	5.8±2.5
	T3	16.3±6.2	0.43±0.09	7.2±2.0***	5.9±2.7

* mean ± standard deviation, difference from existing general light (*=p≤0.05; **=p≤0.01, ***=p≤0.001)

The effects of changes in CCT are revealed by comparing the existing and T2 lighting situations. The illuminance levels at the CVA test were similar for T2 and existing, but the

CCT was higher for the T2 lighting situation. In the T2 lighting situation, it took the subjects longer to read the first row, and the CVA after two minutes was lower, especially for the higher illuminances from the operating lamps. The subjective rating of the T2 lighting situation was similar to that of the existing lighting situation (see Tables 1, 3 and Figure 4).

Figure 4.The figures below show the percentage of subjects that could read the first eight rows in each of the general lighting situations for the three operating light situations (L, M, H). Row 5 is the same as CVA 0.4.



When dividing the results into the different general lighting situations and comparing the different levels of operating light, the rating of the general lighting was better for the low level of the operating light (high levels of operating light produced more glare), except for T3 where the high level received the best rating indicating a lower disturbance of the operating light. But the lower rating of the higher illuminance levels from the operating lights was only significant for the existing and T1 lighting situations (see Table 4.)

Table 4. Results divided into general lighting situations from the contrast visual acuity (CVA) test after the subjects let their eyes adapt to the illuminance levels in the operating light. The time to read the first CVA row; CVA after 2 minutes. Ratings of the general light and operating light in different operating light settings. The significance is calculated compared to low operating light in each general lighting situation (n=29).

Operating light	General light	Time to read first CVA row (s) *	CVA after 2 minutes*	Rating score of general lighting*	Rating score of operating light*
L	Existing	8.6±5.4	0.54 ±0.13	6.4±2.5	6.6±2.0
M		13.9±7.1***	0.48 ±0.09***	6.2±2.4	6.3±2.3
H		18.4±7.7***	0.45±0.09***	5.6±2.5*	5.6±2.6*
L	T1	11.2±7.1	0.46 ±0.10	5.8±2.1	6.2±2.1
M		21.3±10.8***	0.39±0.11***	5.0±2.3	5.7±2.4
H		25.7±9.4***	0.38±0.07***	4.9±2.4*	5.5±2.5
L	T2	8.6±4.2	0.51 ±0.11	6.1±2.0	6.4±2.2
M		17.9±10.8***	0.42±0.12***	6.1±2.3	6.6±2.3
H		22.8±10.4***	0.39±0.07***	5.8±2.7	5.8±2.5
L	T3	7.3±2.7	0.52 ±0.11	6.6±2.1	6.3±2.1
M		12.6±7.5***	0.46±0.11***	7.0±2.1	6.4±2.2
H		16.3±6.2***	0.43±0.09***	7.2±2.0	5.9±2.7

* mean ± standard deviation, difference from low operating light, (*=p≤0.05; **=p≤0.01, ***=p≤0.001)

For each subject, the CVA was performed once more with that subject's first lighting situation after all the twelve lighting situations. The results do not show any systematic learning effects. Some of the subjects performed better and some of them performed slower and had a lower

CVA.

4 Discussion

This is, to the authors' knowledge, the first study that examines the visual effects of general lighting in operating theatres. The purpose was to see how an altered general lighting with an increased illuminance and higher CCT in an operating theatre affects the operating personnel's visual performance and subjective experiences of the lighting. A second purpose was to analyse the effects of glare on the personnel from three different illuminance levels from the surgical luminaire, together with different general lighting situations.

The existing and the T3 lighting situations received the best results in general both on the CVA and on the rating of the general lighting. When comparing the different operating lights in each general lighting situation, the presence of glare had a significant impact on the subjects' ability to see – the more glare, the longer time to see the first CVA row. A bright light can cause a temporary blurring of vision and a reduction in the quality of an image (IES, 2011, Chapter 4), which is referred to as light adaptation glare. After 2 minutes the difference was still present with a lower CVA for the higher illuminance levels from the operating lamp. It is thus essential to reduce the glare from the operating lamp and not to use its highest possible illuminances. "The more – the better" (Weston, 1962) is not true for operating lights. It might have been good to use the de Boer scale for rating glare as a complement rather than just rating the light on a VAS scale (Fekete et al., 2010).

