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International Conference on the Effects of Light on Wellbeing

Y.A.W. de Kort, M.P.J. Aarts, F. Beute, A. Haans, I.E.J. Heynderickx, L.M. Huiberts, I. Kalinauskaite, P. Khademagha, A. Kuijsters, D. Lakens, L. van Rijswijk, A.C. Schietecat, K.C.H.J. Smolders, M.G.M. Stokkermans, W.A. IJsselsteijn .

Keynotes, selected full papers, and poster abstracts
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Preface

From 8 till 15 November, Eindhoven is of course the place to be for light lovers, because of Glow 2014. This light festival is – as always – located in the city centre, but since last year also on Strijp S. This former Philips factory area is now the new creative heart of Eindhoven and host to GLOWNEXT, an innovative and experimental light art platform during the Glow week, and a way for light applications to show social engagement. We therefore felt that Strijp S would be the perfect setting for the third edition of Experiencing Light, our international two-day conference on light and its effects on wellbeing.

As in earlier years, with your help we hope to provide a state of the art overview of how light influences mood and emotions, comfort and performance, and physical and mental health. These effects of light on human functioning are varied, complex, multifaceted and profound. Although there certainly are more – and very relevant – conferences on light throughout the year, Experiencing Light uniquely brings together scholars in image-forming and non-image forming domains, including, psychologists, biologists, designers, physicists and engineers. We hope and have great faith the synergy between all of you will help advance the domain of lighting research.

This year's edition is offering 25 oral and 24 poster presentations by scientists across the globe on five light themes: Perception of light, Circadian & performance effects, Daylight & office lighting, Light & experience – indoor, and Light & experience – outdoor. These contributions present new research and findings, new conceptualizations and designs, and new reflections on light and its psychological impact.

The extended abstracts we present in these proceedings are selected from the large collection of submitted papers through a carefully conducted review process, using blind peer-review. We are greatly indebted to the members of the Scientific Committee for their excellent work in reviewing these papers and selecting the best ones for presentation at the conference.

This year we have invited two inspiring keynotes, both around the theme of darkness. The first Keynote speaker is Paul Bogard, author of the brilliantly written book The End of Night: Searching for Natural Darkness in an Age of Artificial Light. His testimony on behalf of the dark presents the perfect start to the evening's social event: as darkness sets in, we will be sharing a delightful dinner, heart-warming light experience and a vibrant ambiance, which should flow naturally into your GLOWNEXT experience.

On Tuesday morning, Steve Fotios, Professor of Lighting and Visual Perception at the University of Sheffield and renowned expert in the field chooses the perspective of the lonely pedestrian at night as he discusses the sense and nonsense of current research practice – and its implications - in street lighting. Please note that Steve is also one of the speakers at the Holst symposium on the TU/e campus on the Thursday following our event.

Our ever-growing conference committee is proud to present this intensive program. We wish you an inspiring conference!

Yvonne, Mariëlle, Femke, Antal, Ingrid, Laura, Indre, Parisa, Andre, Daniel, Leon, Anne, Karin, Mariska, and Wijnand,

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KEYNOTE LECTURE

The end of darkness?

Paul Bogard

James Madison University in Virginia, USA

Introduction

Night's natural darkness is vitally important for our physical, psychological, and spiritual health. What are we losing as we lose this darkness? How can we protect and restore night's natural darkness in an age of artificial light? In this presentation, author Paul Bogard explores the value of darkness and the threats from light pollution to human health and the health of the world around us.

Bio

Paul Bogard is author of The End of Night: Searching for Natural Darkness in an Age of Artificial Light, and editor of Let There Be Night: Testimony on Behalf of the Dark. He is a professor of creative writing and environmental literature at James Madison University in Virginia, USA.

KEYNOTE LECTURE

Lighting for pedestrians: are we measuring the correct response?

Steve Fotios

University of Sheffield, United Kingdom

Introduction

Lighting in residential roads is designed primarily to meet the needs of pedestrians and for these the critical visual tasks include evaluation of perceived safety and evaluations of other people. The establishment of design criteria requires an understanding of how variations in lighting characteristics such as luminance, spectrum and uniformity affect how well these tasks can be carried out. This presentation will discuss problems associated with experiments that aim to measure these responses, a discussion of experimental bias and understanding of pedestrians needs. For example, while several studies have investigated facial recognition, reporting the distance at which facial recognition was achieved under certain conditions, they failed to question if that distance was the one at which such judgements are desirable, and that has implications for determination of whether variations in lighting are significant. The presentation will also discuss evidence of road lighting and crime. The aim of these studies is to provide empirical evidence to support lighting guidance, somewhat limited in current standards, thus to inform the compromise between visual needs and energy consumption.

Bio

Steve is Professor of Lighting and Visual Perception in the school of architecture at the University of Sheffield where he leads research of lighting and human factors through funding from EPSRC, the Department for Transport, and lighting industry. His strong emphasis on methodology lead to the international research methods workshop Lumenet for PhD students, and the formation of CIE technical committee TC1.80 which established best practice guidance for research of spatial brightness.

The effect of phase on flicker visibility

M. Perz[1], I. M. L. C. Vogels[1], D. Sekulovski[1] & I. Heynderickx[1,2]

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Introduction

Light emitting diodes (LEDs) are revolutionizing the lighting domain because of a number of unique advantages they offer. LEDs provide long operating lifetimes, low power consumption and they are build using environmentally friendly materials (Schubert & Kim, 2005). They also allow for almost full control of their spectra, and their small size provides additional spatial possibilities. Another unique capability of LEDs is their fast response to changes in the driving current. This characteristic can be used to easily control the light output, for instance by rapidly switching the digital signal on and off to simulate a varying voltage. This control scheme is called pulse width modulation (PWM). However, improper selection of the driving parameters, but also dimming of the LEDs or voltage fluctuations in the mains, may result in visible temporal artifacts in the light output, such as flicker, the stroboscopic effect or the phantom array effect (Frier & Henderson, 1973; Hershberger, 1987; Kelly, 1961). Several solutions to reduce the occurrence of these artifacts are known, but they usually require electronics with increased cost and size. Therefore, many LEDs introduced on the market still suffer from temporal artifacts, which can result in visual discomfort and possibly negative health effects (Wilkins et al., 2010). It is therefore important to better understand the causes for the occurrence and visibility of the temporal artifacts.

Flicker is the most studied, but also the most critical artifact. It is defined as the perception of visual unsteadiness induced by a light stimulus whose luminance or spectral distribution fluctuates with time, for a static observer in a static environment. These fluctuations may include periodic as well as aperiodic variations (i.e. transient effects). Flicker visibility depends on many parameters, including the temporal frequency of the light changes, the shape of the waveform and the magnitude of change (De Lange, 1961; Kelly, 1961). A number of measures have been developed in the past with the aim of quantifying flicker perception. The Illuminating Engineering Society of North America (IESNA) developed the Flicker Index (FI). It is defined as the area above the average light output divided by its total area for a single cycle of the fluctuation. The Flicker Index can vary between 0 and 1 and IESNA recommends that for good lighting quality it should remain below 0.1 (IESNA, 2000). Another measure used to quantify flicker perception is the Flicker Percent. In literature, it is also referred to as the modulation depth (MD) and it is defined as follows:

$$\boldsymbol{MD = \frac{L_{max} - L_{min}}{L_{max} + L_{min}} * 100\%} \qquad (1)$$

Where L_{min} is the minimum luminance and L_{max} the maximum luminance emitted by the light source in one cycle of the fluctuation. Even though both the Flicker Index and the modulation depth are widely used criteria in industry and research, neither of them can accurately predict the visibility of all types of flicker. This is due to the fact that these measures do not account for the effect of frequency. Further, De Lange (1961) studied the perception of flicker of differently shaped waveforms; among others a sinusoidal modulation and a square wave modulation. He found that the ratio of the visibility threshold of a square wave over a sine wave is 0.79, while the ratio predicted by the Flicker Index is 0.6. On the other hand De Lange used a flickering stimuli consisting of a 2° test-field in central vision and for the measure to be suitable for general lighting application a stimuli should embrace the entire visual field. More recently, another measure was developed, namely the Flicker Visibility Measure (FVM), which is defined as follows:

$$FVM = \sqrt[2.4]{\sum_{m=1}^{\infty}\left(\frac{C_m}{T_m}\right)^{2.4}} \begin{cases} < 1 \; not\ visibile \\ = \mathbf{1\ just\ visibile} \\ > 1 \; visible \end{cases} \quad (2)$$

where C_m is the amplitude of the m-*th* Fourier component of the waveform and T_m is the flicker visibility threshold for a sine wave at the frequency of the m-*th* Fourier component expressed in terms of modulation depth (Perz, Vogels, & Sekulovski, 2013). FVM, contrary to FI and MD, fully accounts for the effects of frequency and wave shape. However, FVM assumes that there is no effect of the phase difference between the individual frequency components on flicker visibility. This means that two waveforms consisting of the same two frequency components, but with a different phase shift between the components would yield the same FVM value. On the other hand, a change in phase does have an effect on the shape and the modulation depth of the waveform.

The aim of this study is to test the validity of the FVM to predict flicker visibility for waveforms with different phase shifts between the frequency components. Therefore, an experiment was performed to measure the effect of phase difference between the frequency components of a waveform on the visibility of flicker.

Method

The visibility threshold of flicker for four waveforms consisting of two frequency components was determined. Each waveform was presented at two values of the phase difference. Hence, the experiment consisted of a full-factorial 4 (Frequency Combination) x 2 (Phase shift) within-subject design.

Setup

Two typical office luminaires were equipped with LEDs. Each luminaire contained four rows of cool white LEDs and four rows of warm white LEDs. The luminaires were mounted in a frame just below the ceiling, at a height of 2.5 m, next to a white wall and they were separated by 0.8 m. The voltage of the LEDs was controlled by a programmable waveform generator via a laptop. Proper calibration of the setup was ensured by measuring and transforming the relation between voltage and illumination. The color temperature of the light was 6500K. There was a fixation cross on the wall and the light level measured at the fixation cross was 58 cd/m^2.

Stimuli

Waveforms consisting of two frequency components with equal amplitudes, were used as lighting conditions, see Table 1. Their modulation depth was varied between 0 and 5%. For each frequency combination two values of the phase difference were chosen such that the resulting MD of this waveform was either relatively small (depicted as Phase 1 in Table 1) or relatively large (depicted as Phase 2 in Table 1). The light stimulus was covering the entire visual field of the participant.

Tab. 1: Frequency combinations measured in the experiment, together with their phase shift

Frequencies (Hz)	Phase 1 (π)	Phase 2 (π)
1. 10Hz 15Hz	-0.25	1.05
2. 10Hz 20Hz	1.5	0.1
3. 10Hz 30Hz	0	1
4. 20Hz 60Hz	0	1

Procedure

Participants were welcomed and seated on a chair 1 meter from the wall. They read through and signed the consent form, confirming their eligibility for the study. First, they were given oral instructions on the experimental procedure and they were thoroughly explained what flicker was. Additionally, they were given a short demonstration of the test. Participants were instructed to look at the fixation cross at the wall and indicate on a portable numerical keyboard whether the light was flickering or not. They were instructed to press the right arrow key when they observed flicker, and the left arrow key otherwise. For each of the lighting conditions, the visibility threshold was measured using a staircase method (Engeldrum, 2000). This means that the modulation depth that was presented in a given stimulus depended on the response of the participant to the preceding stimulus. The starting modulation depth was set randomly across participants, but always large enough, so that flicker was clearly visible. The modulation depth was decreased if a participant indicated that flicker was visible and otherwise increased. The modulation depth at which the answer changed from ”yes” to ”no” or from ”no” to ”yes” was called a reversal point. The visibility threshold at the probability of 50 % correct was obtained as an arithmetic mean of four last reversal points for each lighting condition (Rose, Teller, & Rendleman, 1970). In order to prevent flicker adaptation, constant light of the same luminance and color temperature was presented after each stimulus for 4 seconds. All staircase stimuli for all lighting conditions were intermingled and presented in a random order, different per participant. The experiment took about half an hour per participant.

Participants

We excluded participants that might be oversensitive to flicker, meaning that we only included participants that did not suffer from epilepsy nor had a family history of epilepsy, and that did not suffer from migraines. The experiment included 14 males and 8 females with their age ranging between 19 and 32 years.

Results

Figure 1 shows the mean visibility thresholds expressed in terms of modulation depth (Equation (1)) (left) and in terms of the Flicker Visibility Measure (Equation (2)) (right) for the four complex waveforms with different phase difference between the frequency components. Black circles represent the thresholds of the waveform with the first phase shift (corresponding to a small modulation depth); whereas red crosses represent the second phase shift (corresponding to a larger modulation depth).

Figure 1 suggests that the visibility thresholds, expressed in terms of modulation depth, are always larger for the waveforms with the second phase shift as compared to waveforms with the first phase shift. An ANOVA was performed with Phase and Condition as fixed factors, Participant as random factor and modulation depth as dependent variable. It was found that Phase had a statistically significant effect on modulation depth ($F(1,126)=7.2$, $p<0.01$). Both Condition and Participant were found not to be significant ($F(3,126)=0.18$, $p=0.90$ and $F(18,126)=1.17$, $p=0.30$ respectively). Further, Figure 1 shows that the visibility threshold expressed in terms of FVM is the same for both phase shifts, for the second composite waveform (10 Hz and 20 Hz).

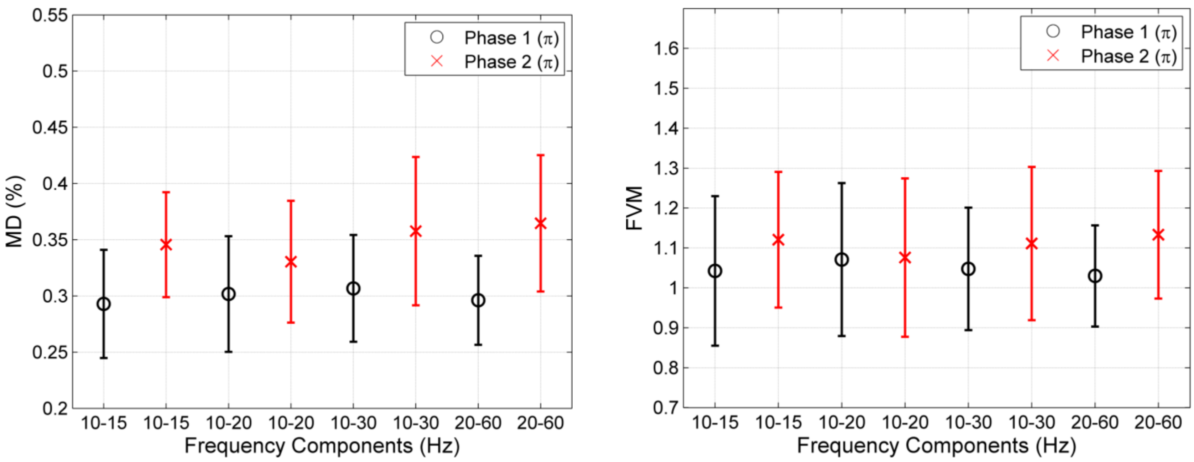

Fig. 1: Mean visibility thresholds expressed in terms of modulation depth (left) and in terms of Flicker Visibility Measure (right) for four different complex waveforms with two different phase shifts. The error bars correspond to the 95% confidence interval of the mean.

For all the other conditions the visibility threshold for the waveforms at second phase shifts are slightly larger compared to the first phase. An ANOVA showed that none of the variables: Condition, Phase and Participant had a significant effect on FVM ($F(3,126)=0.004$, $p=1$, $F(1,126)=1.05$, $p=0.30$ and $F(18,126)=1.52$, $p=0.10$ respectively). Further, a t-test was performed to compare the FVM values at different phases to the expected value of 1. It was found that these effects were not significant (first phase: $t(75)=0.13$, $p=0.90$, second phase: $t(75)=0.28$, $p=0.78$)

Discussion

It was previously reported that the commonly used measures, Flicker Index and Flicker Percent (modulation depth) cannot predict the visibility of temporal light artifacts of all kinds of waveforms. This is because both measures are based on the analysis of a single waveform period, and consequently neither is able to account for the effect of frequency. It was also demonstrated that the ratio of visibility threshold of a square over a sine waveform at the same frequency cannot be predicted by the Flicker Index (De Lange, 1961).

Nowadays, LEDs introduced to the market are characterized by light output with different kinds of regular and irregular waveforms at various frequencies, and therefore it is important to correctly quantify temporal light artifacts. The Flicker Visibility Measure (FVM) is a new measure, which can predict flicker visibility of all kinds of waveforms with different shapes and frequencies. It was developed for stimuli covering the entire visual field, to make it suitable for general lighting application. In the current study, an experiment was conducted with the general aim of testing the validity of FVM by investigating the effect of phase difference between the frequency components on the flicker visibility. It was shown that the visibility threshold expressed in terms of modulation depth depends on the phase difference between the frequency components. This means that it is not possible to set one general limit for the visibility threshold of flicker in terms of modulation depth. Therefore, we confirm that modulation depth is not a suitable measure to consistently quantify flicker visibility. On the other hand, the thresholds expressed in terms of Flicker Visibility Measure remained constant, regardless of the phase shift. The FVM values at threshold were not significantly different from the expected value of 1, which confirms that FVM is a valid measure to predict flicker visibility. Recently, an experiment was conducted, in which the visibility of flicker of real life waveforms were compared with several measures quantifying flicker. The experiment also showed the advantage of FVM over the other measures. The results of this experiment will be discussed at the conference.

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Visibility of spatial chromatic contrast for lighting applications

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Introduction

LED technology offers many opportunities to create radically new luminaire designs at substantial lower cost and reduced environ-mental impact compared to conventional lighting technologies. However, a major issue of LED luminaires is the color non-uniformity of the light. The main reason is the inherent variation in die chromaticity and lumen output during the production process of LEDs. Though within a luminaire special optics may mix the light of individual LEDs to make the color variation unperceivable, color differences can still be perceived between luminaires with the same color specs. In order to determine the allowed variation in chromaticity of LEDs and the minimum requirements of the (usually expensive) optics, one need to understand the perception of spatial color differences.

Several industrial standards exist for the color consistency of a light source. All these standards are based on the research of MacAdam (1942). He measured the standard deviation of making color matches between a reference color and a test color presented in two adjacent semicircles of 2°. The stimuli were surrounded by a uniform field with a color temperature of 6500K at 50 cd/m^2. The standard deviations of color matching were found to depend on the direction of the color change and formed an ellipse in the CIE 1931 xy chromaticity space. The size and orientation of the ellipse varied with the chromaticity of the reference. MacAdam mentioned that the just noticeable color difference between two colors corresponds to three times the size of the MacAdam ellipse. Based on these results, the CIE 1976 u'v' chromaticity space was introduced as an attempt to achieve a perceptually uniform space. More recently, new metrics have been proposed to quantify the visibility of both chromaticity and luminance differences, e.g. the CIEDE2000 (Sharma et al., 2005). Standards on color consistency specify the allowed chromaticity variation of a light source in terms of the number of MacAdam ellipses, e.g. for Solid State Lighting (ANSI C78.377-2011) the maximum chromaticity difference of a light source should be smaller than six times the size of the MacAdam ellipse. It is quite remarkable that the industrial standards are based on the results of MacAdam. First, the data of MacAdam was based on the observations of only one participant. Secondly, the conditions do not resemble real lighting applications. Besides, many factors have been found to influence the visibility of color differences, such as the luminance of the stimuli (Yebra et al., 2001), the size and distance between the stimuli (Seuntiens, 2013) and the adaptation state of the eye (Opstelten et al., 1987).

More interesting for lighting applications is the visibility of chromatic contrast in regular chromatic patterns, which also depends on many factors, such as the spatial frequency (Mullen, 1985), the direction of the chromaticity change (Mullen, 1985), the shape of the waveform (van der Horst, 1969), the luminance of the chromatic pattern (Rovamo et al., 2001) and the velocity of the pattern on the retina (Kelly, 1983). Most of these studies used isoluminous chromatic gratings, made by superimposing two mono-chromatic gratings (red and green or blue and yellow) whose luminance varied sinusoidally 180° out of phase. The visibility of chromatic contrast is usually expressed as the luminance contrast of one of the chromatic components. Most studies found that the just visible contrast is constant at low spatial frequencies but increases at high frequencies.

Unfortunately, the results of these studies cannot be used for lighting applications since the chromaticity variation of a light beam cannot be expressed in terms of luminance contrast. Moreover, the chromaticity can vary in any direction (not only along red-green or blue-yellow), in any regular or irregular way and ranges from low frequency variations for spots to high frequency variations for wall-washers. In order to define more accurate guidelines for the color consistency of LEDs, a new metric has to be developed to quantify the visibility of chromatic contrast for any type of chromaticity variation in a light beam. This paper presents the first step towards this goal. An experiment is described that determines the visibility of chromatic contrast for sinusoidal modulations as a function of spatial frequency and direction of the chromaticity change.

Method

Stimuli

Spatial chromatic patterns were presented on a calibrated 10-bit 27” NEC display with 2560 x 1400 pixels. The chromaticity varied sinusoidally in CIE 1976 u’v’ chromaticity space at a constant luminance of 108 cd/m^2. The chromaticity was modulated at a base color with a correlated color temperature of 2600K, 3800K or 5700K at six spatial frequencies (0.15, 0.3, 0.5, 1.5, 3 or 5 cycles per degree) along four possible directions (Figure 1). The maximum color difference of the pattern ranged from 0 to 0.01 Δu’v’, with steps of 0.0001 Δu’v’, and from 0.01 to 0.03 Δu’v’, with steps of 0.001 Δu’v’. The pattern had a size of 18° x 18° visual angle. In order to eliminate the possible use of edge information, the chromaticity difference was convoluted with a Gaussian shaped function. The background chromaticity of the screen was the same as the base color of the sinusoidal pattern. The pattern could be oriented either horizontally or vertically.

Participants

Six females and twelve males, all working in a research environment, participated in the experiment. Their age ranged from 19 to 38 years. All participants had a normal or corrected to normal visual acuity of 1 (as tested with the Landolt-C test) and normal colour vision (as tested with the Ishihara colour-blindness test).