The surgeon spends most of the time in surgery looking into the operating cavity in open surgery, with only short pauses while looking for something or handing something to the rest of the operating staff. Increased general lighting will probably not have any significant effects on the surgeon's performance. The T3 lighting situation will probably facilitate the visual ability of the scrub nurses due to the reduced luminance contrast between the operating cavity and the instrument table. The anaesthetic nurse will more easily see the patient and the medications, but the amount of illuminance directed at the screens with the T3 lighting situation will probably decrease the contrast on the monitors, which decreases visibility. That effect can be mitigated by some sort of shielding device placed on the monitors to decrease the illuminance directed at the screen.

The difference between T2 and the existing lighting situation for the illuminance at the CVA was only 80 lx, but the CCT was higher for the T2 lighting situation. The existing lighting situation rendered better CVA than the T2 lighting situation. However, the subjects' ratings of the general lighting were similar for the two. The explanations of the differences in CVA could be that pupil size depends on the amount of light available in the short wavelengths (Berman, 1992), causing less light to enter the eye. This can have an effect on the CVA since a good CVA is dependent on the amount of illuminance. So, in order to have a similar amount of light hitting the retina when the pupil is smaller, the amount of illuminance needs to be higher for light with a higher CCT. The subjective discomfort glare is also larger with higher CCTs (Fotios and Levermore, 1998; Flannagan et al., 1989; Bullough, 2009). In a situation where individuals are exposed to glare, and adapted to a higher luminance level, the adaptation can reduce the CVA.

The lighting situations were programmed with an increasing CCT for the T1 (3900 K), T2 (4100 K) and T3 (4300 K) compared to the existing lighting situation (3000 K). An increase of the CCT from 3000 K to about 4000 K can improve visual ability, for example, for the perception of the blueness of the lips (sign of hypoxia). The illuminance levels were changed so that the first, T1, would have similar illuminance as the existing lighting situation. T2 had double the amount of illuminance of T1, and T3 was four times as high as T1. The T3 lighting situation in particular had higher illuminance levels around the operating table to reduce the luminance contrast and decrease the risk of glare. If a similar study were to be performed, it would be better to have several lighting situations paired with the same illuminance but with different CCTs. It would also be interesting to see the results from a lighting situation with the same illuminance as T3 but at 3000 K instead.

There was a tendency for the T3 lighting situation to be better for the CVA in a shorter time frame and for the existing lighting situation to be better after 2 minutes. One reason that the T3 was better in the shorter time frame may be due to the quick contrast response via the ganglion cell light with a high CCT that enhances visibility (Rieke, 2001; Baccus and Meister, 2002). After 2 minutes the glare effect on the retina is reduced since the adaptive glare response affects the bleaching of the photocells, a process that takes longer to reverse (Laming, 2013), and then the existing lighting situation is better. The exact mechanism is still uncertain (Jarsky, et al., 2011).

Would the test results and the subjects' ratings have improved even more if higher CCTs and illuminance levels were used? Most studies of the circadian rhythm use higher CCTs, but since the operating light in this study has a CCT of 4300 K, it might have felt too cold to increase the CCT of the general lighting beyond that level. More studies need to be performed to further clarify the effects of illuminance levels and CCT.

There is a need to check the vision of individuals who are working with visually demanding tasks (e.g., operating personnel) to determine at an early stage the conditions that affect the visual ability of the ageing work force. One of the 30 subjects originally recruited for this study could not read anything on the CVA board. That individual was remitted to an ophthalmologist.

Since the tests in this study were performed in a laboratory setting without any tasks similar to those of real surgery, the results might be hard to compare to real surgery. It was hard to find a test that was representative of the type of work the operating personnel did. For the near vision test, a visual search test was used (Duncan & Humphreys, 1989) consisting of a A5 sized document with several rows of non-target “E” and one target “L” hidden among the non-targets. The visual search test, placed on the instrument table, was inconclusive due to the different difficulty levels in finding the “L”. The Mars (near vision contrast test) test was not included because a contrast vision test was already used at a distance, but it could have been a good detector of glare at near distance as well. The Landolt C Test is commonly used in lighting studies (Berman et al., 1996) but it relies on hand-eye coordination as well. Since the Landolt C Test is used in lighting studies to evaluate visual performance and since most of the tasks performed in an operating theatre require hand-eye coordination, this may have been a better alternative than the visual search test.

The Contrast Precision Vision Test used in this study for distance vision to evaluate these specific circumstances with glare present is not the regular test for disability glare. Most of the existing glare tests require an instrument of a specific luminance, which was not available in this study. The CVA test was the only one that could be used with an operating lamp to evaluate the effect of glare on the contrast vision. The Regan Charts may have been an alternative solution for the glare test at a distance (Elliot and Bullimore, 1993). The results may have been stronger if both the Regan Charts and the CVA tests were used several times and an average time for each participant was calulated for each lighting situation.

The results from this study show that increasing the illuminance to about 2000 lx for the general lighting, 4000 lx around the operating table and 6000 lx on the operating table will affect the visibility and the ratings of the lighting. The European standards only discuss general lighting of 1000 lx, which this study indicates may be insufficient. The North American standards, on the other hand, provide recommendations similar to the ones studied here, but there does not appear to be any research that supports their recommendations. CCT recommendations may also be required, and further studies in this area are needed.

The effect on tiredness and visual ability of the increase of CCT and illuminance level (T3) compared to the existing lighting situation was studied further in a field study see Hemphälä et al. (2014) for the results.

5 Conclusion

The results show that an increased CCT together with an increased general lighting illuminance can improve the subjective lighting quality. The effects of glare from the operating lamp are similar in the existing lighting situation (3000 K and 1000 lx) and the test lighting situation with the highest CCT and illuminance (4300 K and 2000 lx) and with higher illuminance levels around and at the operating table.

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Paper VI

Lighting intervention for an operating theatre

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Abstract

Background: The aim of this field is to study how an increased level of illuminance and an improved luminance contrast in an operating theatre can affect visual ability and tiredness.

Method: In this study two lighting situations, existing and test, were tested in a frequently used operating theatre without access to daylight. The lighting situations differed regarding illuminance levels and correlated colour temperature (CCT) with both parameters being higher in the test lighting situation. The existing lighting situation is representative for typical operating theatres, and corresponds to existing standards. Immediately after performing open surgery procedures in the operating theatre, personnel rated the lighting situation they had experienced.

Results: All personnel (n=114) rated the lighting quality and visual ability of the test lighting better than those of the existing lighting. Tiredness was rated as lower with the test lighting except by the surgeons, who reported low levels of tiredness without significant differences between the existing and test lighting situations. The observed preferences of the test lighting situation are possibly due to its increased illuminance and higher CCT (cooler light) from the general lighting.

Conclusion: The study indicates that an increased general lighting illuminance together with a higher CCT can improve perceived visual ability and lighting quality and decrease tiredness among operating theatre personnel.

Introduction

The visual conditions in an operating theatre are essential for work performance and crucial for patient safety. The amount of illuminance needed in the operating cavity for different types of surgical procedures depends on the procedure as well as the amount of illuminance in the surrounding areas of the room. When the lighting is perceived as inadequate the first reaction seems to be to increase the illuminance levels: "the more – the better" (Weston, 1962). Typically in an operating theatre, there is a high difference between the luminances at the operating cavity and the general lighting. Operating theatres often have no windows and thus no daylight. People working there might experience tiredness, especially during long surgical procedures. The work of surgeons and scrub nurses is visually demanding when working by the operating cavity. Surgeons mainly look into the bright operating cavity and their eyes are adapted to that luminance level, but scrub nurses have to adjust between the high luminance in the operating cavity and the lower luminance levels at the instrument tray and other areas in the operating theatre. It is desirable to have a uniform illuminance over the entire working area. A luminance contrast that is too high will generate glare and cause visual fatigue due to continuous readaptation of the eyes (IESNA, 2011). Glare causes eye fatigue that affects visual ability and productivity (Boyce et al., 2006). The high luminance in the operating cavity causes glare for scrub nurses, disturbing their view of the darker instrument tray. The anaesthesia personnel have to look at monitors for information, check patients' vital signs, and administer medications. Circulating nurses assist other staff, at times having very visually demanding work tasks.