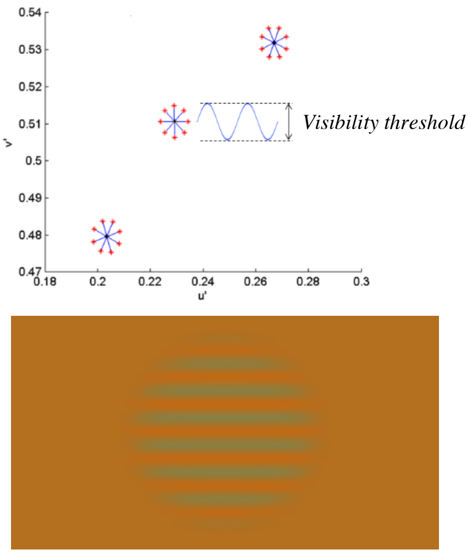

Fig. 1: Chromaticity coordinates of the three base colors and the four directions of the color change in the CIE 1976 u’v’ chromaticity diagram (top) and an example of a horizontal chromatic pattern (bottom).

Procedure

The experiment was divided over three sessions of about 30 minutes. In each session the visibility thresholds for all 24 conditions (i.e. 4 directions x 6 frequencies) of one base color were measured. Before participants started, their vision was measured and oral instructions were given on the experimental procedure. Participants were asked to sit on a chair and place their head in a chinrest at 1 meter in front of the display. Each session started with a homogeneous image with the same luminance and chromaticity as the base color of that particular session. Participants had to look at this image for 10 s to become chromatically adapted. After the adaptation image, a sinusoidal pattern was presented. Participants had to press the left key of a keyboard when the grating was oriented horizontally and the up key when the grating was oriented vertically. After each stimulus the adaptation image was presented for one second. This time the luminance was slightly lower in order to distinguish the image from the chromatic pattern.

Visibility thresholds were determined using the one-up/three-down weighted staircase method that converges to 75% correct responses. There was no reason to expect a response bias in the judgment of a horizontal or vertical grating. Research has shown inconclusive results on the effect of orientation on chromatic contrast sensitivity (e.g. Murasugi and Cavanagh, 1988). The first stimulus had a maximum color difference of 0.03 Δu'v', which is clearly visible to most people. The modulation that was presented next depended on the response to the preceding stimulus. In order to accelerate the converging process, the step size was changed after each two reversal points: 10, 5, 2 and 1. In total, eight reversal points were measured and the last four reversal points were averaged to determine the visibility threshold. The staircases of the 24 conditions were intermingled and presented in a random order.

Results

For each combination of base color, frequency and direction, the average visibility threshold was calculated across participants. An ellipse was fitted through the chromaticity coordinates of the average visibility thresholds of the four directions using the method of least squares (Figure 2). The error of the fit was calculated as the average Euclidian distance between the ellipse and the data points. The maximum error was 1.0×10^{-6} Δu'v', which corresponds to an extremely high goodness of fit. Figure 2 shows that the size and orientation of the ellipse depends on the base color and the spatial frequency of the chromatic pattern. For comparison, also the MacAdam ellipse for the corresponding base color is presented.

Figure 3 depicts the same data, yet now the visibility threshold is plotted as a function of spatial frequency for each combination of base color and direction. The figure shows visibility threshold slightly decreases from 0.15 cpd to 0.3 cpd. After this point, the threshold increases with frequency.

A Linear Mixed Model was performed to test for significant effects of the independent variables base color, frequency and direction. All main and interaction effects were found to be significant at a significance level of 0.05. A posthoc analysis for the effect of base color showed that thresholds are significantly smaller for 2600K compared to 5700K, though the difference is quite small. A posthoc analysis for frequency revealed that all spatial frequencies are significantly different from each other, except for the difference between 0.15 cpd and 0.5 cpd. This means that the decline in threshold at 0.3 cpd is significant. Because the absolute angles of the four directions were different per base color, no posthoc analysis was performed for the factor direction.

Discussion

The results of the experiment reveal that the visibility of chromatic contrast of a sinusoidal pattern depends on the base color of the pattern, the spatial frequency and the direction of the chromaticity modulation in the CIE 1976 u'v' chromaticity space. The effect of direction can be represented by an ellipse. The size and orientation of the ellipse vary with spatial frequency and base color. The results of MacAdam (1942) for two adjacent color patches at a background of 6500K resemble most the thresholds at a spatial frequency of 1.5 cpd.

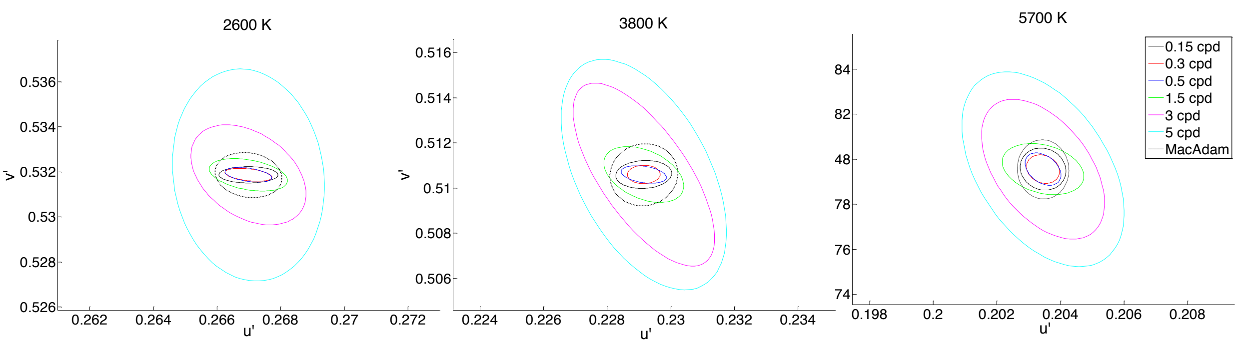

Fig. 2: Ellipses fitted through the chromaticity coordinates of the average visibility thresholds of the four directions for each base color and each spatial frequency (data points not shown).

The effect of spatial frequency follows a bandpass function; the visibility threshold is lowest at 0.3 cpd and increases for lower and higher spatial frequencies. This is not in accordance with the results found by other researchers (e.g. Mullen, 1985; Rovamo et al., 2001). Although they expressed the threshold as the luminance contrast of one of the two chromatic components, this would not change the shape of the sensitivity function. On the other hand, Kelly (1983) did find a bandpass function for isoluminous chromatic gratings. The decrease of sensitivity for lower frequencies might be related to the number of cycles of the grating. The visibility of luminance contrast is known to degrade below five cycles (Savoy and McCann, 1975). In our study the only frequency with less than five cycles was 0.15 cpd. This might explain why the threshold increases at the lowest frequency.

The results demonstrate that MacAdam ellipses are not sufficient to accurately describe the visibility of chromatic contrast for realistic lighting applications, ranging from wall washers with high frequency variations to spots with low frequency variations. Depending on the type of variation, the color difference might be much more or much less visible than specified by the current standards. The data presented in this paper is an important first step towards the development of a more accurate standard. In the near future, more data will be collected for non-sinusoidal chromatic patterns.

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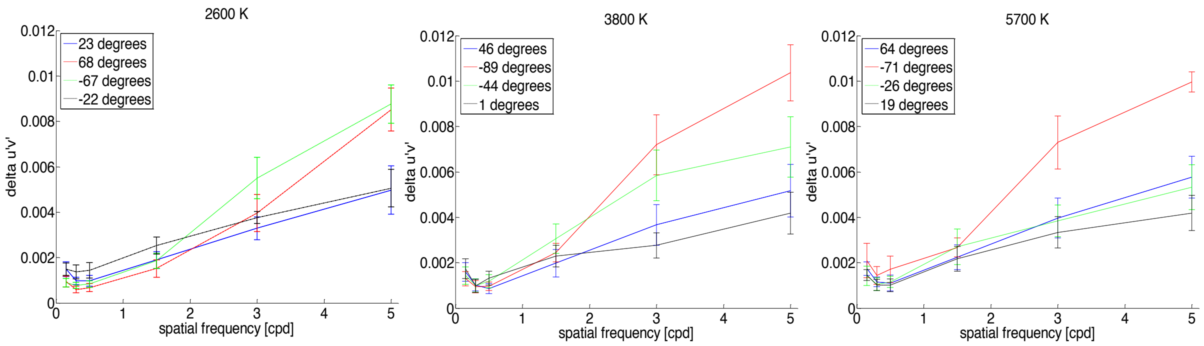

Fig. 3: Visibility thresholds expressed as Δu'v' as a function of spatial frequency for each base color and each direction of change. Error bars correspond to 95% confidence intervals.

Effect of non-uniformity and luminance contrast on the acceptability and the sensation of discomfort of the source brightness

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Introduction

Discomfort glare is defined by the International commission on illumination (CIE) as "glare that causes discomfort without necessarily impairing the vision of objects" (CIE, 1987) and by the Illuminating Engineering Society of North America (IESNA) as "a sensation of annoyance or pain caused by high luminance in the field of view" (IESNA, 2000). Already since 1925, researchers have attempted to quantify the amount of discomfort glare (Luckiesh & Holladay, 1925), but even now, the physiological and psychophysical mechanisms are not fully understood.

The CIE proposed the Unified Glare Rating (UGR) for the assessment of discomfort glare in interior lighting (CIE, 1995), originally developed for uniform light sources. With growing market share of led luminaires for interior lighting, problems arise for the determination of discomfort glare for non-uniform light sources. As an attempt to tackle some problems, the CIE developed a method for small, large and complex sources (CIE, 2002), but discussion about the validity remains, as stated by a CIE reporter (CIE, 2009):

'Your reporter has referred to UGR as a "leaky boat". Is it time, therefore, to develop a new system rather than to try further patch the "leaks"?'

Therefore, discomfort glare sensation from non-uniform light sources cannot be correctly assessed with traditional glare evaluating methods (Cai & Chung, 2013; Kasahara et al., 2006; Scheir et al., 2014; Sendrup, 2001; Takahashi et al., 2007; Waters et al., 1995) and the CIE stated that High Dynamic Range (HDR) luminance maps should be used to predict discomfort glare (CIE, 2013).

While the average source luminance remains constant, discomfort glare sensation for non-uniform luminaires seems to be larger than for uniform luminaires (Kasahara et al., 2006; Takahashi et al., 2007). Kasahara et al. (2006) found that by decreasing luminance contrast and by increasing the number of leds in the same area, discomfort glare decreases.

Most studies on discomfort glare are performed in laboratory settings with a single stimulus positioned near the line of sight. Observers need to use a chinrest and have to look into a box or specially designed apparatus (Cai & Chung, 2013; Eble-Hankins & Waters, 2009; Kasahara et al., 2006; Kim et al., 2008; Kim et al., 2009; Kim & Kim, 2010, 2011; Sendrup, 2001; Takahashi et al., 2007; Waters et al., 1995). In real office settings, luminaires are rarely observed directly but are positioned at the ceiling (Geerdinck et al., 2014).

It's clear that a valid assessment of discomfort glare for non-uniform light sources in a realistic setting based on luminance maps becomes essential. The present study investigates the effect of non-uniformity and luminance contrast on the acceptability and sensation of (dis-)comfort of the source brightness.

Method

Observers were asked to take place in a 3m by 6m room. The walls are painted in neutral gray with a reflection coefficient of 20%. The back ground luminance is highly uniform at 3cd/m^2 and is controlled by dimmable wall washers.

A 60cm by 60cm test luminaire is designed to fit standard dimensions and consists of a 5 by 5 matrix of dimmable led packages behind a diffusor. The wall washers and led packages are controlled with a

DALI/KNX IP gateway (SchneiderElectric, 2012). The luminaire is placed in the ceiling at 1.30m above eye level and is seen at an angle of 20° above the line of sight.

Non-uniformity is controlled by introducing contrast: a central zone of uniform high luminance surrounded by a uniform low luminance area (Figure 1). The central zone is circular with diameter of 65 mm, comparable with the maximum size of the R63 reflector light standard.

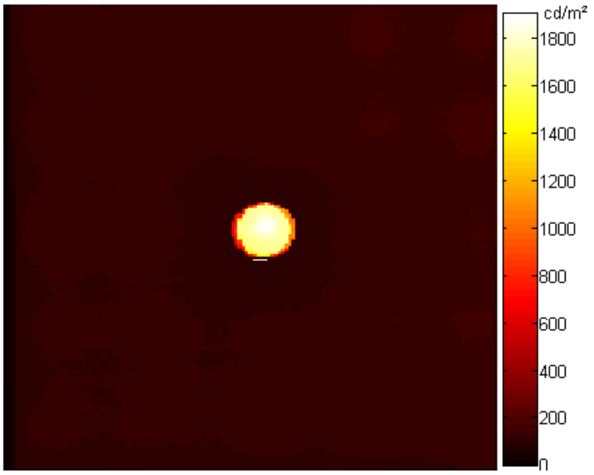

Fig 1: Luminance map of an arbitrary stimulus: a central zone of uniform high luminance level with a uniform low luminance surround.

Three factors are controlled: (1) the luminance of the central zone (L_{center}), (2) the average luminance of the luminaire as a whole (L_{av}) and (3) the uniformity ratio of the low luminance surround ($L_{surround}$) with respect to the high luminance central zone:

$$U = 100\frac{L_{surround}}{L_{center}}. \quad (1)$$

To determine the stimuli, high resolution luminance maps were measured with a calibrated LMK 98-4 luminance camera (TechnoTeam, 2012) mounted on a RiGO 801 near-field goniometer (TechnoTeam, 2009). The diffusor luminaire is Lambertian. The source luminance level is independent of the viewing angle or orientation of the luminaire and differences in luminance level due to change in orientation or viewing angle are minimal. Luminance measurement at one specific angle can be extended to other viewing angels or luminaire orientations without loss of accuracy.

Seven stimuli were chosen (see Table 1). Stimuli 1 and 2 have a constant average luminance level, stimuli 3 and 4 a constant uniformity ratio, stimuli 5 and 6 a constant low central luminance level and stimuli 2 and 7 a constant high central luminance level.

Tab.1: Presented stimuli.

Stimulus	Case	L_{av}(cd/m^2)	U	$L_{central}$(cd/m2)
1	L_{av}=Ce	361.9	7.4	4360
2		365.8	0.14	36677
3	U=Ce	128.0	6.2	1799
4		2262	6.3	31295
5	$L_{central}$=Low	15.6	0.14	1570
6		115.0	6.5	1557
2	$L_{central}$=High	365.8	0.14	36677
7		2354	5.4	36969

While presenting the stimuli, the observers fixate at a point on the wall at eye level and are asked to rate the brightness of the luminaire. In most studies (Cai & Chung, 2013; Eble-Hankins & Waters, 2009; Kasahara et al., 2006; Kim et al., 2008; Kim et al., 2009; Takahashi et al., 2007), observers are asked to assess discomfort glare using a single scale based on the criteria of Hopkinson (Hopkinson, 1950, 1957). Problems arise when using Hopkinson's criteria on a one-item scale (Geerdinck, 2012). It was not the intention of Hopkinson to use the criteria simultaneously on a one-item scale, but each criterion needs to be assessed separately. For the present study, observers are asked to rate the source brightness for 2 criteria: acceptability and comfort level. Both are separately rated on a 5 point scale (e.g. -2 = highly uncomfortable, -1 = slightly uncomfortable, 0 = neutral, 1 = slightly comfortable, 2 = highly comfortable). For each criteria, the median is used for analysis. 13 observers took part in the study.

Results

Comfort and acceptability rating for all 13 observers for stimulus 4 is shown in Figure 2. The inter-observer variability for the assessment of the acceptability and comfort level of the source brightness is large with values ranging from -2 up to +2 for the same stimulus.

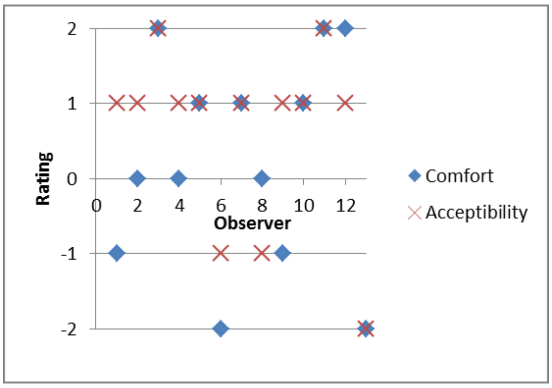

Fig. 2: Acceptability and comfort rating for stimulus 4 for all 13 observers.

In Figure 3 Acceptability (left) and comfort level (right) is plotted against the average luminance level (top) and uniformity ratio (middle). The position, source size or background luminance remains constant. Both average source luminance and uniformity ratio are, on their own, poor indicators for the acceptability and comfort level of the brightness perception.

Acceptability and comfort level generally decrease as average source luminance increases or uniformity decreases. Fitting linear curves results in R-square values of 0.6 down till 0.04 for the acceptability and comfort level respectively. Therefore, a complex combination of both uniformity ratio and average luminance level would be needed for the assessment of discomfort glare:

$$Discomfort\ glare \sim f(L_{av}, U). \quad (2)$$

Alternatively, the acceptability and comfort level is shown against the luminance level of the central zone (Figure 3, bottom) and seem to decrease as the central luminance level increases, regardless of the uniformity ratio or average luminance level. Fitting linear curves results in R-square values of 0.99 and 0.94 for the acceptability and comfort level respectively. Note that the

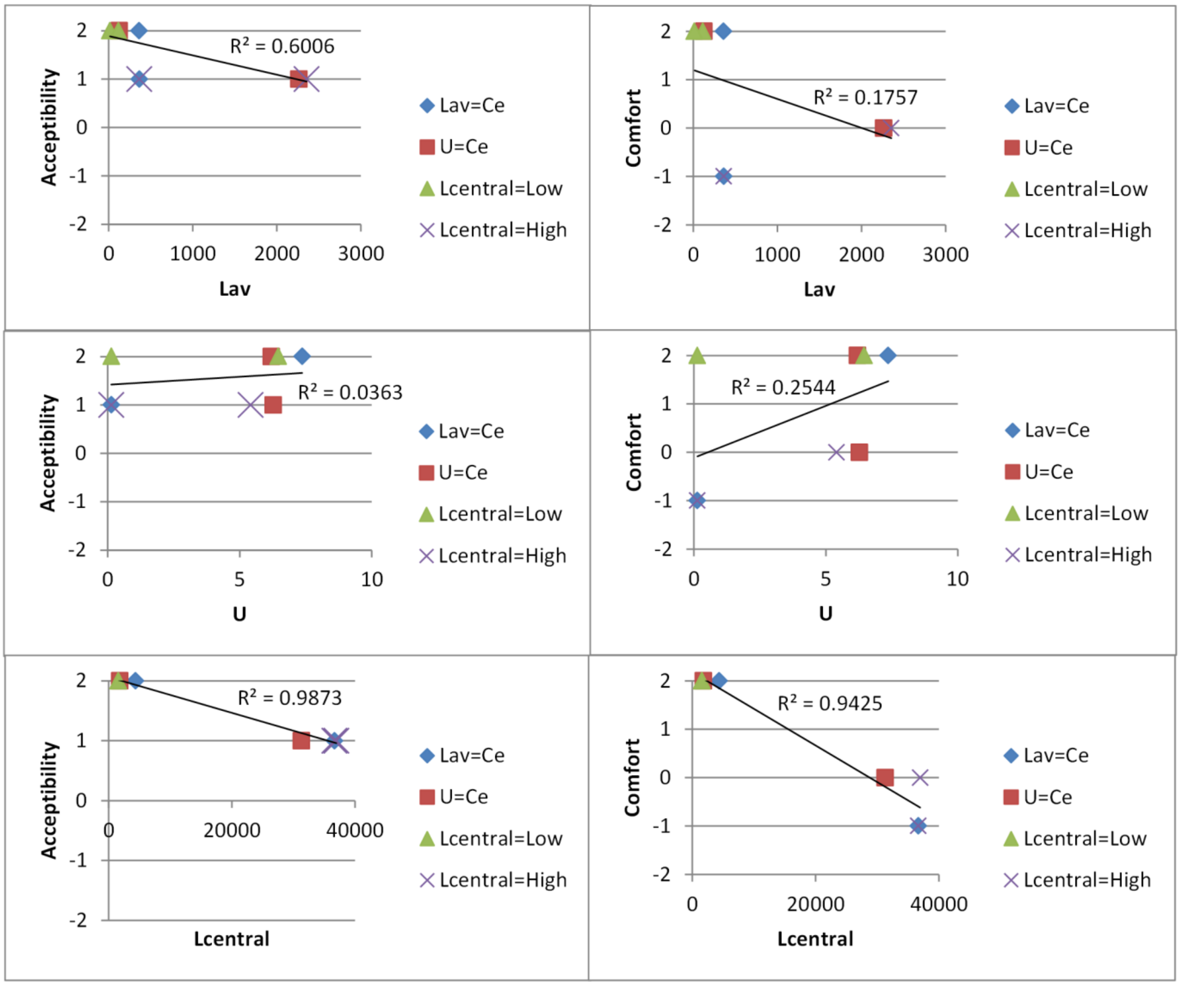

Fig. 3: Acceptability (left) and comfort level (right) versus average luminance (top) uniformity ratio (middle) and luminance level of the central zone (bottom).

central zone has the highest luminance level in the luminaire. In this study, lower luminance areas are less relevant for the prediction of the acceptance and comfort level of the source brightness and equation (2) can be simplified as:

$$Discomfort\ glare \sim g(L_{central}). \quad (3)$$

Conclusion

Both average luminance level and uniformity ratio are, on their own and even without change in position or source size, poor indicators for the prediction of the acceptability or comfort level of the brightness of the light source.

On the contrary, in the present study, the highest luminance level $L_{central}$ is a better indicator for the prediction of acceptability and comfort level of the source brightness: acceptability and comfort level decrease as the central luminance increases, regardless of the uniformity ratio or the average luminance of the luminaire as a whole.

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Dark adaptation to spatially complex backgrounds

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Introduction

Visual adaptation enables the human visual system to perceive a large range of light intensities. In this paper we specifically address dark adaptation, i.e. the process where the visual system adapts from high to low light intensities.

For many years scientists have been interested in dark adaptation. In these studies the adaptation threshold (i.e., the lowest light level that can be detected) was measured as a function of adaptation time. Typically the following method was used: First, participants were pre-adapted to a bright light, and afterwards they were asked to detect a dim target (of a given luminance) in a dark background. The dependent measure was the time that was needed to detect the target.

The vast majority of studies discussed in literature researched dark adaptation to spatially uniform dark backgrounds. However, one may argue the applicability of such adaptation models to every-day activities as driving at night, where the field of view exists of mixed light and dark areas. For predicting adaptation thresholds for these kinds of activities it seems sensible to use models based on adaptation to complex backgrounds.

Yet, research regarding adaptation to spatially complex backgrounds has been very scarce. Plainis, Murray, and Charman (2005) showed that the adaptation threshold for detecting a target in a uniformly *lit* background was higher than detecting a target in a spatially uniform *dark* background. Moreover, Uchida and Ohno (2013) compared the adaptation threshold (for one point in time) of a spatially *uniform* lit background to a spatially *complex* background, and found that the threshold was higher for the spatially complex background, even though the total luminance level of both backgrounds was equal.