According to Veitch (2001), an increase in illuminance within relevant ranges to fulfil recommendations from standards will often result in improved visual performance. International and national standards include recommendations that general lighting in operating theatres should be at least 1000 lx (e.g. SS-EN 12464-1; DIN 5035-5, ANSI/IEESNA RP-29-06). Comments about higher illuminance levels around the operating table are sometimes included. According to SS-EN 60601-2-41, the operating lights or surgical luminaires should provide a minimum central illuminance of 40 000 lx and an upper limit of 160 000 lx in the central illuminance at a one meter distance between the operating light and the operating cavity. When the surgeon needs to look at a computer screen at X-rays, for example, the general lighting has to be dimmed to 50 lx (SS-EN 12464-1). However, no published research has been found to support any of these standards.

In one study, the average diameter of the operating light was 15 cm (Hemphälä et al., 2011), resulting in a small, highly illuminated circle of light with sharp boarders to the surrounding areas with lower illuminance levels; the average illuminance level from the operating lights was 100 000 lx. Usually the scrub nurse helps the surgeon to set the operating light at the beginning of the operation. During the operation they usually only adjust the angle of the light after the surgeon's instructions. The angle of the light is usually changed a few times during an operation depending on what the surgeon is doing and the depth of the operating cavity.. High luminance contrast between the operating light and the immediate surroundings can cause glare for the operating personnel and thus deteriorate their vision (Hemphälä et al., 2011). The light beam of the operating light should consist of a parallel light (give sharp shadows) in order to improve depth perception (Knulst et al., 2011).

The correlated colour temperature (CCT) of light is of significance. For example, cooler light with a higher CCT can increase our alertness (circadian system) and decrease the melatonin (sleep hormone) levels via the photosensitive retinal ganglion cells in our retinas (Brainard et al., 2001). Daylight or light with shorter wavelengths (blue, cool light) affects our alertness (Boyce, 2003).

The integration of circadian light – light that simulates the changes in the natural daylight – in traditional lighting design should be considered to boost the circadian rhythm. The most important factors in boosting circadian rhythm with light are the amount of circadian light, the spatial distribution, the time of exposure and its duration (Rea, 2011).

A cooler light may also facilitate the ability of the anaesthesia personnel to see the blueness of the face and lips present at hypoxia. But the cooler light will also have an impact on the pupil size: the pupil constricts more in cooler light than in warmer (Berman, 1992), causing less light to enter the eye. Thus, there may be a need to increase the illuminance levels if the CCT is increased to get more light into the eye. (See Hemphälä et al., submitted for more information)

In a previous laboratory study, the existing lighting and three test lighting situations with different illuminance levels and colour temperatures were studied (Hemphälä et al., submitted). The existing and test lighting situation with the highest illuminance and CCT had similar results on visual ability after being exposed to glare, and this test lightning situation was rated better than the existing lighting situation by the subjects in the laboratory study.

The purpose was to study the effects of a higher illuminance level (with better luminance ratios) and a higher CCT (cooler light) especially on tiredness and visual ability. The hypothesis was that more uniform lighting together with a higher illuminance and a higher CCT will improve visual ability and decrease tiredness. The luminance contrast on the operating table may affect how the personnel adjust the levels of illuminance of the operating lamps, but high contrast luminance in the visual field decreases visual ability. Unintentionally, this leads to the personnel setting the operating light at a higher illuminance in the belief that more light will enhance the visual ability.

It is of general interest to find out what makes good lighting in operating theatres. In this study, people from the four occupations typically working in an operating theatre compared existing "existing" lighting (which is typical, representative and in line with standards) with "test" lighting. Compared to the existing lighting, the test lighting was designed to provide more uniform illuminance at and around the operating table with less luminance contrast together with a higher CCT to decrease tiredness.

Method

This field study was based on the results from a previous laboratory study and was performed in an operating theatre with no access to daylight. The operating theatre was 6.2 x 6.2 m (41 m^2) with a height of 3.05 m and used for general surgical procedures, urology and gynaecology, procedures on weekdays.
An application for ethical vetting regarding this study was approved by the Central Ethical Review Board in Lund.

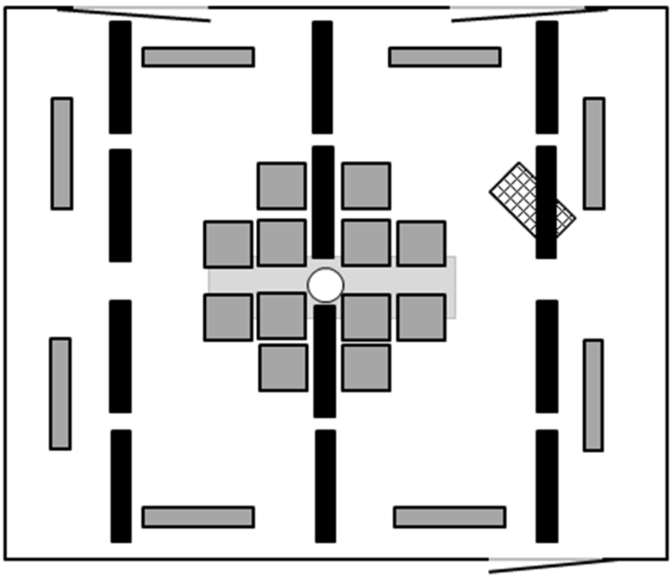

Figure 1. The approximate placement of the general lighting: existing (shown as black rectangles), test (grey squares and rectangles with black edges), operating lamp (round circle in middle), operating table (light grey), and anaesthesia equipment (checked rectangle). The higher illuminance levels are centred on the operating table, and the lower ones on the outskirts of the theatre.

The test lighting fittings were placed in the operating room together with the existing lighting fittings and the operating lamp. The existing general lighting consisted of twelve luminaires evenly mounted directly in the ceiling across the operating theatre; each luminaire was fitted with two T5 fluorescent lighting tubes (CCT 3000K). The test general lighting consisted of: 1) twelve luminaires (0.6 x 0.6m) with WW 940 (CCT 4000K) and 965 (CCT 6500K) fluorescent tubes centred in the middle on the operating table; 2) eight luminaires with fluorescent tubes W840 (CCT 4000K) + RGB (red, green and blue), all of which could be dimmed and programmed to a certain illuminance level and colour temperatures (Figures 1 and 2). The two operating lamps mounted in the middle of the room were X6 marLux from the KLS Martin Group fitted with halogen and metal halide and provide a maximum of 150000 lx. They had a CCT of 4300 K.

Figure 2. The existing general lighting (left) compared to the test general lighting (right).

In the field study, surgical procedures were performed in the operating theatre with the test lighting installed. The general lighting in the theatre was randomized on a daily schedule between the existing and the test lighting situations. The lighting situations differed concerning the amount of illuminance from the general lighting, especially the amount of illuminance approximately 1 m around the operating table, and the colour temperature (Table 1). The general lighting was measured at 23 evenly distributed measure points (including two measure points at the anaesthetic area) at working height in the operating theatre and at two places on the operating table.

Table 1. The average illuminance for the general lighting in the existing and test lighting situations. The average amount of illuminance 1 m around the operating table, the average illuminance for the anaesthetic area, the average illuminance for the operating table, and the correlated colour temperature (CCT) for the different general lighting situations. The higher illuminances were centred on the operating table in the middle and the lower on the outskirts of the theatre.