The exact reason why a spatially complex background leads to a higher adaptation threshold than a spatially uniform background of the same total luminance is unclear. A possible explanation may be found in the concept of veiling luminance. A bright source in a dark background may cast a veiling luminance over the entire field of view, leading to a reduction in contrast between the target and the background, which subsequently can lead to a decreased visibility. Still, it is unknown if veiling luminance fully accounts for the increased adaptation threshold, or if the intrinsic adaptation process itself is affected too.

The studies discussed so far led to initial insights in adaptation models which can be applied to real-life situations, but were still limited in the variations in backgrounds and did not describe the full range of adaptation times. Therefore we extended the existing research by investigating full dark adaptation to various spatially complex backgrounds. Additionally, we studied the underlying mechanisms that play a role in the adaptation process, and therefore researched why spatially complex backgrounds lead to higher adaptation thresholds than spatially uniform backgrounds.

To this end, we set up three experiments: Experiment E1 researched adaptation to a spatially uniform dark background, and served as a reference. Experiment E2 researched adaptation to dark backgrounds containing a bright luminescent source. Experiment E3 researched adaptation to backgrounds having different spatial luminance patterns, but with equal veiling luminance and, where possible, total luminance.

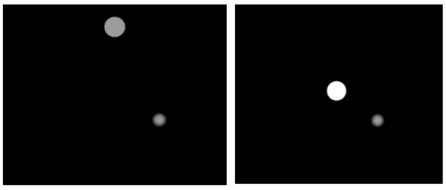

Fig. 1: Backgrounds as used in experiment E2. The left image shows the dark background, containing a target (depicted on the right side) and a subtle luminescent source. The right image shows the background with a target and a harsh luminescent source.

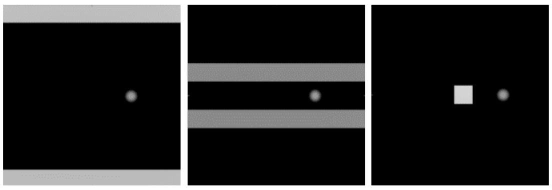

Fig. 2: Backgrounds (including target on the right side) as used in experiment E3. The left image shows a background having two bars at 9° visual angle from the target. The middle image shows a background having two bars at 2.7° visual angle from the target. The right image shows a background having a square in the center.

Methods

In all experiments a similar set up was used. All stimuli were shown on a high brightness display (FIMI-Philips 18" SXGA) of 20º by 20º visual angle, at a fixed viewing distance of 0.75 meters to the participants.

In all three experiments the participants were first adapted to a full white pre-adaptation field of 650 cd/m² for 1 minute. Directly after the pre-adaptation field disappeared, a target was shown at the left or the right side of the center of its background. We asked the participants to indicate whether the target was presented at the left or the right side, as soon as they saw the target. The dependent measure was the time that it took till participants were dark adapted enough to detect the target.

The design and independent variables were different per experiment and are explained separately per experiment.

For experiment E1, where adaptation to a dark background was measured, we used a full-factorial within-subjects design with one independent variable, i.e. the luminance of the target (having six levels, ranging from 11.19 cd/m² to 0.014 cd/m²). All target luminance levels were measured six times by all participants. In this experiment the target was presented in a spatially uniform dark background that only contained a small orientation point. The latter was introduced to make a valid comparison to experiments E2 and E3, where the spatial variations in luminance in the background may have served as orientation cue in the further fully dark environment.

For experiment E2, where we studied the effect of adaptation to a dark background containing a luminescent source, a mixed within- and between-subjects design was used. This design existed of two independent variables: the luminance of the target (similar to experiment E1), and variations to the luminescent source. As depicted in Fi2, two types of luminescent sources were researched: A) a 'subtle' source, located at 10° from the target, having a luminance of 10 cd/m² and B) a 'harsh' source, located at 5° from the target, having a luminance of 650 cd/m². All participants assessed ten target and background combinations, which were repeated six times.

For experiment E3, where adaptation to various spatial luminance patterns in the background was researched, also a mixed within- and between-subjects design with two independent variables was used. The first variable was the luminance of the target, having eight levels (ranging from 11.19 cd/m² to 0.014 cd/m²). The second variable was the spatial luminance pattern in the background, having three levels (as depicted in Fig 3). The first luminance pattern was made by adding a bar to the top and bottom of the otherwise dark background at 9° visual angle from the target. The second pattern was made by adding two bars to the dark background, located at 2.7° visual angle from the target. The third pattern was created by adding a square to the center of the dark background, in between the two potential positions of the target (located at 4.3° visual angle from each target). In all backgrounds of experiment E3 the veiling luminance (calculated by CIE (1999), equation 11) at the location of the target was 0.07 cd/m². The average luminance per pixel of the total background was 1.02 cd/m² for the second and the third luminance pattern but had to be higher (8.41 cd/m²) for the first luminance pattern in order to keep the veiling luminance constant. For those backgrounds having equal total luminance and equal veiling luminance, the contrast of the target and the background was equal. All participants assessed eight target and background combinations, which were repeated for four times.

Six participants (four males, two females) with an average age of 28 (Standard Deviation (SD) = 5.1) performed experiment E1. A total of thirty participants (17 males, 13 females) joined experiment E2. Their average age was 27.9 (SD = 4.7). Thirty participants (19 males, 11 females), having an average age of 28 (SD =7.3), joined experiment E3.

The data were analyzed with two Linear Mixed Models (LMM) using IBM SPSS Statistics 20. Firstly, we prepared the data by excluding incorrect measurements, and corrected for guessing. Following this we analyzed the data of experiment E1 compared to experiment E2 in LMM1 and the data of experiment E3 in LMM2. Further, we analyzed the correlation between veiling luminance and adaptation time for the backgrounds of experiment E2.

Results

The results of LMM1 (graphically depicted in Figure 3) showed significantly longer ($p < .001$) adaptation times for detecting a target in the background containing a harsh luminescent source compared to detecting a target in the background containing a subtle luminescent source and detecting a target in the spatially uniform dark background. No significant difference was found between detecting a target in the background containing a subtle luminescent source and detecting a target in the spatially uniform dark background.

The backgrounds studied in experiment E2 showed a high correlation ($r = 0.85$ for a target of 0.014 cd/m²) between the calculated veiling luminance and the measured adaptation time.

The results of LMM2 (see Fig 3) showed significant longer adaptation times ($p < .01$) for detecting a target in the background having a central square, than for detecting a target in the background having two bars at 9° distance. Further, we found a small increase ($p = .056$) in adaptation time for detecting a target in the background having two bars at 2.7° distance, compared to the background having the two bars at 9° distance from the target. No significant difference in adaptation time was found for detecting a target in the background having two bars at 2.7° distance from the target compared to the background having a square in the center.

Discussion

The present study researched the effects of spatially complex backgrounds compared to spatially uniform dark backgrounds on the dark adaptation process, and additionally studied the underlying mechanisms explaining potential differences.

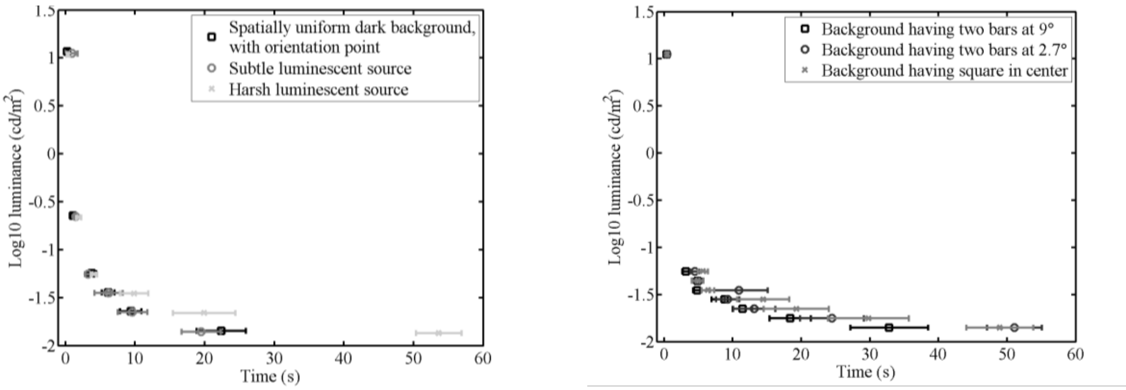

Fig. 3: Adaptation time (on x-axis, in seconds) for different luminance levels of the target (on y-axis, in cd/m²). The left figure presents the results of a spatially uniform dark background, of a background containing a subtle luminescent source, and of a background containing a harsh luminescent source. The right figure presents the results of a background having two bars at 9°, of a background having two bars at 2.7°, and of a background having a square in the center.

We found that a considerable longer adaptation time was required for detecting a target in a background containing a harsh luminescent source than for detecting a target in a spatially uniform dark background. Hence, this finding shows the importance of using models based on spatially complex backgrounds to predict adaptation thresholds for activities as driving at night, because models originating from spatially uniform backgrounds may lead to an overestimation of the visual systems' sensitivity. However, creating such models may not be trivial, since the present study also showed differences in adaptation time depending on the specific shape of the spatially complex background. Detecting a target in a background containing a harsh luminescent source resulted in a longer adaptation time than detecting a target in a background containing a subtle source. Moreover, adapting to a background containing a subtle luminescent source did not differ from adapting to a spatially uniform dark background. As discussed before, these effects may be explained by veiling luminance. Indeed, the correlation analysis confirmed a relationship between veiling luminance and adaptation time. Still, this analysis couldn't reveal whether veiling luminance was the only underlying factor explaining the differences in adaptation time.

Experiment E3 provided additional insights: it demonstrated that differences in adaptation time for detecting a target in a complex background could not exclusively be explained by veiling luminance, since different spatial backgrounds with equal veiling luminance yielded a different adaptation time. Therefore, the results showed that the intrinsic adaptation process was affected as well. More specifically, detecting a target in a spatially complex background having luminescent areas closer to the target (e.g., a background with bars at 2.7° distance from the target and a background with a square at 4.3° distance from the target) resulted in longer adaptation times than detecting a target in a background with bars at 9° distance. This effect was found despite the total luminance of the latter background being higher than the total luminance of the former backgrounds.

No difference in adaptation time was found for detecting a target in the background with the square and in the background with the bars at 2.7° distance. Veiling luminance and total luminance were equal for these two backgrounds, though other features, such as the surface area and location with respect to the potential target, were very distinct. Our first results indicate that these other features are less important in the adaptation process than veiling luminance and total luminance. However, our current experimental design was too limited to draw firm conclusions. Hence, more research is needed to better understand the full extent of the mechanisms underlying dark adaptation to spatially complex backgrounds, in order to create models that are fully applicable to activities as driving at night.

Conclusion

The results of the present study show that detecting targets in spatially complex backgrounds may lead to longer adaptation times than detecting targets in spatially uniform dark backgrounds. Therefore, we conclude that it is important to make use of models based on spatially complex backgrounds when predicting the adaptation threshold of a motorist driving at night. Moreover, we may conclude that besides an effect of veiling luminance, the intrinsic adaptation process itself seems to be affected by the specific shape of the spatially complex background.

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Spectrum and Scene Brightness Perception

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Introduction

Studies of scene brightness suggest that "cooler appearing" sources achieve higher brightness at lower illuminances than "warmer appearing" ones (CIE, 2014). And while a sense of safety appears to be correlated with perceived scene brightness in outdoor environments (Rea et al., 2009), "warm" appearance might be preferred for certain scenarios (Rea et al., 2009). With light emitting diode (LED) sources being customizable in terms of their spectral distribution, targeted research can lead to user oriented and energy efficient solutions for outdoor lighting.

A metric to design light source spectra based on the brightness perceptions they can elicit, could help in optimizing preferred spectral appearance and perceived brightness for different conditions.

Background

Light levels are measured using the photopic luminous efficiency function, V(λ). It converts energy measured in irradiance into light level measurements in illuminance. Brightness perception however is nonlinear and depends on factors like the field of view of the observer and the spectral composition of the light.

Many studies have been conducted to test scene brightness perception of light sources with different spectra. These empirical studies show that scenes lighted by sources with higher short-wavelength content are perceived as being brighter at the same light level than sources with lower short wavelength content (Rea et al., 2011; Fotios and Cheal, 2011; Bullough et al., 2014).

This might be due to contributions from photoreceptor types not included in V(λ): rod photoreceptors, which are active at light levels typical for outdoor nighttime lighting (Fotios and Cheal, 2011; Rea et al., 2004), and short-wavelength (S) cones (Rea et al., 2011; Bullough et al., 2014). Both rods and S-cones are sensitive to short wavelengths (below ~500 nm). Different brightness metrics have been suggested utilizing either rods (CIE, 2014) or S-cones (Rea et al., 2011) in addition to V(λ).

Some studies (e.g., Fotios and Cheal, 2011) show that not all spectra are well predicted by a metric using V(λ) and S-cones (Rea et al., 2011). Other studies, evaluating relative brightness at different light levels (between 2 and 100 lx) suggest a shift in spectral sensitivity toward increased short-wavelength sensitivity, which also increases in magnitude as a function of light level (Rea et al., 2011; Bullough et al., 2014). This shift is in the opposite direction of the Purkinje shift (Wyszecki and Stiles, 1982) mediated by increased contributions from rod photoreceptors as light level decreases, and which is incorporated into the scotopic/photopic (S/P) ratio underlying the system of photometry unifying photopic and scotopic responses recommended by the Commission Internationale de l'Éclairage (CIE) for characterizing visual performance in the mesopic range (CIE, 2010). In this system, spectral sensitivity shifts toward longer wavelengths as the light level is increased due to a relative decrease in contribution from rod photoreceptors.

Recently a new set of photoreceptors has been discovered, the intrinsically photosensitive retinal ganglion cells (ipRGCs) (Dacey et al., 2005), containing the photopigment melanopsin. Melanopsin has a peak spectral sensitivity near 480-490 nm (Dacey et al., 2005), similar to the peak sensitivity of rods (~500-510 nm) (Boyce, 2003). Some evidence suggests that ipRGCs contribute to scene brightness perception (Brown et al., 2012) and other visual responses (Spitschan et al., 2014).

Two experiments were conducted to assess whether perceived scene brightness at different light levels (~3-150 lux) could be modelled more accurately by including a contribution from ipRGCs to a brightness perception model based on V(λ) and S-cone contributions (Rea et al. 2011). A refined model based on these results was developed and tested in larger spatial context in a third follow-up experiment.

Experiments 1 and 2: Methods

Experiments 1 and 2 (Besenecker, 2013) utilized a customized LED light box, set-up in controlled laboratory conditions. Ten color-normal (Ishihara, 1960) participants compared two sequentially-presented large-field stimuli and reported which of the two appeared to be brighter. Judgments were recorded at two different light level ranges (low ~3-20 lux, and high ~20-150 lux).

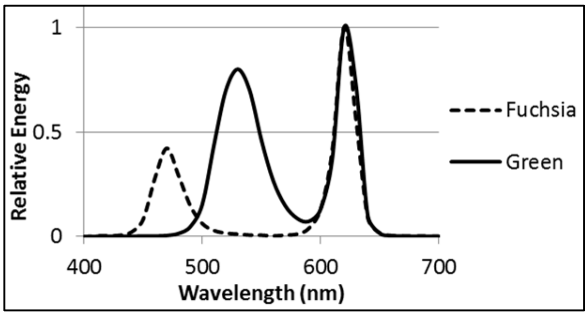

Fig. 1: Spectral Power Distributions Experiment 1

In Experiment 1, two stimuli of different color appearance were compared, each mixed by two LED sources, denoted Green (~525 and ~625 nm) and Fuchsia (~468 and ~625 nm). Four experimental sessions were conducted. Two used Green as a reference at 67 lux (high light level range) and at 12 lux (low light level range). Two used Fuchsia as a reference at 30 lux (high range), and at 6 lux (low range). The reference stimulus was compared to the respective test stimulus at five different light levels: one near the light level predicted to be equally bright using a 2011 brightness model (Rea et al., 2011), as well as two lower and two higher light levels in 30% increments. Each subject saw each sequential pair of stimuli six times, three times in reversed sequence.

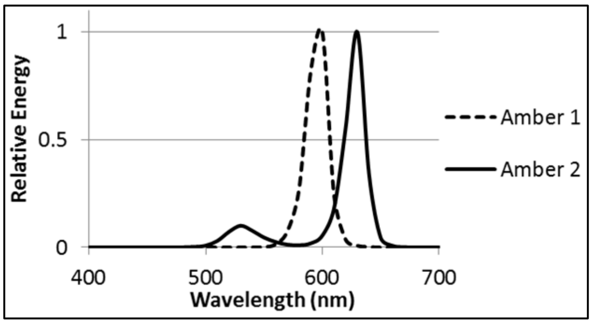

Fig. 2: Spectral Power Distribution Experiment 2 and Follow-up Experiment

Experiment 2 used two stimuli of almost identical color appearance, one using a single amber LED source (~600 nm) and the other mixed by two LED sources (~520 and ~630 nm), denoted, Amber 1 and Amber 2, respectively. The procedure in four sessions was the same as used for Experiment 1, with the difference that the reference stimulus was compared to the test stimulus only at three light levels, not five. Two sessions used Amber 1 as a reference (at 108 lux for the high light level range and 6 lux for the low range) and two used Amber 2 as a reference with the same values as Amber 1, since the model from Rea et al. (2011) predicted the brightness of both sources to be nearly equal (Rea et al. 2011). The respective test stimuli were presented at the same light level, one about 30% lower and one about 30% higher.

Each subject made thirty evaluations of which of the two stimuli looked brighter in each experimental session. The order in which the stimuli were presented was randomized. All stimuli varied in their relative ipRGC stimulation.

Experiments 1 and 2: Results

Using the experimental results from each session in both experiments the light levels were derived at which the respective test and reference stimuli would be judged brighter half of the time (i.e., at which they would appear equally bright). The overall results suggested an increased short-wavelength spectral sensitivity as a function of increasing light level (Besenecker, 2013).

Experiment 1 confirmed the significance of S-cone contributions. Experiment 1 and 2 confirmed that a metric of spectral sensitivity for scene brightness perception that included ipRGC contribution (Bullough, 2013) in addition to incorporating a shift in short-wavelength sensitivity at higher light levels, was able to predict the experimental data with significantly less error than a metric using cone input only (Rea et al., 2011).

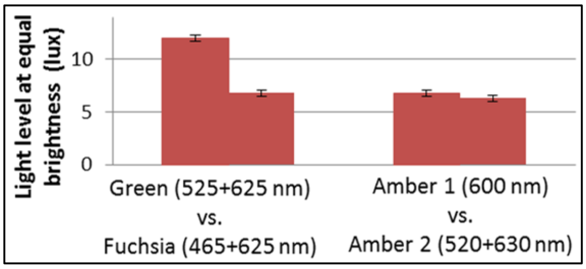

Fig. 3: Mean Results for Light Levels Being Evaluated Equally Bright in Experiments 1 and 2 at Low Light Levels (n=10)

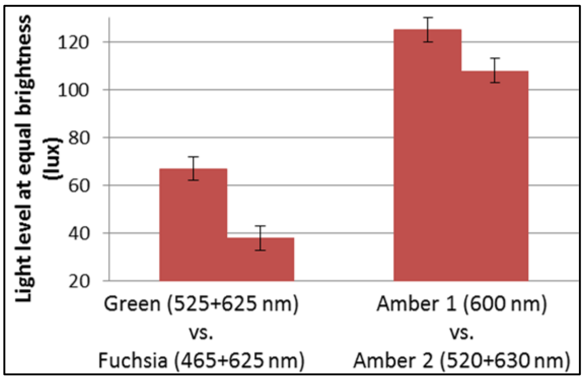

Fig. 4: Mean Results for Light Levels Being Evaluated Equally Bright in Experiments 1 and 2 at High Light Levels (n=10)

Tab. 1: Percentage Error between Predictions by Different Metrics and the Experimental Results, where V(λ)is the photopic luminous efficiency function, S(□) is a luminous efficiency function based on S-cone contribution, Mel(λ) is a luminous efficiency function based on the spectral sensitivity of the ipRGCs, g and k are respective coefficients that logarithmically increase as a function of photopic illuminance (in lux)

Provisional Brightness Metrics	Experiment			
	1 (high)	1 (low)	2 (high)	2 (low)
$B_1(\lambda) = V(\lambda) + g\,S(\lambda)$ Rea et al., 2011	35%	25%	16%	4%
$B_2(\lambda) = V(\lambda) + 0.6g\,S(\lambda) + 0.5Mel(\lambda)$ Bullough, 2013	17%	11%	10%	2%
$B_3(\lambda) = V(\lambda) + 0.3g\,S(\lambda) + k\,Mel(\lambda)$ Besenecker, 2013	3%	15%	4%	1%

The results suggested that ipRGCs might contribute to scene brightness perception at the light levels used. The experimental data also suggested that the relative contribution of ipRGCs might also increase as a function of light level. The metric was refined to account for that possibility (Besenecker, 2013).

Follow-up Study: Methods

To test the refined metric and further investigate brightness perception under sources with very similar color appearance, and while exploring the relevance of the prior findings for lighting application, a follow-up experiment was conducted.

Two off-the-shelf 4-channel color changing LED outdoor fixtures were chosen to illuminate two identical spatial scenes located side-by-side within a large room. Ten color-normal (Ishihara, 1960) participants compared a reference condition at a fixed light level of around 50 lux on a vertical wall to a test stimulus at various light levels higher and lower than the reference condition in 5% increments from 20 lux to 80 lux. The stimuli used were similar to the Amber 1 and Amber 2 sources used in Experiment 2.

Follow-up Study: Brightness

The results confirmed that the two similar-looking amber sources (Amber 1 vs. Amber 2) with different spectral compositions were evaluated differently in terms of brightness when they produced the same photopic illuminance. The source with higher ipRGC stimulation was judged as being brighter at an equal light level. The evaluations were consistent with model predictions using a brightness metric (Besenecker, 2013) that includes ipRGC contributions. The calculated percentage error between the model prediction and the experimental results were 3% - 10%.