Illuminance (lx)					
	General lighting (min-max)(lx)	1 m around op table (lx)	Anaesthetic area (lx)	Operating table (lx)	CCT (K)
Existing	1100 (750-1300)	1200	850	1250	3000
Test	2950 (1500-6500)	3800	1800	5700	4300

Eighty-four open surgical procedures were evaluated during a five month period (Jan.-June 2013). The participation was initiated by the personnel, mostly the circulating nurse and the surgeon. Questionnaires were answered by surgeons and assisting personnel immediately after the surgical procedures. Laparoscopic surgery procedures were excluded. It was mandatory for the surgeon, scrub nurse and anaesthetist nurse to answer the questionnaires but voluntary for the circulating nurse. To reduce risk of infection, the circulating nurse held the photometer (Hagner Screenmaster) 10 cm above the operating cavity when measuring the illuminance of the operating light once after the surgeon had made the first cut. The illuminance at the operating cavity level was therefore slightly lower than the illuminance data reported. Even though the circulating nurses were trained in how to measure the illuminance there may have been slight differences in procedures between individuals.

The questionnaire consisted of visual analogue scales (VASs) (10 cm long lines) regarding the surgeons' and assisting personnel's ratings of general lighting and their visual ability during the procedure (ranging from very bad [0] to very good [10]), the colour of the light (ranging from very warm [0] to very cold [10]) and their tiredness during the procedure (ranging from very sleepy [0] to very alert [10]).

Questionnaires were obtained from 84 surgical procedures, 26 in the existing lighting system and 58 in the test. The questionnaires from eleven of the procedures were not answered by all of the personnel. A total of 303 questionnaires were completed by 114 participants (some of the participants answered the questionnaires more than once after different surgical procedures). The four occupations present in the operating theatre who answered the questionnaires were: 36% surgeons (average age 43; 12 women, 34 men), 25% anaesthetist nurses (average age 46; 18 women, 12 men), 27% scrub nurses (average age 47; 23 women, 1 man), and 12% circulating nurses (average age 50; 14 women).

In 23 of the surgical procedures (16 in the test lighting situation) a computer screen was used by the surgeons to look at X-rays or endoscopic procedures for 10-15 minutes. The operating light was turned off during this time and the general lighting was dimmed to 70 lx over the anaesthesiology equipment/patient's head in both lighting situations.

The average illuminance on the outskirts of the operating theatre for the test lighting situation was 1800 lx, shining too much light on the displays used during surgical procedures, such as the anaesthetist nurse's computer screens. In the existing lighting situation, this was 800 lx. The displays were placed at slightly different locations in different surgical procedures making the average towards the screens differ some.

After the questionnaire evaluations of the lighting that took place during the five months, a second similar questionnaire was distributed at a morning meeting with all personnel present that day for a retrospective session. The personnel that had worked in both the existing and the test lighting situations at some time during the five months field study filled out the questionnaire. Forty individuals rated their experience from both the existing and the test lighting situations; they rated the general lighting and their visual ability on VAS's ranging from very bad to very good. They also rated the colour of the light from very warm to very cold.

Statistical analyses

Four self-rated questions in the first questionnaire (experience of general lighting, colour temperature, visual ability and tiredness) were analysed using Multivariate Analysis of Variance (MANOVA) for multivariate effects where significance was tested using Wilks'

Lambda. For univariate effects T-tests were used. Where Levene's Test for Equality of Variances was significant (i.e. where the assumption of homogeneity of variance is violated) this is corrected by not using the pooled estimate for the error term for the t-statistic and adjusting the degrees of freedom using the Welch-Satterthwaite method.

Correction of the "Tiredness" variable was performed by adjusting for the treatment-effect of the dimming of the light. Also, the length of the operation was adjusted for using a regressional approach.