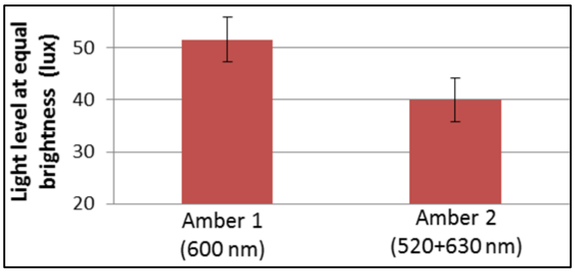

Fig. 5: Mean Results for Light Levels Being Evaluated Equally Bright in Follow-up Experiment (n=10)

Follow-up Study: Preference

The follow-up experiment also evaluated participants' overall preference of the two different, amber looking spectra when adjusted to produce equivalent brightness. A questionnaire was used to assess the role of spectral composition and aesthetics to overall preference. The results suggested that participants largely agreed on which stimulus would be preferable for a given scenario, and that different spectra would be preferred for different scenarios. 90% of the participants chose Amber 2 as preferred for unfamiliar and potentially dangerous locations (e.g., a bus shelter late at night), while 70% of the participants chose Amber 1 as preferred for familiar and safe-feeling ones (e.g., a local outdoor café).

Conclusion

The experimental results confirmed that a metric that includes ipRGC contribution in addition to conventional photoreceptor mechanisms might enable a more accurate estimation of human brightness perception at the photopic light level ranges tested, and that not only stimuli of different color appearance, but also stimuli that appear similar in color (including warm amber appearance) can be optimized for brightness. These findings provide additional tools for lighting design.

Acknowledgements

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Simulating aged vision for real environments

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Introduction

The amount of elderly people (aged 60 years or above) grows rapidly; it is predicted that the proportion of aged people will reach about 22% of the population in 2050 (Population Division, 2012). This growth has considerable health and well-being consequences. As the body ages, some functionality degrades, e.g., also in the visual system. The eye's lens becomes thicker and more densely yellow with age (Kessel, Lundeman, Herbst, Andersen, & Larsen, 2010). Hence, the amount of light transmitted to the retina is reduced in the eyes of elderly people. This change significantly affects elderly people's visual acuity (Haigh, 1993), color perception (Okajima & Takase, 2001) and contrast sensitivity (Owsley, 2011). Currently literature reveals knowledge on aging effects of the human eye for relatively simple patches and stimuli (Okajima & Takase, 2001; Owsley, Sekuler, & Siemsen, 1983; Tang & Zhou, 2009), but not how these effects accumulate in a real scene or mitigate as a consequence of adaptation.

Light designers usually are relatively young, but also design lighting environments for the elderly population, e.g., in hospitals or care centers. Since they want to make these light designs optimal for the elderly population, they need to understand how their designs are perceived by elderly. Hence, our aim is to construct a filter, mimicking elderly vision, which can be convoluted with light designs. This filter will start from the existing knowledge, but will be further fine-tuned with elderly to account for accumulation of aging effects or for adaptation. Such a filter would help the younger designers to understand what elderly people perceive, and thus, would facilitate light designs that are functional, efficient and attractive for elderly people.

Related work

Although aged vision also deteriorates in temporal sensitivity, motion perception and processing speed of visual information (Haigh, 1993; Owsley, 2011), we here first focus on daily static scenes, and therefore, on aging-related changes in light transmission, color vision and contrast sensitivity.

Light transmission

Literature suggests that part of the differences in visual performance between young and elderly people can be accounted for by differences in retinal illumination (Owsley et al., 1983; Sturr, Church, & Taub, 1988). Such reduced retinal illumination can be simulated either by reducing the luminance of a display on which stimuli are shown (Sturr et al., 1988) or by placing a neutral density filter in front of the eye (Owsley et al., 1983; Whitaker & Elliott, 1992).

Color vision

As the eye's lens yellows with age, it absorbs a larger amount of short wavelength light than of long wavelength light (Kessel et al., 2010). Kim, Han, and Park (2013) employed the spectral transmittance of a yellow filter to model color appearance perceived by elderly people. Okajima and Takase (2001) simulated the extent to which chromaticity of light reflected from Munsell color chips shifts for elderly people, using a model of an aged human lens as proposed by Pokorny, Smith, and Lutze (1987). They found that young participants cannot quickly adapt to the equivalent D65 white incident on the retina of elderly people, since younger people matched the white perceived by elderly as yellowish.

Contrast sensitivity function (CSF)

Contrast sensitivity affects the ability to see the outline of an object clearly. Aging reduces contrast sensitivity, especially at high spatial frequencies (Owsley, 2011). When targets are presented at low temporal frequencies, low spatial frequency sensitivity at photopic levels is not or only minimally impacted by aging, but the spatial contrast loss increases with increasing spatial frequency. Consequently, elderly people perceive blurred edges in scenes. However, so far this deterioration in spatial contrast sensitivity has not been simulated yet.

Construction of the filter

Although earlier research has suggested that some neural compensation may also operate in color vision of elderly people (Okajima & Takase, 2001), we here simulate elderly vision mainly based on reduced light transmission through the lens with consequence in perception of light intensity and color vision. Elderly people's contrast sensitivity function is simulated based on the experimental data from Owsley et al. (1983). Figure 1 shows a schematic overview of the filter. First, we reduce the luminance of an original image (in the linear light domain) and shift the color of each pixel according to the differences in spectral transmittance between elderly and younger people. Then, the luminance corrected image is adapted for the change in spatial contrast sensitivity. The three filtering steps are detailed below.

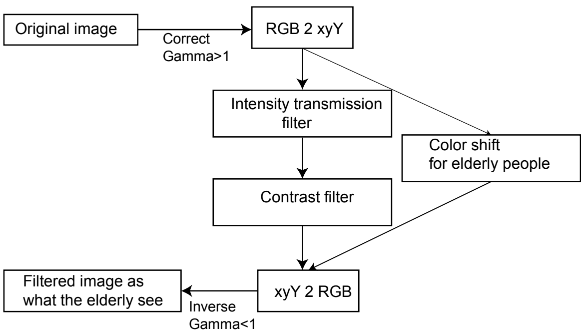

Fig. 1: Filter simulating for an original image what elderly see

Light transmission

We employed the "Two-factor model" proposed by Pokorny et al. (1987) to simulate the spectral optical density L of a human lens as a function of wavelength λ and age A, i.e., $L(\lambda,A)$. The related spectral transmittance of a human lens can then be expressed as $\tau(\lambda) = 10^{-L(\lambda,A)}$. The lens transmittance of an elderly person of age A_2 simulated for a young person of age A_1 is then $F(\lambda, A_2, A_1) = \tau(\lambda, A_2) / \tau(\lambda, A_1)$. Figure 2 shows the resulting spectral transmittance for a filter simulating vision of a 75-years old person for a 32-years person.

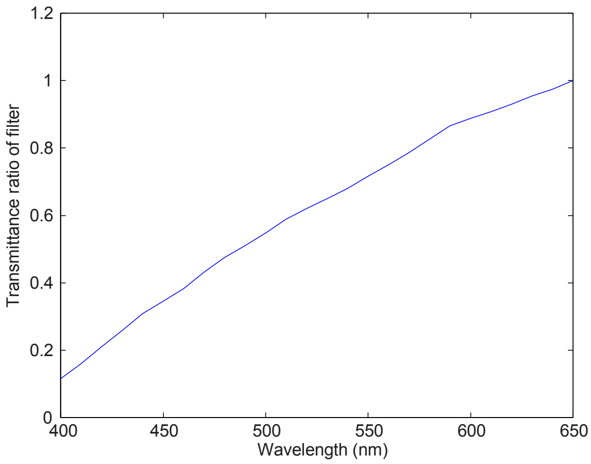

Fig. 2: Spectral transmittance for a filter simulating vision of a 75-years old person for a 32-years person

Color shift

For an object whose spectral reflectance is $\rho(\lambda)$ under a light spectrum $E(\lambda)$, the tristimulus values (X,Y,Z) can be calculated using the following transformation:

$$X(A) = K\sum_{400}^{650} \rho(\lambda)E(\lambda)\bar{x}(\lambda)F(\lambda, A, 32)\Delta\lambda$$

$$Y(A) = K\sum_{400}^{650} \rho(\lambda)E(\lambda)\bar{y}(\lambda)F(\lambda, A, 32)\Delta\lambda$$

$$Z(A) = K\sum_{400}^{650} \rho(\lambda)E(\lambda)\bar{z}(\lambda)F(\lambda, A, 32)\Delta\lambda$$

where K is 683 lumen/W, $(\bar{x}(\lambda), \bar{y}(\lambda), \bar{z}(\lambda))$ are the standard CIE color matching functions, and $\Delta\lambda$ is a constant wavelength interval. The resulting chromaticity coordinates $(x(A),y(A))$ for age A can be calculated as:

$$x(A) = \frac{X(A)}{X(A)+Y(A)+Z(A)}$$

$$y(A) = \frac{Y(A)}{X(A)+Y(A)+Z(A)}$$

The shift in (*x,y*) chromaticity coordinates from younger to older age is shown in Figure 3 for the 1600 glossy Munsell color chips under standard D65 illumination (University of Eastern Finland).

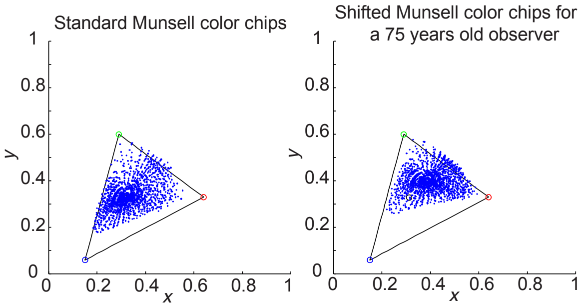

Fig. 3: CIE xy coordinates of 1600 Munsell color chips seen by a 32-years old observer (left) and by a 75-years observer (right).

Based on these data we used (blind) curve fitting in Matlab to relate the *xy* coordinates of a 75-years old observer to those of a 32-years old observer. The final function selection for the *x*- and *y*-coordinate separately was based on the goodness of fit, i.e., R^2. The resulting transformations between the standard CIE *xy* coordinates and those of a 75-years old observer are:

$$x' = a_1 \sin(b_1 x + c_1) + a_2 \sin(b_2 x + c_2)$$

$$y' = p_1 y^3 + p_2 y^2 + p_3 y + p_4$$

with: $a_1 = 1.579$, $b_1 = 0.70$, $c_1 = 0.011$, $a_2 = 0.021$, $b_2 = 12.01$, $c_2 = -2.07$, $p_1 = 3.41$, $p_2 = -4.19$, $p_3 = 2.36$, and $p_4 = -0.050$.

Contrast sensitivity function

Owsley et al. (1983) measured contrast sensitivity in a large sample of adults ranging in age from 19 to 87 years. Based on these data, we fitted the ratio in contrast sensitivity of a 75-years old observer to a 32-years old observer; the results of this fit as a function of spatial frequency is shown in Figure 4.

Since contrast sensitivity varies with spatial frequency, we filtered an original image to the frequency domain (with units of cycles per degree, taking into account the viewing distance of the observer to the image and the visual field of the image, i.e., the angular dimensions of the image's width and height). Note that we only used the Y-component of the image (i.e., contrast reduction was applied on the luminance signal and not on the color signal). After the image was transformed to the frequency domain, the zero-frequency component was moved to the center of the image array and the high frequency components were moved to the edges of the image array. According to the definition of contrast, i.e., the difference between maximum and minimum luminance divided by their sum, we kept the mean luminance of the image constant, and varied the difference between the maximum and the minimum luminance of each pixel based on the ratio of sensitivity shown in Figure 4. Eventually, the resulting image array was transformed back to the time domain.

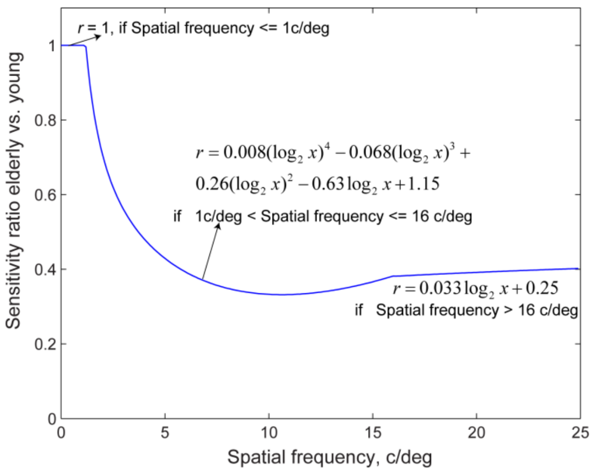

Fig. 4: Contrast sensitivity ratio between 75 and 32

Simulating real light environments

To simulate what we expect elderly to see in a complex real environment, we combined the above three filters and applied them to images of lighted environments. Figure 5 gives such an example; the top picture shows the original scene, and the bottom picture shows the result after filtering. Obviously, the filtered picture looks darker, more blurred and more yellowish as compared to the original one.

Experimental validation

As mentioned before, the filtered picture in Figure 5 just shows the sum of the (separate) effects known from literature.

Hence, we don't take into account possible interactions between these effects that may occur in real scenes, or possible temporal adaptation to changed vision in general. In order to be able to account for these limitations, the filter might need fine-tuning based on experimental results with elderly.

Fig. 5: Comparison between an original image (upper) and the filtered image (lower)

Since we cannot measure directly what people actually see, we try to validate our filter through an experiment in which elderly people perform a simple task on non-filtered images, while their task performance is compared to that of younger people who perform the same task, but on the filtered images. If both task performances are equal, we at least validate that elderly have similar visual information in the non-filtered images as younger people in the filtered images.

In a first experiment, the contrast threshold between a target (Landolt C with its gap direction either at the top or at the left) and a complex background (a real lab environment) is measured with a staircase method. By also varying the luminance of the background (i.e., the simulated illumination level in the scene), we can measure whether changes in luminance difference between target and background with age are well predicted by our designed filter. In addition, four different sizes of the target are used, to simulate the effect of different spatial frequencies. As the contrast sensitivity decreases with spatial frequency above 2 cycles/degree for elderly participants, it is expected that both the young and elderly participants perform better when the target in the image is relatively large (so, has lower spatial frequencies). Furthermore, we can measure whether a possible effect of age on frequency dependent target visibility is predicted by our filter. First results of this experiment will be presented at the conference.

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Exploring inter-individual variations in light exposure patterns and sensitivity to acute vitalizing effects of light in everyday life

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Introduction

Studies on non-image forming effects of light have shown that the acute effects of light on affective, cognitive and physiological functioning vary with light intensity (e.g., Cajochen, 2007). Whereas most of these studies were performed during the biological night, several laboratory studies have provided evidence that exposure to bright light during the biological day can also induce acute alerting and vitalizing effects (Phipps-Nelson, Redman, Dijk & Rajaratnam, 2003; Rüger et al., 2006; Smolders, de Kort & Cluitmans, 2012; Smolders & de Kort, 2014; Vandewalle et al., 2006). Extending these results acquired under controlled laboratory conditions to everyday life, a recent field study confirmed a significant relationship between light intensity and subjective vitality during daytime (Smolders, de Kort & van den Berg, 2013). Participants reported higher vitality when they had were exposed to more light during the previous hour. Subjective vitality refers to the positive feeling of having energy or resources available to the self, and is important for well-being, health, performance and success in life (Ryan & Frederick, 1997).

Recent research also showed that the effects of light intensity on alertness and vitality during daytime may depend on the timing of the light exposure and a person's momentary state (e.g., sleepy vs. alert). More specifically, exposure to higher levels of light induced stronger feelings of alertness and vitality in the morning and when individuals felt sleepy and less vital (Smolders et al., 2013; Smolders & de Kort, 2014). However, little is known about inter-individual differences in the sensitivity to these acute effects during daytime.

Controlled laboratory studies (Chellappa et al., 2012; Vandewalle et al., 2011) have provided evidence that individuals' sensitivity to light may not only depend on local time (i.e., clock time), but also on a person's internal time (chronotype; Roenneberg, Wirz-Justice & Merrow, 2003). Whether chronotype as well as persons' level of general fatigue also affect their sensitivity to light during daytime in real life is as yet unknown. Such insights, however, would be vital for the development of intelligent person-centered lighting scenarios.

In the current study, we explored inter-individual variations in light exposure and sensitivity to acute vitalizing effects of light in real life as a function of chronotype, social jetlag and general fatigue. Chronotype refers to an individual's preference in the timing of sleep and wake and quantifies an individual's phase of entrainment (Roenneberg et al., 2003); social jetlag refers to the amount of misalignment between biological and social time (Wittmann, Dinich, Merrow & Roenneberg, 2006).

We will report on additional analyses on the data collected in Smolders et al. (2013), exploring time-dependent variations in light exposure and subjective vitality patterns during the day in early vs. late chronotypes, individuals with a relatively high vs. low social jetlag and individuals who experience relatively high vs. low levels of general fatigue. In addition, we investigated differences in the strength of the relationship between the amount of light experienced and subjective vitality during daytime in everyday life as a function of chronotype, social jetlag and general fatigue.

Method

We applied an experience sampling protocol, combined with a continuous measurement of light exposure, a morning diary and an online questionnaire (see Smolders et al. (2013) for more details).

Participants. Forty-two healthy individuals participated in this field study, of which 10 participated twice, resulting in 52 sessions. For the present analysis, data of 38 participants (48 sessions) were analyzed due to missing data on chronotype, social jetlag and general fatigue of four participants. Of these participants, 20 were male and 18 were female (mean age 26 years ± SD = 8.1, range: 19-56).

Procedure. Participants wore the light measurement device and reported on their level of vitality during three consecutive days from 8 am to 8 pm during their daily routine. The questions of the experience sampling were administered on an hourly basis with a questionnaire provided by an app on a mobile phone. An interval-contingent sampling was applied to have multiple assessments of individuals' momentary affective state throughout the day and explore the relation between fixed (non-overlapping) light exposure periods prior to completion of the questionnaires and person's affective states. Participants completed the online questionnaire at the end of the week.

Measures. The amount of light at eye level was continuously logged with a head-worn device (Daysimeter, developed by RPI's Lighting Research Center, supplied by LumenTech Innovations, USA).

Subjective vitality was assessed with four items adopted from the energetic arousal subscale of the Activation-deactivation checklist (α = .84; Thayer, 1989).

Chronotype and social jetlag were assessed with the Munich Chronotype Questionnaire (Roenneberg et al., 2003). General experienced feelings of fatigue were assessed with a subscale of the Checklist Individual strength (Beurkens et al., 2000) consisting of 8 items (α = .93). These scales were included in the online questionnaire.

Statistical analyses. Average light intensity at eye level (in lx; log transformed) was computed for each 1-hour interval prior to each momentary assessment. If the light measurement device was worn for less than 50% of the time, the data for that hour was coded as missing. Hierarchical linear model (HLM) analyses were performed with Session and Day as independent random variables and Measurement hour as repeated random variable for each day (using an autoregressive covariance structure) to indicate that the measurements were nested within a day, which in turn was nested within a session. To explore potential moderations in light exposure and subjective vitality patterns with time of day (clock time) by chronotype, social jetlag and level of fatigue, the data was split based on the median for chronotype (*Mdn* = 4.78; range: 3.14-6.38), social jetlag (*Mdn* = 1.25; range: 0.00-2.63) or level of general subjective fatigue (*Mdn* = 2.56; range: 1.38-5.50).

First, systematic variations in light exposure were modeled as a function of clock time: HLM analyses were performed with Time of day and Time of day squared as fixed factors and hourly light level as dependent variable for participants with an early or late chronotypes, a relatively high or low social jetlag and a high or low level of general subjective fatigue respectively.

To explore differences in dynamic patterns of vitality throughout the day, similar HLM analyses were performed with subjective vitality as dependent variable separately for early vs. late chronotypes, participants with a high vs. low social jetlag and with a high vs. low general fatigue, respectively. In addition, Hourly light exposure was added as fixed factor to the model to explore differences between the respective groups in the strength of the relationship between hourly light exposure and subjective vitality, after controlling for systematic variations in feelings of vitality as a function of clock time.

Results

On average, late chronotypes were exposed to lower light levels and reported lower vitality in the morning than early chronotypes (Figure 1a). Participants with a higher social jetlag received more light at

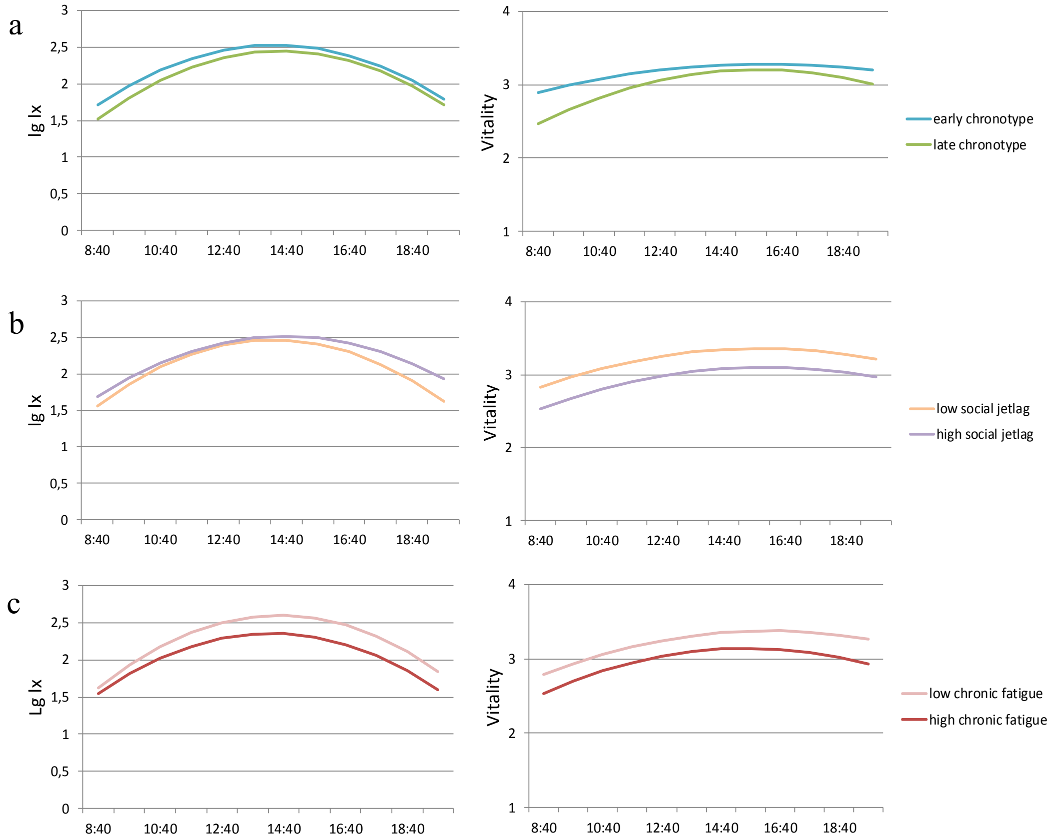

Fig. 1: Average light exposure and subjective vitality patterns throughout the day among (a) early vs. late chronotypes, (b) persons with a relatively small vs. large social jetlag and (c) persons with a relatively low vs. high general level of subjective fatigue.

eye in the late afternoon and early evening than those with a lower social jetlag, but they reported lower vitality throughout the day (Figure 1b). Participants with high ratings of fatigue were exposed to lower light levels and reported lower vitality throughout the day (Figure 1c).