The questions in the second questionnaire (experience of general lighting, colour temperature and visual quality for the existing and the test lighting situations) were analysed using paired T-test since the same respondents answered the same question with regard both to the test and the existing lightning. In paired sample t-test the null hypothesis that the rating is the same for both the existing and the test lightning is analysed using a standard t-test.

All analyses were carried out by SPSS 20.0 (IBM Corp., Armonk, NY, USA). Statistical significance refers to *$p \leq 0.05$ (two-tailed).

Results

The effect of the lightning was multivariate significant ($p=0.000$) for both the entire dataset and for each profession. The subjective rating of the test lighting system was significantly higher in the test lighting. The general conclusion is that the participants rated their visual ability and the quality of the general lighting higher in the test lighting than the existing lighting ($p<0.000$). (See Table 2) The rating of colour temperature was higher (more cool light) in the test lighting than in existing lighting for most of the participants, except the anaesthetist nurses.

Table 2. Subjective ratings (mean ± standard deviation) for the existing and test general lighting for the lighting quality, visual ability, tiredness and colour temperature (CT).

Professions	General lighting	Rating Lighting Quality		Rating Visual Ability		Rating Tiredness*		Rating CCT	
All participants	Existing	4.8±2.1	p=0.000	5.3±1.9	p=0.000	4.1±2.5	p=0.000	4.1±1.6	p=0.000
	Test	7.7±1.4		7.3±1.5		2.7±2.0		5.2±1.3	
Surgeons (N=107)	Existing	5.6±2.5	p=0.000	6.1±2.0	p=0.000	2.4±1.6	P=0.401	4.3±1.6	p=0.003
	Test	8.0±1.4		7.6±1.5		2.1±1.8		5.2±1.2	
Anaesthetist nurses (N=76)	Existing	4.7±1.9	p=0.000	5.1±1.6	p=0.000	5.1±2.7	p=0.003	4.7±1.8	P=0.090
	Test	7.2±1.7		7.2±1.7		3.3±2.1		5.3±1.3	
Scrub nurses (N=81)	Existing	4.2±1.5	p=0.000	4.6±1.7	p=0.000	4.8±2.3	p=0.000	3.6±1.3	p=0.000
	Test	7.8±1.0		7.2±1.4		2.8±2.0		5.1±1.3	
Circulating nurses (N=39)	Existing	4.2±1.8	p=0.000	4.7±1.9	p=0.000	5.1±2.2	p=0.004	3.6±1.2	P=0.006
	Test	7.7±1.2		7.1±1.0		3.2±1.6		5.0±1.4	

*adjusted for duration of the operation and eventual dimming of the general lighting during operation

The reported tiredness was significantly lower in the test lighting situation compared to the existing one (2.7 vs. 4.1, p<0.001) for all professions except the surgeons. At surgical procedures when the general lighting was dimmed down while looking at computer screens compared to not dimming (and not looking at computer screens) an insignificantly lower the level of tiredness was observed, (2.8 vs 3.3, p=0.112, corrected for duration).

The amount of illuminance from the operating light was measured in all surgical procedures but one (in a total 83) and was on average 60 000 lx in the existing lighting situation, compared to 55 000 lx in the test situation.

After the five-month field study, personnel from all professions rated the test general lighting as better concerning lighting quality and visual ability (Table 3). The CT was rated as cooler for the test lighting situation.

Table 3. The results from the second questionnaire, personnel that had worked in the two lighting situations were asked to rate both of the lighting situations at the same time concerning lighting quality, colour temperature and visual quality.

All Professions (n=40)	General lighting	Rating (mean ± standard deviation)	P value
Lighting quality	Existing	3.6±1.3	0.000
	Test	8.2±1.2	
Colour Temperature warm/cold	Existing	4.3±2.0	0.048
	Test	5.2±1.4	
Visual Quality	Existing	4.4±1.7	0.000
	Test	7.3±1.7	

Discussion

In this study a test lighting situation was compared to an existing lighting situation during surgical procedures. All of the personnel rated the test lighting situation significantly better than the existing regarding lighting quality and visual ability in the first questionnaire. Since both the CCT and the illuminance levels were changed, it is uncertain which had the largest effect. In the previous laboratory study, an increased CCT with similar illuminance levels and resulted in lower ratings and lower performance on a contrast vision test (Hemphälä et al., submitted).