HLM analyses to test whether variations in the average amount of light experienced per hour were related to feelings of vitality for each group revealed inter-individual differences in the relational strength as a function of chronotype and social jetlag. The relationship between the average amount of light experienced during the hour prior to completing the questionnaires and vitality was significant among late chronotypes (β = .14; p<.01), but not among early types (β = .03; p = .36). Similarly, light intensity was a significant predictor for subjective vitality among participants with a high social jetlag (β = .13; p < .01), but not with a low social jetlag (β = .05; p = .14). General level of subjective fatigue did not moderate the relationship between light exposure and vitality. Yet, this relationship was significant for participants with either a low (β = .11; p < .01) or a relatively high level of general fatigue (β = .09; p = .03). Note that both circadian phenotype measures were related (r = .67, p < .01), while general fatigue only showed a subtle correlation with chronotype and social jetlag (r = .28 and r = -.10, respectively).

Discussion

The current results show that individuals' light exposure during the day ánd acutely vitalizing effects of white light in everyday life depend on chronotype. These findings complement earlier results by Martin et al. (2012), which demonstrated inter-individual differences in light exposure patterns throughout the day as a function of individuals' chronotype. Moreover, they corroborate results on inter-individual differences in responsiveness to acute effects of blue or blue-enriched light exposure on alertness as a function of individual's clock gene polymorphisms (Chellappa et al, 2012;

Vandewalle et al., 2011). In the current study, late chronotypes felt more energetic when they were exposed to more light during the previous hour, while light intensity was not significantly related to subjective vitality in early chronotypes.

It should be noted that the current results cannot be translated to individuals' sensitivity to acute activating effects of light in the late evening, as we did not measure participants' light exposure and feelings of vitality at these time points (i.e., after 8 pm). In fact, results by Chellappa et al. (2012) suggested stronger acute effects of light with a high compared to low correlated color temperature on alertness in the late evening among early chronotypes.

In the current study, we also assessed inter-individual differences as a function of social jetlag and subjective fatigue. Participants with a higher social jetlag appeared to benefit most from exposure to higher light intensities during daytime hours. Yet, although individuals with relatively high levels of general fatigue were exposed to lower levels of light and reported lower vitality as compared to the less fatigued subjects, light intensity was a significant predictor for vitality in both groups.

In conclusion, we believe that our findings presented here will not only inspire further follow-up studies, but will also help to design biologically healthier lighting environments in the future.

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Shining light on memory:
The effects of daytime bright light exposure on memory task performance varying in difficulty level.

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Introduction

For humans, lighting is the most important environmental factor for visual perception. However, light can also exert non-visual circadian and acutely physiological, psychological and cognitive effects, although the latter class of effects has received less attention than the first (e.g., Cajochen, 2007). In general, this line of research suggests that bright light exposure, as compared to dim light exposure, leads to acute alerting effects and improvements on (cognitive) task performance.

Recently, two studies focusing on the non-visual effects of diurnal light exposure, investigated the effects of bright (1000 lux) versus dim light (200 lux) on cognitive task performance (Smolders, & de Kort, 2014; Smolders, de Kort, & Cluitmans, 2012). These studies revealed that bright light exposure, although beneficial for vigilance tasks (i.e., the Psychomotor Vigilance Task; PVT) proved to be detrimental for more complex tasks measuring inhibitory capacity (GoNoGo task) and working memory abilities (2-back task). Similarly, studies employing nocturnal light exposure also revealed differential performance effects for different types of tasks, some showing improvement under bright light, while others appeared unaffected (e.g. Badia et al., 1991; Boyce et al., 1997). More research is needed to develop a deeper understanding of these differential non-visual effects of light on cognitive performance.

One possible mediating variable for these differential effects may be participants' state arousal level. The impact of arousal on task performance has been originally described by the Arousal Theory developed by Yerkes and Dodson (1908). The Yerkes-Dodson Law (YDL) states that the relationship between arousal and task performance follows the pattern of an inverted U-shape, with lower performance levels if arousal is too low or too high, and maximum performance levels under intermediate arousal levels. Furthermore, YDL states that performance levels on relatively difficult tasks (i.e., tasks relying on higher executive functions) indeed show an inverted U-shape relationship with arousal levels, while easier tasks (i.e., tasks needing only focused attention on a restricted range of stimuli) benefit from increased arousal levels in a dose-dependent manner following a logistic function. Since previous studies found that bright light exposure can enhance bodily arousal levels (Smolders et al., 2012; Rüger et al., 2006; Saito et al., 1996), it could be hypothesized that the non-visual effects of light on cognitive performance depends on task complexity.

A second mediating mechanism is implied by a handful of studies focusing on light-induced brain modulation (see Vandewalle, Maquet, & Dijk, 2009 for a review). These studies indicate that light exposure during the execution of a cognitive task can modulate specific brain areas that are involved during the performance of this specific task. Based on these studies, it could be hypothesized that light-induced modulation of these brain networks may temporarily enhance cognitive capacities, which may subsequently result in improved task performance.

In sum, there is considerable evidence that environmental light exposure can exert non-visual effects on cognitive performance. However, the mechanisms through which these effects are manifested are still not fully understood. Task difficulty could be a possible factor explaining the inconsistent findings of bright light exposure on cognitive task performance.

Especially in our current society, where partial sleep deprivation resulting in sleepiness during the day is not uncommon (Groeger, Zijlstra, & Dijk, 2004) and where busy daily schedules often lead to mental fatigue (Åkerstedt et al., 2004), it would be highly beneficial to investigate possibilities to improve alertness and cognitive performance during the day. We therefore argue that it is important to develop a deeper understanding of the effects of illuminance level on tasks with various complexity levels. Therefore, the current study investigated the effects of bright versus dim light on cognitive performance, employing two tasks in which the difficulty level was manipulated. We controlled for potential time-dependent variations in cognitive performance caused by homeostatic and circadian regulation.

Method

Design

We employed a mixed design to investigate the effect of light intensity (200 vs 100 lux at eye level) on cognitive performance as a function of task difficulty. Illuminance level and digit-span difficulty were manipulated within subjects. *N*-back task difficulty and time of day were manipulated between subjects.

Participants

Sixty-four participants (mean age: 21.4; *SD* = 2.1) completed both lighting manipulation condition. The order of experimental conditions was counterbalanced across participants.

Participants were recruited at the University of Technology in Eindhoven via advertisements, social networks as well as via the University's participant database. Extreme chronotypes, as measured by the Munich Chronotype Questionnaire (MCTQ; Roenneberg, Wirz-Justice, & Merrow, 2003), were excluded from participation. Participants were informed to register for the same timeslot on both experimental sessions (9:00 AM, 10:45 AM, 12:15 PM, 13:45 PM or 15:45 PM), which were separated by at least two full days.

Setting

The laboratory room was a simulated office environment at the Eindhoven University of Technology in The Netherlands with a size of 3.9 m by 7.4 m. Four work stations were created of approximately 1.95 m by 3.7 m, separated by a curtain and a 1.8m high panel in between desks. Each work station was fitted with a desk and chair, and a 15.6-inch laptop with a keyboard, headphones and mouse.

The laboratory room was equipped with recessed Philips Savio luminaires in the ceiling. Each ceiling luminaire (Philips Savio TBS770 3x54W/827/865 HDF AC-MLO CVC) contained three fluorescent tubes of 54 W, of which two tubes of 6500 K and one tube of 2700 K. All luminaires have an acrylate micro-lens optic cover, which blends the two lamp types to create a virtually homogeneous luminous surface.

Light manipulation

During the baseline phase, participants were exposed to 100 lux at eye-level in both lighting conditions (275 lux at the work plane). Subsequently, illuminance levels were set to either 200 lux, 4000K at eye-level (580 lux at the work plane) or 1000 lux, 4000k at eye-level (2900 lux at the work plane).

Measures

Task performance: In each measurement block, participants first engaged in a 3.5-minute *n*-back task (Mackworth, 1959), where they heard a sequence of one-syllable consonants (at 1-second intervals) and were asked to press a button every time a consonant was identical to the consonant *n* positions back. This task assesses working memory and in particular mental updating abilities. For this task, correct target responses and reaction times (RTs) to targets were used as outcome variables. Subsequently they completed an auditory FDST, of six digit-span lengths (4, 5, 6, 7, 8 and 9 digits long, two trials per length) and an auditory BDST (3, 4, 5, 6, 7, and 8 digits long, two trials per length). These tasks respectively assess short-term memory retrieval and working memory abilities. For both tasks, the total number of correct responses per measurement block were used as an outcome variable.

Subjective task performance: After each task, participants rated their performance on the previous task. Visual Analogue Scales (VAS), ranging from 0 (not at all) to 100 (very much) assessed how well participants thought they had performed on the task, how motivated they were to perform the task to their best ability, how much effort they put into performing the task, how well they could concentrate on the task, and how much mental effort they had to put into the task.

Subjective sleepiness, vitality, mood and tension: Subjective sleepiness was examined after each task using the Karolinska Sleepiness Scale (KSS; Åkerstedt & Gillberg, 1990), ranging from 1 (extremely alert) to 9 (extremely sleepy - fighting sleep). Positive and negative affect, subjective vitality and tension (Thayer, 1967) were assessed after each measurement block using six-item scales ranging from 1 (definitely not) to 5 (definitely).

Procedure

Each experimental session started with instructions and a practice phase in which all tasks were practiced. Subsequently, participants completed a 15-minute baseline phase (100 lux at eye level). After the baseline phase, illuminance levels were set according to the experimental condition, and participants completed four additional 15-minute blocks. A 15-minute block consisted of all three tasks (*n*-back, then FDST, then BDST), short questionnaires on sleepiness and subjective performance after each task, and vitality mood and tension ratings at the end of each block. A full overview of the experimental procedure is shown in Table 1. After completing both sessions participants received a 30-euro compensation. The study took place from March to May 2014.

Statistical analyses and results

The complete results of this study (including figures and statistical data) will be covered during the conference.

Linear mixed model (LMM) analysis using Lighting condition and Measurement block as fixed factors were used to examine the effects of illuminance level on repeated measures data of task performance and subjective indicators. To compare difficulty levels for each of the tasks, Task type (for BDST vs FDST) and N-back version were also used as fixed factors. In addition, Time of Day was added as a fixed factor to investigate differential effects of illuminance level for morning versus afternoon sessions.

Regarding the FDST and the BDST, no Lighting condition * DST version * Time of day interaction was found, indicating no effect of task difficulty on performance. Investigating the tasks separately, results showed a trend towards better performance under bright light on both tasks during the morning sessions, while there was no effect of illuminance level during the afternoon sessions on the FDST and worse performance on the BDST.

Tab. 1: overview of a full experimental session

100 lux at eye-level		200 or 1000 lux at eye-level				
Practice phase	Baseline	Light exposure phase; measurement blocks similar to baseline				
Instructions and task practice	Baseline task performance, and subjective ratings	Block 1	Block 2	Block 3	Block 4	Questionnaires: light ratings, prior wake-fullness etc.
10 minutes	15 minutes	15 minutes	15 minutes	15 minutes	15 minutes	5 minutes

When comparing the 2- and 3-back task on accuracy (the 1-back task was not included because of a ceiling effect), a trend towards a significant Lighting condition * N-back version * Time of day interaction was found. Post-hoc comparisons showed that illuminance level did not affect performance on the 3-back task, neither in the morning nor in the afternoon. However, performance on the 2-back task yielded a trend towards better performance during the morning sessions under bright light exposure, but significantly worse performance under bright light exposure during the afternoon sessions.

No effects of light intensity were found on RTs on any of the *n*-back tasks. This is partly in line with the study of Smolders et al. (2014) showing no effects of similar light exposure on 2-back RTs.

In sum, we did indeed see non-significant trends towards differential effects of bright light for less vs. more complex tasks (FDST vs BDST and 2-back vs. 3-back). However, Time of day appeared to be a more pronounced moderator of bright light effects than task difficulty: participants seemed to benefit slightly from bright light exposure (in terms of accuracy) during the morning hours on most of the tasks (FDST, BDST and 2-back task) while they did not benefit or even performed worse under bright light during the afternoon hours on these tasks.

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Effective illuminances for the five photopigments in the human eye determined by LED and fluorescent light scenes

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Introduction

Finding a way to predict non image-forming (NIF) responses to a light stimulus is a topic of great interest nowadays.

Starting from Brainard et al. (2001) and Thapan et al. (2001) action spectra for melatonin suppression in humans, many models to predict the circadian impact of a light stimulus have been proposed.

Gall and Bieske (2004) defined a circadian metric based on a circadian action function c(λ) (Gall, 2002). This metric is based on the calculation of a circadian action factor a_{cv} which represents the ratio of circadian and photometric radiation quantities and allows to evaluate the degree of circadian impact of different light spectra.

Pechacek et al. (2008) proposed the calculation of a "circadian efficacy" based on a circadian photoreception sensitivity function C(λ), which peaks at approximately 480 nm. This circadian efficacy is expressed in circadian weighted watt. It is easy to notice that these two models have a similar approach and, while they are surely easy to apply, they probably simplify too much how the circadian system works. Therefore they are probably not very accurate in predicting the circadian response to a light stimulus.

Rea et al. (2005,2010,2012) proposed a model of circadian phototransduction, which has been modified during the years, that takes into account the contributions of rods; S, M and L cones and ipRGCs. Starting from spectral irradiance data this model allows to calculate circadian light (CL_A), which is circadian spectrally weighted irradiance (weighted W/m^2), and circadian stimulus (CS), which represents the relative effectiveness of CL_A for producing a meaningful circadian response. The definitions of CS and CL_A are based on the actual knowledge about nocturnal melatonin suppression in humans, taking into account an hour-long exposure to light, near the midpoint of the melatonin production curve, and with naturally-constricted pupils.

Recent researches question the reliability of Rea's model in describing all mRGC related responses, given that there is still doubt on the role of rods and cones in NIF vision and there is also evidence of the existence of different mRGC classes (al Enezi et al.,2011; Schmidt & Kofuji,2010).

Therefore, during the 1st International Workshop on Circadian Neurophysiological Photometry, the Irradiance Toolbox was proposed by Lucas et al. (2013). This toolbox allows to calculate effective illuminance for each of the five photopigments in the human eye starting from measured irradiance data. It is important to notice that this model allows to predict the photoactivation of the different photopigments but it does not allow to predict the magnitude of any behavioral or physiological response to a given light stimulus. This may appear as a step back from the models previously illustrated but, given that there are still many uncertainties about how NIF responses work, it is probably best to stop at this point.

In this paper the results of the application of this toolbox to measured eye level irradiances of eight LED and fluorescent light scenes are reported.

Method

Eye level spectral irradiances of the different light scenes were recorded using a Konica Minolta CS 2000 spectroradiometer in a test room. The light scenes were set up in order to obtain similar eye level illuminances (about 450 lx) and CCTs. Table 1 reports eye level illuminances (named E_e), along with lamps and eye level CCTs (named CCT_l and CCT_e). Light scenes are named Warm Fluorescents (WF), Cold Fluorescents (CF), Warm LEDs (WL) and Cold LEDs (CL), the suffix 1 and 2 is used to distinguish among the light scenes with the same color tone and same technology.

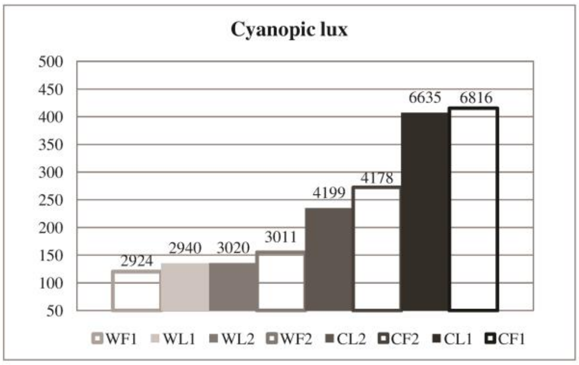
Tab. 1: Light scenes' characteristics

Light scenes	E_e [lx]	CCT_l [K]	CCT_e [K]
WF1	461	2924	2822
WL1	451	2940	2712
WF2	471	3011	2915
WL2	476	3020	2673
CF2	495	4178	3962
CL2	481	4199	3523
CL1	456	6635	5610
CF1	448	6816	6158

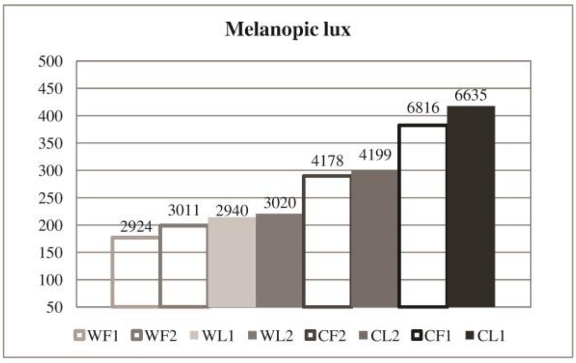
Results

Figures 1a,b,c,d,e report the results of the application of the irradiance toolbox to the light scenes' spectral irradiances. The numbers on each bar correspond to the light scene's measured CCT (K).

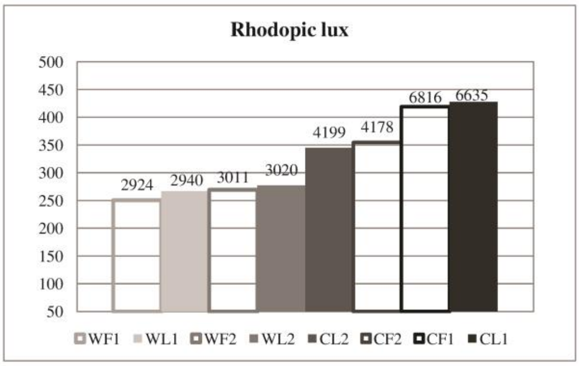
a)



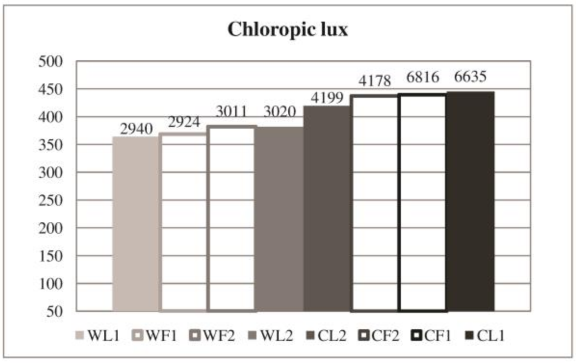
b)



c)



d)



e)

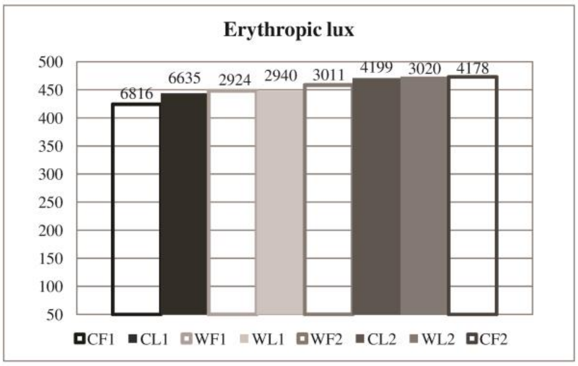


Fig. 1a,b,c,d,e: Effective illuminances for the five photopigments in the human eye

From Figure 1a it can be noted that the greatest amount of cyanopic light is obtained with CF1 and CL1. The smallest values are achieved with WF1 and WL1. Given that cyanopic lx represent the sensitivity of S cones the result is explained by the fact that CF1 and CL1 are the light scenes with the highest CCT and therefore they probably also have the greatest emission in the short wavelengths. The conclusions for melanopic lx (Figure 1b), which represent melanopsin sensitivity, are similar. It can be noted that, in this case, LED light scenes values are higher than those of the corresponding fluorescent scene with the same CCT. The greatest amount of rhodopic light (Figure 1c) is again obtained with CL1 and CF1 and the smallest values are again WF1 and WL1 ones. However in this case there is less difference between the light scenes.

Figure 1d reports the values of chloropic lx (M cones); in this case the differences are really small and, in particular, CF1, CL1 and CF2 have almost equal values whereas for CL2 they are a little lower. Similarly WF1, WL1, WF2 and WL2 show almost equal values. This probably means that light sources with CCT comprised between 2900K and 3020 K determine the same degree of M cones' activation, the same happens for light sources with a CCT comprised between 4200K and 6600K.

For erythropic light (Figure 1e) the results are different compared to the previous cases, in fact the highest degree of L cones photoactivation is achieved with CF2, WL2 and CL2 whereas the lowest is obtained with CF1.

Discussion and conclusions

From the results presented in this paper it is clear that light scenes with the same CCT and eye level illuminances but different luminaire's technology differently stimulate the photopigments in the human eye. This results depend on the different eye level spectral distribution and, therefore, this is an important parameter that should be taken into account when designing a lighting system if we want to achieve a certain degree of photopigments' stimulation. However at the present time it is not possible to determine how this values translate into a given physical or behavioral response. Therefore the future steps of the research in this field should be focused on trying to find a way to assess if and how a light stimulus determines NIF effects in humans.

Acknowledgements

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Implementing Programmable LED Lighting in a Hospital Setting: A Multi-Method Multi-Phase Quasi Experiment

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Introduction

Researchers have demonstrated the importance of light for effective task completion and proper functioning of the circadian rhythm. Researchers have also revealed an effect of light on a variety of other outcomes including perception, mood, stress, and length of hospital stays. The purpose of this research is to examine patient and staff outcomes through a quasi-experiment conducted in a hospital setting. The research takes place both prior to and after the hospital's implementation of a new adjustable and programmable LED lighting system.

Task performance and lighting have been studied to identify the optimal intensity of light for a variety of tasks. Most workers seem best able to perform best within the range of 30-35 footcandles (Sundstrom, 1986). However, optimal lighting levels depend upon the visual requirements of a task. In a study of pharmaceutical dispensing, conducted by Buchanan, Barker, Gibson, Jiang, and Pearson (1991), error rates were inversely related to increases in light intensity. At 1500 lux, error rates dropped to 2.6% as compared to 3.8% in the 450 lux condition. Despite examination of pharmaceutical dispensing tasks, there is a lack of studies on optimal lighting conditions to support tasks performed by medical staff, such as nurses and physicians (Joseph, 2006). Additionally, the performance of tasks has changed with the incorporation of new technological tools, such as smart devices. The incorporation of these devices into the routine work performed by medical staff and workers in a variety of fields raises issues related to glare, luminance surrounding visual displays, and the interactive effects of lighting and various computer and device screens (Sheedy, Smith, & Hayes, 2005). Hence, there is a growing need for research defining ideal lighting conditions for the performance of job tasks amidst the increasing use of these tools.

Researchers studying light and the influence on circadian rhythm have demonstrated that exposure to light of varying intensity can influence a person's sleep/wake cycle. Medical researchers have proposed that changes in light-dark (e.g., shift work, light at night, dim light) exposure can desynchronize internal circadian rhythms from the external environment (Rea, Figuerio, & Bullough, 2002; Rea, Figueiro, Bullough, & Bierman, 2005; Stevens, 2006; Stevens et al., 2007; Stevens & Rea, 2001). In addition to impacting the sleep/wake cycle, disrupted circadian rhythms have been shown to affect physiological and metabolic processes---possibly leading to a variety of negative health outcomes and diseases (see Bullough, Rea, & Figueiro, 2006; Kloog et al.,2008; Knutsson, 2003; O'Leary et al., 2006; Stevens, 2006; Stevens et al., 2007; Stevens & Rea, 2001). Workers assigned to non-standard shifts can experience difficulties when entrained to be in the sleep portion of the cycle during the work hours and vice versa (Boyce, Hunter, & Howlett, 2003; Rea, et al., 2002; Rea, et al., 2005; Van Bommel & Van den Beld, 2004). Together these findings suggest that lighting of hospital environments with 24/7 workers is an important environment for study.

Walch and colleagues (Walch et al., 2005) conducted a study on the effect of sunlight exposure on patients staying in a hospital. This study revealed that those patients exposed to 46% greater intensity of sunlight found on the brighter side of the hospital, used less pain medication, perceived less stress, lower levels of pain and incurred 21% lower pain medication costs. Similarly, patients suffering from bipolar depression staying in east-facing rooms exposed to higher intensity sunlight in the morning stayed in the hospital an average of 3.7 days less than those staying in west-facing rooms (Bandetti, Colombo, Barbini, Campori, & Smeraldi, 2001). Shorter stays were also found among myocardial infarction patients staying in sunny rooms, on an average of a day less than those staying in dull rooms (Beauchemin & Hays, 1996).

As demonstrated above, lighting conditions affect the patients and staff in hospital settings in a variety of ways. The purpose of this study is to track the effect of a new programmable LED lighting system before and after installation on a variety of outcomes for hospital occupants.

Research Questions

Automated systems have been developed to optimize indoor lighting conditions and have been increasingly installed and used in buildings. However, these systems are difficult to configure, as optimal lighting must be continually optimized for all occupants within the space, and can include considerations of lighting at different heights, across assorted furniture and other obstacles and surfaces, while also taking into account varying environmental conditions (Selkowitz & Lee, 1998). Many environmental conditions can impact internal lighting conditions, including time of day, weather conditions, time of year, through the interaction of these conditions with the fenestration of the building (Laouadi & Parekh, 2007; Selkowitz & Lee, 1998).

As a local hospital is planning to incorporate a programmable LED lighting system in the patient bed tower, we saw the opportunity to monitor the reactions and outcomes related to the new lighting system installation. The research questions of interest for this study include:

- How is satisfaction with the work environment and job satisfaction among hospital staff impacted by the installation of a programmable LED lighting system that should allow for refined control of lighting conditions in patient rooms?
- How does the new lighting system impact patient satisfaction?
- How does the new lighting system impact health outcomes for patients?

Based on past research, we expect that introduction of a programmable lighting system with a wide spectrum (e.g. 2000K-6000K+) will have positive benefits to the patient experience resulting in positive effects on sleep, synchronization with circadian rhythm, pain management, and other related components including enhanced care-giver interaction. If the lighting system is capable of simulating natural day and night changes, patient satisfaction among other metrics like length of stay, could have significant improvements.

Methods

We will be using a triangulation approach to studying the impact of a new LED lighting system being installed in a hospital located in the Midwestern region of the United States. The triangulation approach will involve an ongoing qualitative and quantitative study of the experience of staff and patients at the hospital in reaction to the new lighting system installation. As part of the first phase, we plan to conduct surveys and interviews with staff, in response to the sample set-up that will be installed over fall 2014. At the same time, patients will be alternately assigned to rooms with the new lighting system and those without. To test for the effects of the new system, we will be analyzing de-identified patient data collected over the same time period from patients in the rooms with or without the new lighting system. As a follow-up, we plan to collect additional data about six months after the installation, to test for longitudinal effects.

Specific variables of interest we will examine include satisfaction, comfort, length of stay, vitality, alertness, tension, positive and negative affect, and biological measures as available. We may add measures as they emerge as important through ongoing qualitative data collection and analysis.

Because of the wish to limit interference with patients, survey items will be administered by nurses making rounds using tablet devices to record patient responses, and survey items will be limited. To assess subjective alertness, the Karolinska Sleepiness Scale will be used. Mood, including vitality, tension, and affect, will be assessed similarly to Smolders, de Kort, & Cluitmans (2012).

To assess comfort, we aim to ask patients to rate their comfort with lighting in the room throughout each day for the duration of their stay. To assess satisfaction, we aim to ask patients to rate their satisfaction with lighting conditions throughout each day and across the total duration of their stay. We also plan to ask staff for their feedback on their comfort and satisfaction and perceptions of patient comfort and satisfaction with the light emitted from the new system.

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Simulation Study of a Virtual Natural Lighting Solutions Prototype: Validation and Analysis

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Introduction

The benefit of natural light and view from windows in buildings has been widely reported (e.g. Berman et al., 2008; Aries et al., 2010). However, there are some situations in which natural light is absent, for example, due to hygienic or safety reasons. To answer this challenge, the concept of Virtual Natural Lighting Solutions (VNLS), which are systems that can artificially provide natural lighting as well as a realistic outside view with properties comparable to those of real windows and skylights, is proposed.

This study aims to find how a certain VNLS prototype influences the indoor lighting condition and visual comfort. In particular, this study focuses on lighting measurement and simulation of a 'second generation' VNLS prototype. Two objectives are defined: (1) to validate the illuminance distribution results obtained from *Radiance* simulation (Ward & Shakespeare, 1998) with the ones obtained from measurement, by evaluating the interior lighting condition inside the test room; and (2) to determine the effect of various prototypes configurations on the space availability, uniformity, and visual comfort in the test room.

Case Description

A VNLS prototype has been built in the new ExperienceLab of Philips Research at the High Tech Campus in Eindhoven, the Netherlands. The light sources of this prototype were eight *Philips Origami BPG762* luminaires (Figure 1), each measured 0.595 m × 0.595 m × 0.050 m, incorporated to provide the light as well as to construct the view of the prototype. Each luminaire housed four smaller tiles consisting of 108 *LUXEON RGB* power LEDs, and were able to display colours in red, green, and blue (RGB) components.

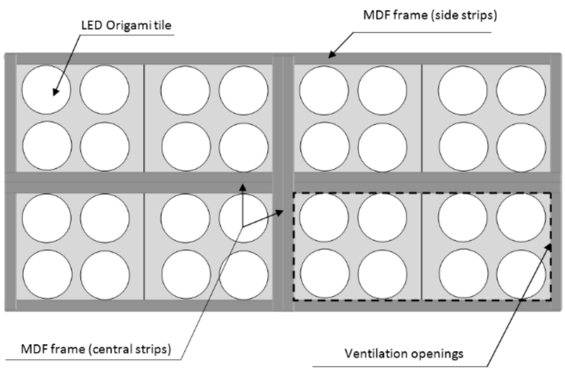

Fig. 1: Rear view illustration of the 2 × 4 Origami BPG762 arrays in the prototype; taken from Mangkuto et al. (2014)

The prototype was set to display a diffuse view by applying a diffuse panel. The original displayed view was a scene of nature, composed of a green ground and a bluish, cloudy sky. The horizon was set at the eye height; therefore the 'ground' elements occupied only 0.25 of the total view height. Using an image processing software, a mosaic filter was applied to turn the image into 32 pixels.

Figure 2 displays the appearance of the prototype from inside the test room, at the 'on' condition, after applying the diffuse panel and window glass.

Fig. 2: The prototype appearance from inside the test room at the 'on' condition; taken from Mangkuto et al. (2014)

Measurement Protocol

The prototype was placed in a test room of 6.81 m × 3.63 m × 2.70 m (L×W×H). There were two openings for the prototype; each had a dimension of 0.90 m × 1.20 m (W×H), while the height of the window bottom was 0.93 m from the floor. The distance between the frames of the two openings was 0.14 m. Figure 3 illustrates the floor plan of the test room.

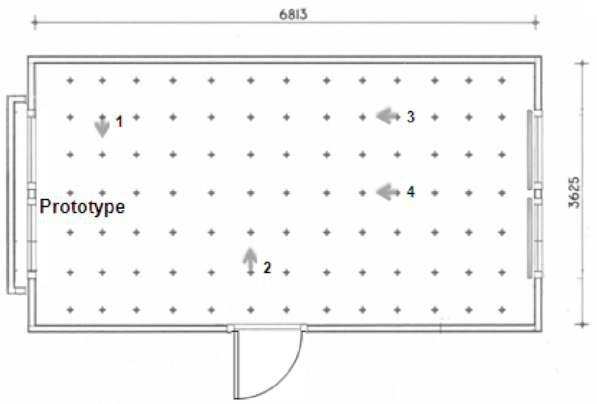

Fig. 3: Floor plan view of the test room

Data were collected at three settings: 25%, 62.5%, and 100% of the maximum. Horizontal illuminance on the workplane (0.75 m from the floor) were measured at 91 points (see Figure 3), using *Lutron LX-1118* light meter (instrument error ± 5%). Vertical illuminance were measured at four positions (see Figure 3), at a height of 1.20 m from the floor. Reflectance of interior surface materials data were measured using *Konica Minolta CM-2600D* spectrophotometer (instrument error ± 0.1%). The horizontal illuminance data were post-processed to obtain the average illumi-nance values (E_{av} [lx]), uniformity (U_0), and space availability (*%A* [%]). The latter is the percentage of measuring points satisfying the criterion of minimum illuminance value. The Daylight Glare Probability (DGP) (Wienold & Christoffersen, 2006) was used as an indicator for visual discomfort.

Simulation Protocol

The first objective of this study is to validate the illuminance distribution results obtained from simulation using *Radiance* with the ones obtained from measurement. *Radiance* itself has been validated against CIE test cases (CIE TC-3-33, 2005) with a good accuracy (Maamari et al., 2005). Therefore, the actual conditions under the three lighting scenes were modelled and simulated. Comparison was made between the simulated and measured values of horizontal illuminance at the measurement points in Figure 3, as well as between the simulated and measured values of the space availability and uniformity.

Each *Origami* tile was modelled as a box of 0.30 m × 0.30 m × 0.05 m, constructed with a 'light' material. Each lamp had various red, green, and blue radiance components, in proportion to the actual DMX settings.

To validate the model, simulations were run for the settings of 100%, 62.5%, and 25%. One-to-one comparison between measurement and simulation was done for the values of horizontal illuminance at all measurement points.

There is no definitive agreement on an acceptable degree of accuracy whether a simulation result is fit for the purpose of reproducing the actual scene (Ochoa et al., 2012). Fisher (1992) suggested an acceptable criteria range of 10% for average illuminance calculations and 20% for measured point values. Moreover, the European Standard EN 12464-1 (CEN, 2002) mentions that "a factor of approximately 1.5 represents the smallest significant difference in subjective effect of illuminance", as given in the recommended scale of illuminance for various conditions in work places. This is roughly in agreement with the findings of Slater et al. (1993), which suggested that illuminance ratios of minimum 0.7 (or maximum 1.4 if inversed) between two work stations were 'generally acceptable'. In other words, the ratio of simulation and measurement values at any measuring point should not be less than 2 : 3 (or approximately 0.67) and not more than 3 : 2 (or 1.50), so that the values do not lead to a significant difference in their subjective effect. This criterion is applied in the following sections to evaluate the simulation results.

Configurations Setting

The second objective of this study is to determine the effect of various configurations of the prototype inside the test room. Two prototypes were modelled inside the test room, and were placed either on the short walls or on the long walls. Seven configurations (namely 1 until 7) were introduced, see Figure 4. In most configurations, the prototype was split into two equal parts; each consisted of 4 × 4 tiles. Each opening had a dimension of 0.90 m × 1.20 m, and the height of the window bottom in all configurations was 0.93 m from the floor, i.e. the same as in the tested configuration.

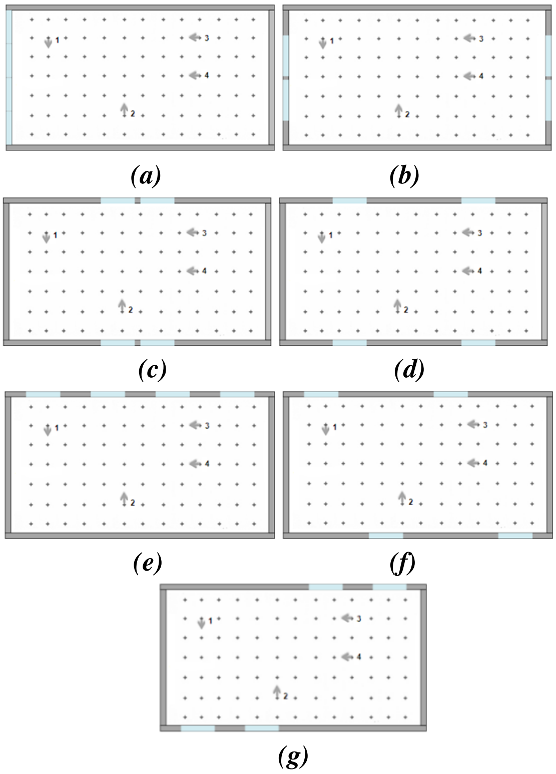

Fig. 4: Floor plan of the test room with the prototypes in configurations (a) 1, (b) 2, (c) 3, (d) 4, (e) 5, (f) 6, and (g) 7; adapted from Mangkuto et al. (2014)

Simulations in *Radiance* and *Evalglare* were run to obtain the space availability, uniformity, and DGP at the defined four observer's positions. For this analysis, the space availability was evaluated for the minimum criteria of 500, 300, and 200 lx.

Results

The lighting simulation and measurement results of the prototype generally show a good agreement, as shown in Figure 5, for all measurement points and settings. The maximum relative difference was 28% at the farthest point under the 25% setting, possibly dominated by measurement accuracy limits. Ratio of the simulated value to the measured one at all points is always found to be within the range of 0.67 ~ 1.50, suggesting that the computational model is sufficient to reproduce the scenes without yielding a significant subjective difference.

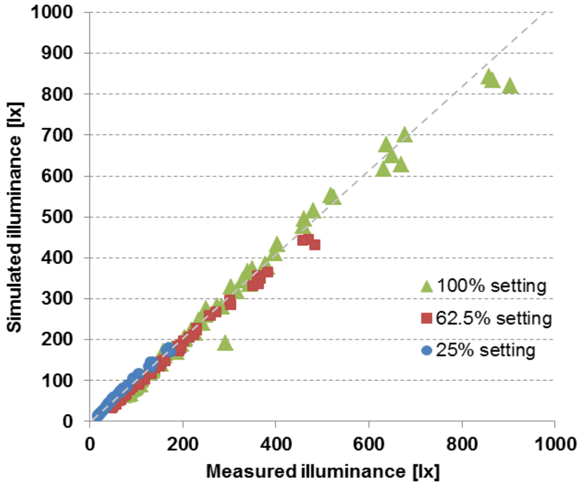

Fig. 5: Graphs showing the relationship between simulated and measured horizontal illuminance under 25%, 62.5%, and 100% of the maximum setting

Tab. 1: Space availability, uniformity, and maximum DGP in the test room, under all simulated configurations at 100% setting

	C1	C2	C3	C4	C5	C6	C7
%A 500lx	34	29	48	31	34	25	33
%A 300lx	52	93	67	89	92	84	81
%A 200lx	68	100	96	100	100	100	100
U_0	0.28	0.59	0.35	0.51	0.55	0.48	0.55
DGP max	0.30	0.29	0.27	0.25	0.26	0.25	0.26
Pos.	1	1	3	1	2	2	1

The results of space availability, uniformity, and maximum DGP in the test room under all simulated configurations at 100% setting are illustrated in Table 1, for all measurement points. Taking 200 lx as the criterion for minimum workplane illuminance, nearly all of the configurations yield a space availability of 100%, except Configuration 1 in which all of the four openings are placed on a short wall. Taking 300 lx as the criterion, the largest space availability (92 and 93%) is found in Configurations 2 (two openings on each short wall facing each other) and 5 (four openings on a long wall). Taking 500 lx as the criterion, Configuration 3 (two openings on each long wall facing each other, 0.14 m distance between openings on the same wall) yields the highest space availability of 48%.

Regarding visual discomfort, the largest maximum DGP is found in Configuration 1 (0.30), whereas the smallest one is found in Configurations 4 and 6 (0.25). DGP values of less than 0.35 are considered 'imperceptible' (Wienold, 2009; Reinhart & Wienold, 2011). Hence, it is expected that the observers will experience a very minimum amount of discomfort glare, when viewing the prototype configurations.

Conclusions

A VNLS prototype has been constructed in a test room to provide blurred view, diffuse and directional light. The prototype consists of an array of LED tiles and an array of LED linear fixtures. Based on the performed measurement and simulation, computational model of the prototype is considered sufficient for the purpose of reproducing the test room scene.

Seven configurations of two prototypes with equal total opening size in the test room were modelled and compared to each other. Space availability in the test room can be optimised by placing a prototype on each short wall facing each other, or by placing two prototypes on a long wall.

This work aims to assess how VNLS influence the indoor lighting performance and visual comfort in the early design stage. Therefore, it is based on measurement and computational modelling and simulation of the relevant prototypes. Future works should be focused on assessing user's perception of the prototypes. A thorough study and analysis on how people actually appraise VNLS in reality would turn be the pre-requisite before implementing the design in the real world application.

Acknowledgements

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Evaluating the experience of daylight through a virtual skylight

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Introduction

People generally have a clear preference for daylight over electric lighting as a source of illumination (Boyce et al., 2003). For example, in an office setting people prefer to have daylight for enhanced psychological comfort, a more pleasant office appearance, increased productivity, and assumed health benefits (Heerwagen & Heerwagen, 1986). Moreover, daylight affects humans psychologically and physiologically and has been associated with many positive health and wellbeing effects such as improved mood, enhanced morale, lower fatigue, and reduced eyestrain (Edwards and Torcellini 2002). However, in current times, people spend most of their time indoors in rooms with no or limited daylight entrance. This raised the questions whether it is possible to create electric lighting solutions that mimic daylight in spaces where there is no or limited access to real daylight. For example, in bathrooms, meeting rooms, basements, hotels, or shopping malls.

Virtual skylight

Some attempts to create virtual daylight sources and virtual windows have been made (e.g. Van Loenen et al. 2007; Fraunhofer, 2012; Skyfactory, 2014). These solutions proved successful in creating a virtual outside view, but typically are less successful in mimicking the daylight. Most existing solutions provide an outside view using displays, printed translucent sheets, or coloured light sources, resulting in light effects in the room that are typically not appreciated by people. For example, due to the unnatural colours of the skin when being exposed in coloured light. Another problem is that these solutions typically do not provide sufficiently bright white light for functional use.

Fig. 1: Virtual skylight in a hospital corridor

This paper presents a virtual skylight concept that was inspired by the two main components of daylight, namely the diffuse blue light as a result of the Rayleigh scattering principle in the sky and the direct white or yellowish sunlight. The virtual skylight concept, developed in Philips Research Laboratories in Eindhoven, is a lighting solution that aims to create a realistic blue sky view, and at the same time provide high quality white light in environments with no or limited access to daylight. Under larger angles, the luminaire appears blue to provide the illusion of a blue sky view, while underneath the luminaire white light is emitted providing the impression of direct sunlight.

User experience test

Goal of this study is to investigate the user experience of a virtual skylight, focusing on the experience of the light effect. For this study, the virtual skylight was prototyped using a commercially available 600x600 LED module (Philips SmartPanel, 4000K, 3400lm). This product was adapted by adding an optical structure to provide a blue sky effect. The virtual skylight (VS) was compared with the standard panel without the optical structure (SP) and the same module with a blue filter to mimic a blue sky (BF). The BF concept was created by a local lighting designer using an additional translucent blue acrylic filter under the LED panel, a common method to create a blue sky effect.

Since the main focus of this study is the user experience of the light effect created by the VS (blue sky view combined with white sun light) compared to alternative solutions (SP and BF), as much of the other factors were kept the same between the three conditions VS, SP and BF. Identical diffuse LED light panels (Philips SmartPanel, 3400lm, 4000K) were used in all three conditions, but in the VS and BF the aforementioned modifications (optical structure / blue filter) were made. All light panels were installed in identical positions in equal size rooms and all modules were slightly recessed in the ceiling to provide the illusion of a ceiling window / skylight. As it was decided to compare the 3 concepts using the same LED panels with and without modifications, the resulting illuminance and CCT levels varied per condition. Also, the light distribution varied between the three conditions with the SP and BF having a more uniform distribution in the room (brighter walls), while VS had a more directional white light output (darker walls). It was decided not to control for these differences, but compare the total light effects resulting from the 3 product concepts.

Three test rooms were prepared on the 17th floor of an office building in Shanghai, China, one for each condition. The rooms were at the inner side of the building with limited daylight entrance. The test rooms had almost identical dimensions (see Figure 2). In each room, four lighting modules of 600x600 mm each were installed at similar locations in the room in a 1x2 configuration (see Figure 2). In each room, illuminance and spectral measurements were taken horizontally at the desk and vertically at position of participants' eyes to objectively specify the lighting conditions in each room.

Tab. 1: Light measurements in experiment rooms

	VS	SP	BF
Illuminance desk (lux)	675	1286	413
Illuminance eye (lux)	379	809	252
CCT desk	5158	3903	12895
CCT eye	5637	3907	12830
CRI desk	85	82	60
CRI eye	81	82	60

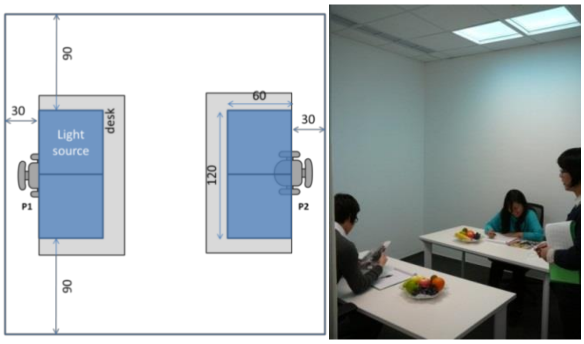

Fig. 2: Experimental setting

Table 1 presents an overview of the main differences between the three experimental conditions.