Most of the questionnaires were answered in the test lighting situation, even though the different lighting situations were set to every other day. Since there is a difference between the lighting situations the personnel might be more motivated to remember answering the questionnaires in the test lighting situation.

Tiredness was also reduced in the test lighting for the assisting personnel but not for the surgeons. The surgeons did not notice any difference in tiredness between the two lighting situations, and did not report any higher levels of tiredness either in any of the lighting situations. But since the surgeons are looking into a very high amount of illuminance (more than 50000 lx) during most of the surgical procedures, the effect of the surrounding illuminance on them may not be so large. The assisting personnel reported a significant improvement in the test situation.

The subjective opinion about the colour of the light in both of the lighting situations shows that the personnel did not experience the test lighting as too cold or that the existing lighting was too warm. Most of the personnel rated both of the lighting situations around the middle of the scale going from too warm to too cold, so both of the colour temperatures used were acceptable for the personnel.

The average illuminance level on the operating table increased with the test lighting, 5700 lx (according to IESNA, 2011, the illuminance on the operating table should be 4000-6000 lx), compared to 1250 lx (according to SS-EN 12464-1 the general lighting should be 1000 lx), resulting in a more even illuminance level on the table surface. This fact may have contributed to the increased rating of the visual ability in the test lighting situation. Another factor is that the average illuminance levels from the operating light in the operating cavity are approximately 5000 lx lower in the test compared to the existing lighting situation, supporting the hypothesis that if the general lighting and the luminance contrast are better there is no need to increase the amount of illuminance from the operating light. This supports the theory that a more even light distribution at the working area will reduce the need for higher illuminance levels from any task-specific light.

The amount of illuminance in the anaesthetic area increased from 850 to 1800 lx. This led to an increase of the illuminance levels hitting the computer screens. This caused a decrease in contrast on the screen and glare from the displays. Some of the anaesthetist nurses commented on this in their questionnaires. They felt that the test general lighting reflected on the screens, disturbing the visual ability. This was anticipated from the start of this study, so monitor hoods to shadow the displays were obtained and placed on the screens after the study was completed. The displays used during surgical procedures can get lower contrast and reflections from too much light hitting the screen, causing a reduced visual ability and eyestrain. It is thus necessary to select, locate and arrange the luminaries to avoid disturbing high brightness reflections (IESNA, 2011) or to reduce the light hitting the screens by using some sort of shielding device. The amount of illuminance hitting the displays should not exceed 500 lx (ANSI/IEESNA, 2004); otherwise, the image contrast on the screen decreases.

At the end of the study some of the personnel rated both the test and the existing lighting situations retrospectively. Previously they had rated the lighting in the lighting situation scheduled for that day. This questionnaire gave them an opportunity to rate both the test and the existing lighting simultaneously. The results of the final questionnaire showed a similar positive impression for lighting quality, colour and visual ability.

It cannot be ruled out that the presence of the research team and the test luminaires that looked more advanced might have affected the personnel's opinion about the test lighting. Such a Hawthorne effect (Levitt & List, 2011) cannot be excluded, but since the test lighting was rated better or equal to the existing lighting situation and gave equal or better results on the visibility test in a previous laboratory study (Hemphälä et al., submitted), this effect should be minor.

The alertness the personnel reported following the increased illuminance and higher CCT of the test lighting could bring immediate improvements in patient safety. However, in the long run it might be harmful to the personnel. The test lighting used in this study has characteristics similar to daylight. Other research (Hansen, 2001; Lie et al., 2006) has indicated possible health risks of exposure to strong light at night work. Consequently, the effects, including possible side effects, of using bright general lighting in an operating theatre need to be further examined.

Conclusion

Increased illumination and CCT improved visual ability for operating personnel. Tiredness among personnel decreased and better general lighting may be an efficient way to improve surgical results and medical safety.

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