Per test session, two participants were welcomed and shortly introduced into the objective and procedure of the experiment. Then, following a counter-balanced rotation schedule, participants visited one of the experimental rooms and were seated behind the desk. They were asked to perform some free reading tasks in glossy magazines and non-glossy newspapers. After this task, they were asked to answer a lighting experience questionnaire containing items about brightness perception, color rendering, naturalness, daylight experience, and overall light quality. After completion of the questionnaire, participant moved to the second and third room, following the same procedure. After experiencing all three conditions, participants were interviewed ("*Which of the three scenes: 1) are most attractive and why?; 2) provides the strongest skylight effect and why?; 3) makes you feel most pleasant and why?*") and asked to rank the three light conditions on the daylight impression they provided.

Thirty Chinese participants were recruited via an external agency with the following profile: 25-40 years old (male and female); office workers of foreign companies, state-owned companies, and local companies; no eye/sight problems. All participants received a monetary compensation for participating in the test through the agency.

Results

The first impressions of VS and SP were similarly positive. The main difference between VS and SP in initial participant responses was that VS was perceived to give a natural light effect and SP was considered to give a bright and warm light effect. The first impression of BF was very different and less positive. It was often described as giving a cold and depressing light effect, although some people also referred to it as refreshing.

Participants (N=30) rated the lighting experience in the room on a 5-point scale for 13 items. For the first three items, bi-polar scales were used. For example, for brightness in the room, 1 would mean too dim, 3 would be optimal, and 5 would be too bright. For the other items, Likert scales were used where 1 is the worst rating and 5 the most positive rating. For each item, the mean scores per condition (VS, SP, BF) are presented in the second column of Table 2. To test whether the means for the VS condition were significantly different from the SP and BF condition, paired t-tests with a confidence interval of 95% were conducted. The third column 'VS versus SP' presents the direction of the difference. For example, if VS scores better than SP this is denoted with VS > SP. Furthermore, it lists the p-values. Similarly, the fourth column presents the results of the comparison between VS and BF. It should be noted that in total 26 paired t-tests were done which introduces the risk of type I errors due to multiple testing. Even if there would be no differences between the conditions, one could expect 1 significant result by chance (0,05 x 26). In our study, 19 out of the 26 comparisons showed significant difference. No formal correction for multiple testing was done, due to the known problems with these methods (i.e. Nakagawa, 2004).

After being exposed to all three conditions, the participants were asked which concept provided the strongest skylight effect. 57% of the participants believed the VS provided the strongest skylight experience, versus 30% for BF and 13% for SP. Some illustrative remarks participants made about the VS (translated from Chinese) are: "Yellow sunlight", "Blue sky", "Feeling of depth", "Feels like the sun is coming through the window", "Bright", and "Sun effect." Based on their comments, the main reason they choose the VS is that it could best mimic the effect of daylight passing through a ceiling window, combining the yellow sunlight with the blue sky.

Tab. 2: Mean scores light experience questionnaire for three conditions including direct comparisons (t-test)

N=30	**Mean score**			**VS versus SP**		**VS versus BF**	
	VS	*SP*	*BF*	*Direction*	*p*	*Direction*	*p*
Brightness room[1]	2,73	3,4	2,2	VS > SP*	0,000	VS > BF*	0,003
Brightness desk[1]	2,83	3,37	2,4	VS > SP*	0,025	VS > BF*	0,025
Color tone room[1]	3,2	2,6	3,7	VS > SP*	0,004	VS > BF*	0,014
Comfortable light	3,33	3,7	2,83	SP > VS	0,110	VS > BF*	0,019
Naturalness of objects	3,5	3,67	3,03	SP > VS	0,455	VS > BF*	0,008
Naturalness of skin tone	3,6	4,07	3	SP > VS*	0,008	VS > BF*	0,003
I feel this room has a ceiling window	3,43	2,93	3,07	VS > SP*	0,037	VS > BF	0,054
I feel daylight is entering the room	3,47	3	2,77	VS > SP	0,060	VS > BF*	0,001
Natural light	3,4	3,37	2,83	VS > SP	0,856	VS > BF*	0,001
Make me feel relaxed	3,6	3,6	2,97	VS = SP	1,000	VS > BF*	0,006
Makes me feel energetic	3,23	3,77	2,67	SP > VS*	0,013	VS > BF*	0,002
Makes me feel pleasant	3,5	3,77	2,97	SP > VS	0,234	VS > BF*	0,000
Overall light quality	3,5	3,97	2,93	SP > VS*	0,014	VS > BF*	0,004

** indicates statistical significance at 95% confidence;*

[1]Please note that these items were scored on a bi-polar scale, meaning that 3 is the best possible score.

Discussion and conclusion

Overall, the results clearly show that VS scores better on all items than the BF. On some items SP scores better than VS (‘Naturalness of skin tone’, ‘Energetic feeling’, and ‘Overall light quality’), while the VS scores better than SP on brightness, color tone, and items related to daylight experience. The daylight experience was measured with three items: “*I think the room gives me the feeling that there is a ceiling window*”; “*I have the feeling that there is natural light from outside coming into the room*”; and “*I find the light in this room very natural*”. Based on the results, we can conclude that the VS provides the best daylight experience of the three conditions that we tested. However, on several items including overall light quality the SP scored better. There are a few possible explanations for this. First, the SP provided much more light than VS and BF, including a large amount of indirect light reflected from the walls. The VS provided less indirect lighting via the wall due to the optical structure that creates the blue sky effect. As a result, people appreciated the light quality under the VS but did not appreciate the darker walls compared to the SP room. Furthermore, the light solutions were presented in an office setting and participants were provided with a reading task. The overall light quality has likely been evaluated with this specific context and task in mind. For other environments or tasks, other factors might determine experienced light quality.

To conclude, this paper presented a study to explore whether it is possible to create an electric light source that can provide an impression of daylight. The virtual skylight concept was presented that aimed to provide the impression of a blue sky view through the ceiling, combined with good quality white light in the room. The results of the user study showed that the virtual skylight can create a pleasant light experience that is closer to a daylight experience than standard electrical lighting and the tested alternative solution. One should realize the limitations of this study and that only three electric lighting solutions were compared. There might be other electric lighting systems that provide a similar or even better lighting experience than the VS. Also, the VS was not compared with a real skylight. This would be interesting for future research, although it still seems very difficult to come close to the real daylight experience. But all in all, this study shows first indications that the virtual skylight might become a viable alternative to traditional electric light sources and provide a more natural light experience indoors. In particular for applications where functional, aesthetic, and emotional lighting needs have to be fulfilled.

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An Extensive Daylight Assessment Through Quantitative Appraisal and Qualitative Analysis

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Introduction

The dynamic nature of sunlight poses many challenges when defining quantitative and qualitative targets to effectively illuminate an interior space. Using a complex calculation approach in order to evaluate an appropriate sun lit space often disregards the real need of the final users, making Daylight Assessment completely ineffective as a response to multiple requirements.

An integrated approach that considers CBDM, *Climate Based Dynamic Modelling*, thus disregards from the process of existing dynamic analysis a comprehensive assessment of the preferences of the occupant, which may vary not only in relation to the target audiences, but also on the users positions in the room.

Based on these preliminary assumptions, the paper aims to define how to relate a dynamic quantitative approach with a qualitative assessment in order to get a comfortable daylit room to respond users' needs. The paper proposes some reflections about what are the actual relation in-between natural light thresholds, according to national regulations, the quantitative evaluations, involving dynamic metrics and the actual users preferences (Mardaljevic and Nabil, 2006).

Qualitative assessment and users preferences in daylight evaluation

A qualitative type assessment can be carried out by questionnaires that evaluate subjective preference about daylight doses, about users' preference between direct or indirect light and other daylight parameters, whose precise purpose is to investigate the real perception of light, levels of illuminance, contrast levels and any type of visual discomfort conditions.

The tool most widely used consists of the assessment questionnaires known as POEs, *Post Occupancy Evaluation*, which measure the degree of satisfaction of real users within the interior space, but whose major weaknesses stays in the fact that POEs failed to function spatially.

This paper focuses on the evaluation of building performance relevant to daylight availability and internal light distribution, referring to visual comfort, occupant satisfaction, by using the CBDM approach. The methodology involved basically covered both quantitative evaluation, carried out by new Daylight Dynamic Metrics and occupants' subjective assessments, considering the *adaptive comfort model*.

Toward the definition of an extensive daylight assessment procedure

The most common and diffuse approach to Daylight Assessment can be defined according to a "bottom up" methodology, i.e., one based on the principle that, in accordance with the requirements to be pursued, it is necessary to determine the limits and thresholds within which the daylight levels need to be established to satisfy an effective daylit environment and to carry out visual tasks.

The analysis proposed below aims at outlining an "integrated cascade analysis framework" (Fig.1). The potentiality expressed by the CBDM method is thus enhanced thanks to different reading schemes. It will be possible to use light distributions maps- useful in order to detect users' preferences-, to obtain a comprehensive picture of the actual lighting conditions, and helpful to predict potentially harmful situations in terms of glare and local overheating. A large amount of lighting and users' behaviour data should provide valuable clues from which to derive *targeted actions* to reduce or increase the amount of light in some specific areas.

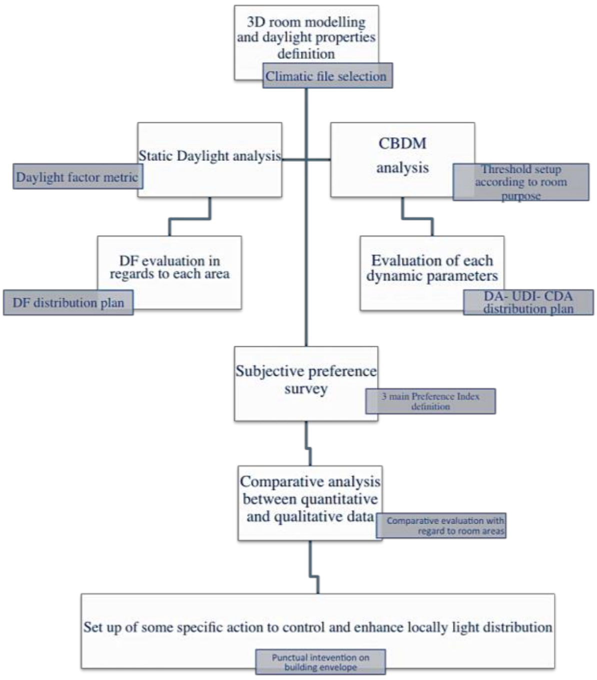

Fig. 1: Integrated cascade analysis framework

The numeric and quantitative evaluation according to dynamic daylight metrics is to be followed by a further survey, to collect additional information to correlate the presence of natural light with the subjective perception of the occupants. By means of the POE, based on ASHRAE 55/1992, in accordance with ISO 7730/1994, it is possible to understand the as yet unexploited potential of a building, increasing its receptive capacities and developing proper Daylighting devices, appliances for artificial light and shading systems.

The research, hitherto carried out on a number of interior spaces for education, was a first attempt to combine traditional quantitative data with a review of the individual preferences that guide users' choices, integrating a cognitive-emotional assessment with a regular lighting appraisal.

Case study and application of the new assessment protocol

The new integrated Daylight Assessment procedure was tested in different rooms-seminar ones, lecture halls and traditional rooms with loose seating- at the Faculty of Engineering of the University of Parma, Italy. The objective of the survey was to deduce, starting from analysis of objective luminous parameters and assessing the degree of comfort associated with them, the overall degree of environmental acceptability of a room. The procedure encompasses a qualitative appraisal, carried out through questionnaires distribution among students and a subsequent quantitative analysis through in-site daylight measurements and CBDM metrics calculations. Four assessment campaigns were carried out during March, June, September and December 2012, mostly under CIE overcast sky conditions and ca.90 students per time were inquired. The examined classroom has daylight opening on two sides, with large floor-to-ceiling windows on SE, and 5 windows (1.5x2.0m) on NW side, each one equipped with venetian blinds.

According to the first part of the framework, DF evaluation was carried out firstly and then *Daylight Autonomy-DA*, *continuous Daylight Autonomy-cDA* and *Useful Daylight Illuminance-UDI* were calculated. The quantitative outcomes were thus obtained by integrating several reprocessing steps, using diverse software packages: Dialux helps for DF and lighting levels evaluation, Daysim for CBDM metrics calculation and Ecotetc was eventually involved to easily visualize values distribution. This phase is followed by a simultaneous analysis of the reviews of preference and visual satisfaction obtainable from subjective questionnaires (Hygge and Loftberg, 1997). The Italian questionnaire, duly adapted and translated from POEs (Watson, 1997), and other questionnaires (Fornara et al., 2007), consisted of distinct sections, on sensorial perception of students and on *emotional quality of places*.

On that premises, the aggregate read of data obtained for each classroom surveyed was combined to achieve some significant parameters referring to *Index of dissatisfaction with the lighting*, *Index of discomfort due to the lighting*, *Index of lighting preference* (Gherri, 2013), and in order to allow easier reading of the percentage values with respect to the position of each occupant with respect to the three areas (Front 1-NE, Front 2-SW and Interior Wall).

Results of qualitative analysis of visual comfort through subjective evaluations

The preferences expressed by the interviewees show all a strong variability in the results, as can be seen on the classroom plan schemes (Fig. 2, 3, 4).

Above all, the survey results demonstrate strong discrepancies with respect to the experimental values calculated by the softwares, as well as in the students' preferences (Tab. 1).

On the *Index of dissatisfaction* (Tab. 2), referring to the aggregate values of the questions about the sensation perceived by the occupants in respect of illumination levels, to the possible presence of discomfort glare, irritating reflections and other manifestations of over- or under-illumination, it can be deduced that the majority of the interior space is characterized by poorly lit areas. Only a small number of interviewees, seated in the vicinity of the two fenestrated fronts express discomfort due to the presence of an excessive amount of incoming light (7% and 12% in Tab. 1).

Tab. 1: Index of Dissatisfaction

Quality of the lighting	Front 1	Front 2	Wall
Excessive	7%	12%	12%
Bearable	31%	20%	20%
Agreeable	27%	15%	15%
Insufficient	31%	40%	40%
Almost absent	4%	13%	13%

Tab. 2: Index of Discomfort

Quality of the lighting	Front 1	Front 2	Wall
Optimal	8%	6%	15%
Pleasant	48%	60%	43%
Agreeable	19%	17%	14%
Irritating	4%	13%	21%
Unbearable	21%	4%	7%

Tab. 3: Index of Lighting Preference

Quality of the lighting	Front 1	Front 2	Wal 1
Highly controllable	6%	3%	5%
Controllable	28%	37%	12%
Constant	33%	23%	28%
Not controllable	11%	27%	35%
Unmanageable	22%	10%	20%

It is evident, despite the absence of sources of direct light, that for the inner wall opposite the NE front, where DF values are equal to 0.5% a small share of interviewees perceived excessive lighting (20 and 12%, Tab.1), while the values of *Dissatisfaction with the lighting* (Fig. 2) show general appreciation from those sitting in the vicinity of the windows.

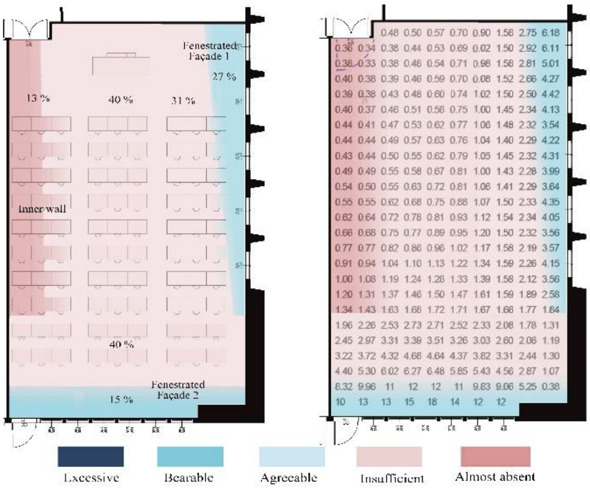

Fig. 2: Index of Dissatisfaction and DF values

In the same way, the close proximity of some subjects to Front 2-SW, where the percentage of DF medium is fairly high (12-18%) according to Italian recommendations, do not cause any discomfort among the interviewees, who seem to enjoy the high

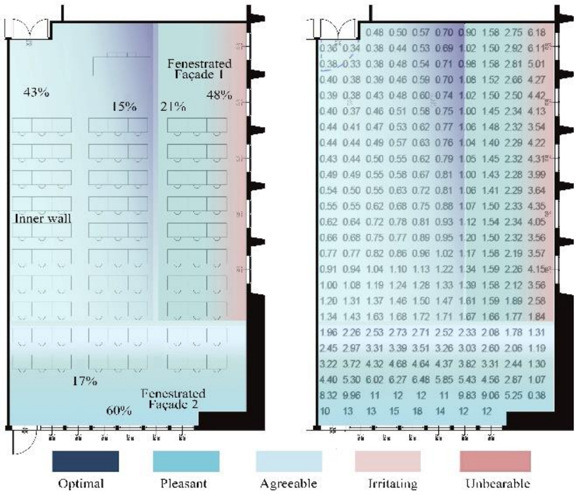

Fig.3: Index of Discomfort and DF values

illumination levels, 15% to 20%, confessing their appreciation.

Aggregated values relating to visual discomfort (Tab. 2) are pointed up by a general propensity of the subjects to express positive opinions, assessing the natural lighting in the vicinity of Front 1-NE and Front 2-SW pleasant or appreciable (in blue), both in the areas immediately adjacent to the windows, where the DF exceeds the recommended threshold of 3% according to Italian lighting regulation and in the remoter areas, where daylight is virtually absent.

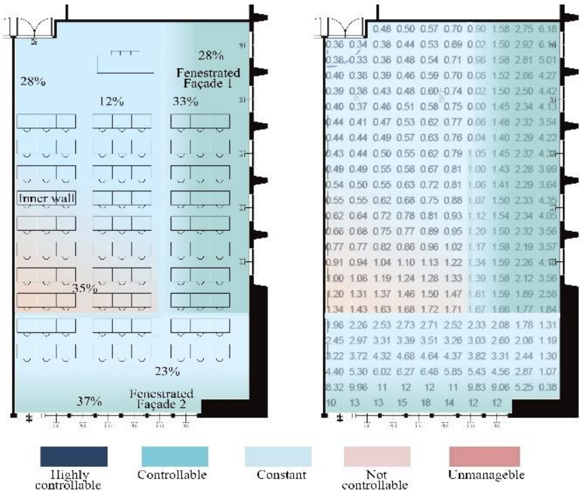

Fig. 4: Index of Lighting preference and DF values

A small percentage of votes states the occurrence of irritating and unbearable lighting situations, especially for those seats behind the south front (Front 2), which seem, however, not to suffer from excessively high levels of illumination.

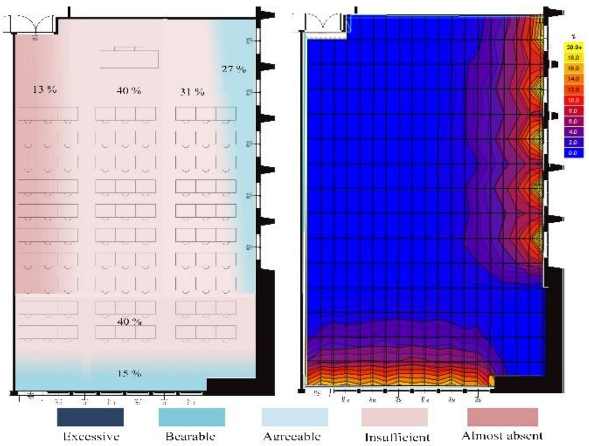

Fig. 5: Index of Dissatisfaction and DA_{500} values

Similarly, positive votes and general appreciation were also expressed for those areas that, despite not reaching the prescribed value of 500 lux or the 3% threshold for DF, settling instead on much lower levels, show again how the prescribed limits are not reliable and very distant from the actual users desires. Instead, what came out of the comparison between DA_{500} and the *Index of dissatisfaction with the lighting* is that the threshold target of 500 lux, evaluated as optimal for visual tasks, is actually only reached 20-30% of the time.

Therefore, it would seem useful to intervene to maximize the percentages relating to the DA_{500} and to ensure uniform light distribution in this area. As demonstrated by this comparison, a reading combining dynamic parameters and values from the subjective questionnaire can better disentangle information arising from a strictly qualitative assessment from those of a quantitative variety to complete Daylight Assessment. Therefore, it would seem useful to intervene to maximize the percentages relating to the DA_{500} and to ensure uniform light distribution, in accordance to what most of the users expect for internal illumination.

Conclusions

The synchronous analysis of the data, divided by area and intervals of illumination, can provide timely and targeted interventions, differentiating actions aimed at enhancing the illumination or at shading areas excessively lit, in order to increase the uniformity of the illumination or to set solutions for artificial lighting. As demonstrated, a Daylight Evaluation encompassing dynamic analysis and users' preference values, gathered from tailor-made questionnaire can better disentangles information arising from a strictly qualitative assessment from those of a quantitative one, in order to integrate Daylight Assessment.

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Personal Lighting Control for Open Offices

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Introduction

Does it make sense to offer consensus lighting controls in open office spaces? This was the starting point for our research.

Many benefits of personal controls have already been demonstrated for private offices and open offices offering workstation-specific lighting (Boyce et al, 2000; Veitch et al, 2010). In an open office lighting is often designed as a regular grid of luminaires in order to satisfy local regulations and design guidelines for lighting quantity and uniformity in the most efficient way. The furniture layout is often not known and office layouts are likely to change throughout the lifespan of a lighting installation. As a result, the luminaires grid in most cases does not match the desks grid. This makes it challenging to offer lighting controls in an open office in a truly personal way.

As luminaires get combined into control groups, users of the same group need to agree on their preferred light level. Naturally, difficulties might occur when trying to reach this consensus, since individual light level preferences vary considerably. This consensus way of controlling lights might lead to a conflict experience (Moore et al, 2000) possibly undermining the known benefits for true personal control. As a result, the focal question for the current study was to explore whether the benefits of having control outweigh the nuisance of needing to share control compared to a fixed light level installation.

Method

In order to observe long term effects of having controls and create the possibility to explore the experience of conflict, the choice was made to conduct a field study. For this we modified a lighting installation in an existing open office space (south facing). Then we relocated office workers from a similar open office in the building into our test bed office.

The top view of the office where the field study was conducted is shown in Figure 1. The challenge was to give lighting controls to users positioned at the middle desks situated in between the two rows of luminaires. In order to give the participants equal access to the lights, luminaires were combined into control groups. We strived for the smallest control group size possible in order to make it easier for members of the same group to reach a consensus, as shown in the study of Moore (Moore et al., 2002). This resulted in

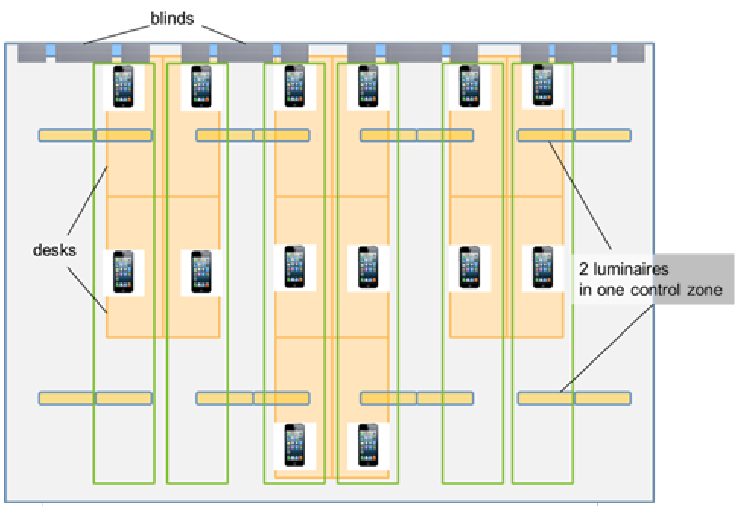

Fig: 1. Top view of the test bed

combining two luminaires per group as shown in Figure 1, leading to 6 control groups with 2-3 users per group. This way, the control of lighting is not personal but labeled as "consensus" control. Within every control group 2-3 users need to agree on the light level they choose for their two luminaires.

To realize our experimental test bed, we used an existing lighting installation in an open office space with 16 TL5 49W lamps. The 16 luminaires were equipped with DALI dimmable ballasts and mounted light and occupancy sensors at every luminaire. During the "user control" phase of the study, every participant had 2 options to control lights; an app on an iPod that was placed at every desk, and a software widget installed on the user's laptop. Both options allowed participants to control lighting over the whole dimming range from off up to 500 lux output by using a slider on the user interface. The center 12 luminaires were controllable with the user interface, while the outer 4 luminaires adjacent to the walls were fixed at the default level to maintain sufficient and uniform wall brightness.

The study participants were asked to evaluate the office lighting conditions by filling out a 5 minute survey each week. Every three weeks a 20 minute elaborate survey was accompanied by a one-on-one 15 minute interview. 14 participants took part in the study, involving 3 females and 11 males. 9 participants were older than 45 years of age and 5 were younger.

During the study, every participant had a fixed desk and every desk controller was hard coded to be connected to a particular control zone. The occupancy based lighting control in the test bed was implemented for the whole space so that when the first person would enter the space the whole space would light up. When the last person would vacate the space, after a timeout of 30 minutes, the lights would go off. The light level selected last for each zone was remembered and restored every morning when the lights were switched on again.

Data was collected from the start of September till mid-December. We designed the experiment to first start with a reference "no control" condition where the participants did not have lighting controls yet. All luminaires were set at their full output delivering on average 500 lux on the desk surface (excluding daylight). Data of 3 weeks was collected while the participants experienced this fixed light level condition. After this period, we brought in the iPod controllers and installed the light dimming widget on their laptops initiating the 7 weeks of the "user control" condition. Due to the novelty of the controllers, users played with light levels in the first week disproportionally more than in the rest of the "user control" period. Therefore this first week was excluded from the analysis. Finally, the "no control" condition was repeated for the remainder of 3 weeks by removing the iPods and uninstalling the widgets. This design balanced the number of sunny and cloudy days occurring in "no control" and "user control" conditions in the first and second half of the experiment. At the same time, we wanted to counterbalance the order effect of the two conditions.

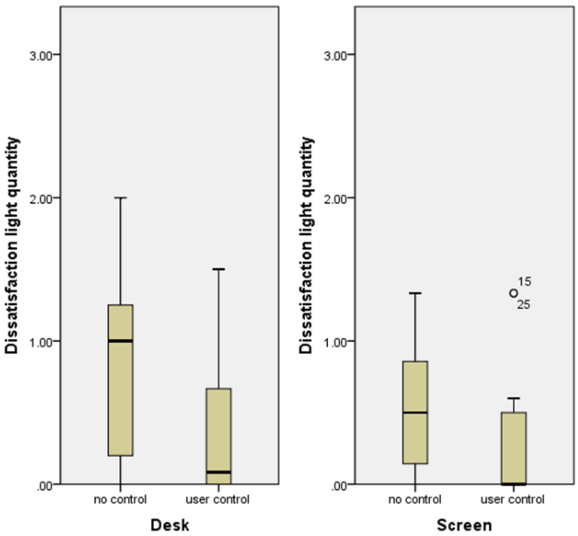

Fig. 2: Dissatisfaction with the amount of light (0 = satisfied, 3 = dissatisfied)

The elements included in the survey were evaluated by the participants on an ordinal scale. Hereby, as well as due to the relative small sample size, the data was analyzed using a non-parametric Wilcoxon signed ranks test.

For the significance tests a liberal level of significance of α=0.1 was motivated by the explorative nature of this study, a relative small sample size and the use of non-parametric statistics.

Results

Each week, we asked the participants to assess the amount of light they experienced at their desks, on their screens and due to daylight. The box-plots shown in Figure 2 illustrate the differences between median scores and distributions obtained in the two conditions. The amount of light on their desks as well as on their screens was rated with a significantly lower dissatisfaction in the "user control" condition (Z= -2.179, p= .029, r= .582 on the desk and Z= -1.988, p=.047, r= .531 on the screen). At the same time, there was no effect of the controls on the assessment of daylight in both experimental conditions (Z= -1.246, p=.213).

The quality of light (shown in Figure 3) was evaluated significantly higher (Z=-1.664, p=.096, α= .1, r= .445) in the "user control" condition than in the reference condition.

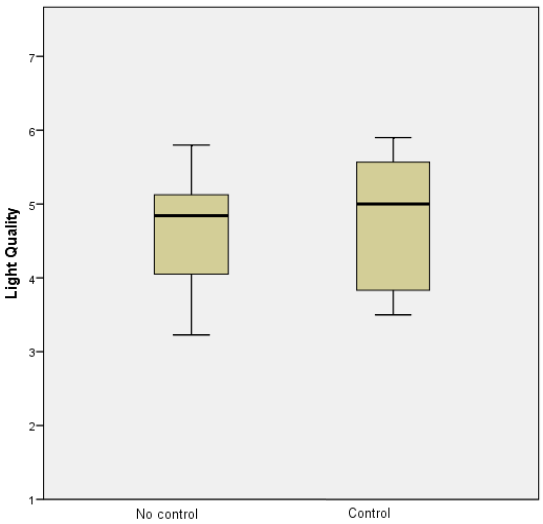

Fig. 3: Satisfaction with the quality of light (scale from 1 to 7: higher = better quality)

With respect to the self-rated workplace satisfaction no difference was found between the conditions. Similarly, we did not find any effect of the controls on the mood state of the participants.

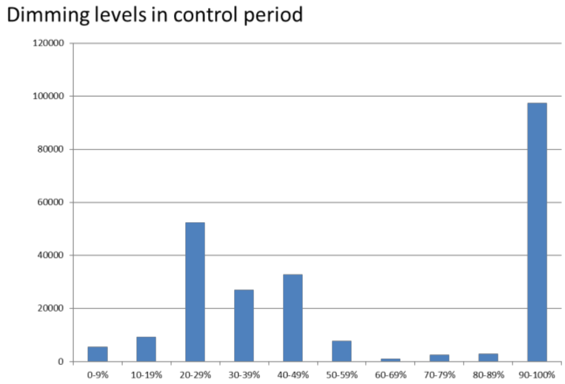

Fig 4: Histogram of the dimming levels distributed across luminaires output in %

Regarding conflict-related aspects, we asked the participants to estimate the frequency of conflict they experienced with other users when trying to control lighting on a 7-point scale, from 1-never to 7-frequently, and to estimate the degree of the experienced conflict from 1-no conflict at all to 7-very high conflict. The median of the frequency of conflict lies at 2.32 (st. dev. 1.49) and for the degree of conflict at 1.61 (st. dev. 0.83). The questions around conflict were not asked in the reference condition to avoid a possible bias as a result of subject-expectancy. As such we cannot compare the conflict scores to a baseline but we can conclude that the degrees of conflict experienced are relatively low, being close to "no conflict at all" (score 1).

During the last interview with the participants, we sketched them a scenario in which they could decide whether to sit in an office without lighting controls or in an office with controls offered in the same way as they experienced them during the user study. 10 out of 14 participants gave a preference for an office with "consensus" controls, 3 said it would not make a difference for them and 1 preferred an office without controls.

Apart from the effects on the user experience, we also looked into the energy saving potential of the controls. For this reason, Plugwise power meters were installed to measure the amount of electric energy consumed by the luminaires in the "no control" (299.24kWh) and "user control" (216.92kWh) conditions. The saving in the condition with user controls amounts to 27.5%. This result is in line with previous studies that showed an average saving of 31% due to personal control (Williams et al, 2012). When expressed in luminaires output difference, in the "user control" condition the lighting was running at a 45% lower output level than in the "no control" condition. This can be illustrated with a histogram of the dimming levels in the "user control" period distributed across luminaires output in %, as shown in Figure 4. A high percentage of time spent behind a screen and in a space with daylight admittance was shown to be associated with lower dimming levels chosen by office workers (Moore et al, 2002; Newsham et al, 2008). It is important to note that daylight harvesting was deliberately excluded in this study to enable proper interpretation of the results. As such, the comparison is done to a reference condition in which all luminaires ran at a 100% output level that was not daylight regulated.

Discussion

The effect on the lighting quality turned out to be smaller than on the lighting quantity. This could be explained by the fact that the participants had the biggest influence on the amount of light at their desk, while lighting quality relates to the lighting conditions in the entire office space with aspects outside of the direct influence of the participants.

Even though no effect was observed regarding workplace satisfaction and mood, the result is worth mentioning. It shows that consensus control did not introduce any negative effects on either the workplace evaluation or on the emotional state of the participants.

Conclusions

The study shows that finding a consensus lighting level is not trivial and does introduce a small element of conflict. However, this conflict is small to such an extent that it fails to exert any adverse effect on people's emotional states or their workplace attitude. On the contrary, having lighting controls did introduce a positive effect on the evaluations of the amount and quality of light as experienced by the participants. Finally, a vast majority of users preferred to be sitting in an office with shared controls rather than without controls.

Although personal controls were positively experienced by end-users, they are not among decision makers who make a choice for a particular lighting installation. From this perspective, a 27.5% saving offers an attractive energy bill reduction that could be offered on top of other energy savers like occupancy control and LED based luminaires.

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Acceptable Fading Time of a Granular Controlled Lighting System for Co-workers in an Open Office

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Introduction

Currently available state-of-the-art intelligent lighting systems have integrated occupancy and daylight harvesting sensors, offering the ability to have granular dimming in the office space. Each luminaire is capable to detect and respond independently to people's presence at their workplaces as well as regulate luminaire output dependent on available daylight. This granularity of control also allows the ability to choose personal lighting preferences. These systems enable efficient lighting energy use.

Besides energy saving benefits user satisfaction is an important aspect of light dimming in open offices. So, how fast can lighting be dimmed without causing discomfort for the users in the office?

Studies done on dimming speeds show that acceptable dimming speeds for workers themselves are between 16 and 37 lux/second when dimming down from 500 lux in 10 seconds (Akashi & Neches, 2004; Newsham, et al., 2008), and around 27 lux/second when dimming up from 300 lux in 10 seconds (Akashi & Neches, 2004). These dimming speeds were demonstrated for a situation where 1 person was sitting in a room when only light changes occurred.

In an open office set up however, users might not only experience light changes at their own workplace but maybe even more often at other workplaces in their surroundings. No studies had been performed yet where occupants experience was evaluated while light changes occurred at other workstations.

Research objective

The objective of this study is to examine what the acceptable dimming behaviour is of a lighting system with granular control in an open office.

Granular dimming of a lighting system constituted of a grid of luminaires is defined as dimming per luminaire per workstation.

For this study dimming is triggered by an occupancy change, i.e. a person leaving or arriving at his or her workstation.

The acceptance criterion in this study is set at 70%, meaning at least 70% of the co-workers need to find the granular dimming behaviour acceptable. This criterion is chosen to be similar to the maximum achievable acceptance reported for a fixed light level lighting installation where 70% of the office workers would be within 100 lux of their preferred light level (Boyce, et al., 2006).

Methods

This study was designed as a randomised repeated measures within-subjects experiment.

Participants

Fifty-five university students (30 Female and 25 Male; age 18-30 years) participated in the study. Each participant participated in one session, which lasted from 9AM to 12PM. Each session consisted of 4 participants. 3 participants performed a task behind desk 1, 2 or 3 (N=41; 22 Female and 19 Male). 1 participant was assigned to be an 'actor' (N=14) who had to leave and enter the room at predefined moments from desk 4. These 'actors' were all excluded from the analysis of the dimming speed acceptance.

Office design

The experiment was conducted in the Experience Lab of Philips Research at the High Tech Campus in Eindhoven, the Netherlands. Daylight was controlled during the experiment by closing the screens to exclude outside light variations. The test bed (Fig.1 and Fig 2) existed of one large office room (7.2x7.2x2.8m). The office was furnished as an open office with 5 workstations, of which 4 were used for this study (desk 1-4) with desks arranged perpendicular to the window.

The electric lighting system consisted of 6 recessed ceiling based Philips PowerBalance LED Luminaires (0.6x0.6m², 3000K, CRI 80, LED28S, 2800lumen) and 10 Philips StyliD Compact power LED spots (3000K, CRI 80, SLED1700, 2000lumen) illuminating the walls to an average vertical luminance of 75cd/m². Only the light output of the luminaire above desk 4 (L4) was varied during the experiment by dimming between 540 and 310 lux on desk 4. The other luminaires remained at the initial light setting, i.e. 30% of maximum output level above desks 1-3, and 1% for the luminaires above desk 5.

Fig.1: Experiment room - luminaire above desk 4 (black circle), which was dimmed during the experiment. Screens were closed to exclude daylight.

Procedure

The experiment included 17 conditions which were presented in random order to the participants during a 2 hour experiment, with a 15 minute break after 1 hour. In this paper only 9 of the conditions will be discussed.

In 6 conditions the luminaire above desk 4 was dimmed down from 540 to 310 lux after the 'actor' left the office, among those 3 conditions were without a delay between leaving and the light change, and 3 had a delay of 5 minutes. For the 3 conditions with and without a delay the fading times were 0, 5 and 10 seconds, resulting in dimming speeds of 230, 46, and 23 lux/second.

In the other 3 conditions the luminaire above desk 4 was dimmed up from 310 to 540 lux after the 'actor' entered the office. The 3 fading times used were 0, 2 and 5 seconds, resulting in dimming speeds of 230, 115, and 46 lux/second.

Participants were not informed prior to the experiment that light changes would occur and no observers were present in the room during the tests.

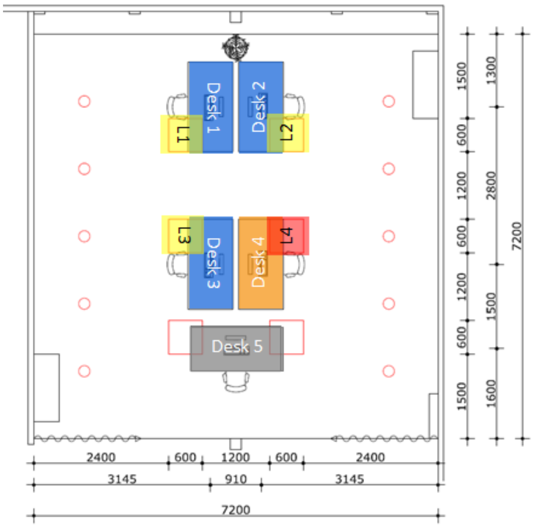

Fig. 2: Plan view of the experiment room.

Task

The participants were asked to perform a cognitive performance task consisting of reading and summarising several texts. All 18 texts were taken from High School English Exams, pre-university education level (CITO, 2013). The reading and summarising was done on a pc screen. This is a typical office task in most offices nowadays. The participant behind desk 4 had the additional task to leave and enter the room when triggered by the experiment leader via a chat message.

While performing their task the participants were asked to press a button on the bottom left of their screen as soon as they noticed a change in their environment. This could for instance be a change in temperature, sound, ventilation, light, odour or occupancy. After they indicated which change(s) they noticed, they were asked for each change to rate how acceptable the change was. This was done on a 7-point Likert scale ranging from 'very unacceptable' (1), via 'neutral' (4) to 'very acceptable' (7). If the participant did not indicate a change when the lights were dimmed the participant was assigned the value 'not noticed' (8). When a change was not noticed we considered it to be acceptable for the participant.

The responses 'acceptable' (6), 'very acceptable' (7) or 'not noticed' (8) are considered to fall into the category 'accepted'. The bars are divided into a light coloured area, representing the 'acceptable' and 'very acceptable' values, and dark coloured area, representing the 'not noticed' values. The white area above the bars till 100% are the combined values from 'very unacceptable' (1) to 'slightly acceptable' (5).

The black dashed line in *Figure 3* represents the 70% boundary value for the 'accepted' responses.

Results

The results for the 9 conditions are presented in *Figure 3*. Dimming down without a delay is acceptable for more than 70% of the participants when this is done in 5 or 10 seconds. The same results are obtained for dimming down with a 5 minute delay. Dimming up in 5 and 2 seconds is also acceptable for at least 70% of the participants. Dimming up and dimming down with and without a delay in 0 seconds is not accepted by at least half of the participants.

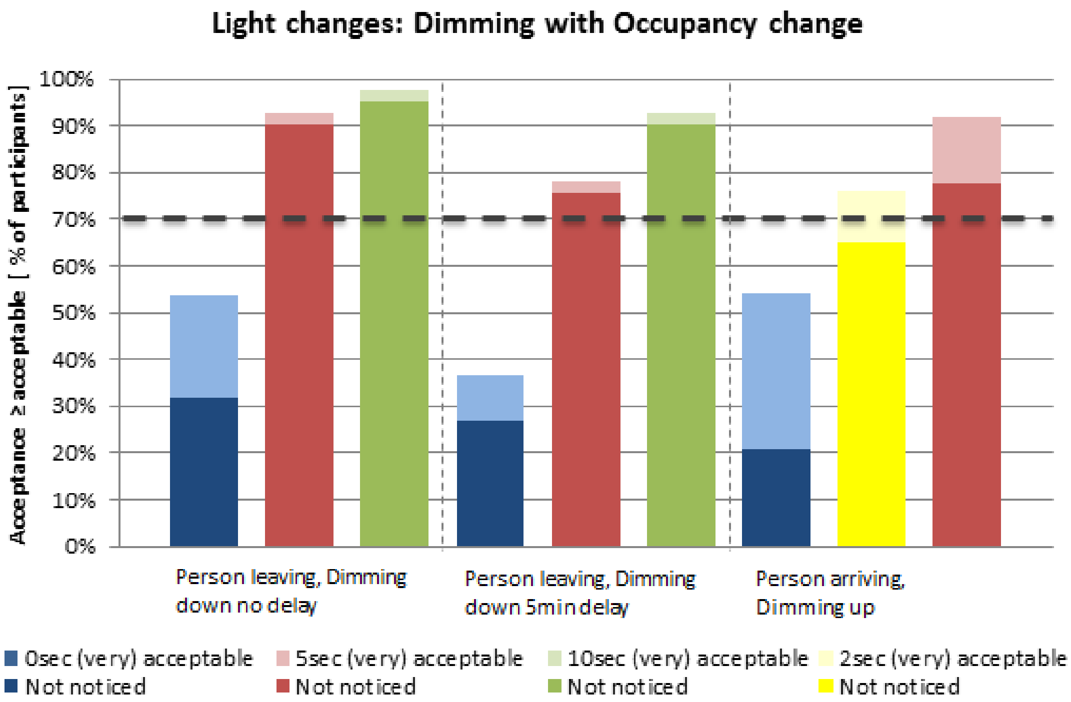

Fig. 3: Graphs of the acceptance level for the three fading times. The black dashed line - - represents the 70% boundary value for acceptance. N=41.

Tab. 1: Test Statistics. Comparison of all dimming down and dimming up conditions for the three different fading times.

	Dimming down No delay			**Dimming down 5 min delay**			**Dimming up**		
	0 vs 5 seconds	0 vs 10 seconds	5 vs 10 seconds	0 vs 5 seconds	0 vs 10 seconds	5 vs 10 seconds	0 vs 2 seconds	0 vs 5 seconds	2 vs 5 seconds
Z	-4.105[a]	-4.646[a]	-1.219[a]	-4.020[a]	-4.199[a]	-1.984[a]	-2.702[b]	-3.549[b]	-1.202[b]
Asymp. Sig. (2-tailed)	.000*	.000*	.223	.000*	.000*	.047*	.000*	.000*	.079

Wilcoxon Signed Ranks Test - N=41. [a] = Based on positive ranks. [b] = Based on negative ranks. *p-value <0.05

A comparison has been made between three fading times in N=41.

TaTable 1 for dimming up and for dimming down with and without a delay to examine if the acceptance level of those fading times would be significantly different.

Also a comparison between dimming down with and without a delay has been made for each of the three fading times. The results of this comparison are presented in Table 2.

Tab.2: Test statistics. Comparison for dimming down with and without a delay for the three different fading times.

	Light Change: dimming down with person leaving; No delay vs 5 minute delay (N=41)		
Fading time	0 seconds	5 seconds	10 seconds
Z	-1.432[a]	-2.083[a]	-1.511[a]
Asymp. Sig. (2-tailed)	.152	.037*	.131

Wilcoxon Signed Ranks Test N=41. * p-value < 0.05. [a] based on negative ranks

Significant differences between the conditions are marked with an * in Table 1 and Table 2.

A significant difference has been found when comparing the acceptance levels when the luminaire was dimmed down in 5 seconds between no delay and a 5 minute delay (p=0.037, avg. acceptance no delay = 7.61, avg. acceptance 5 minute delay = 6.95).

No significant differences are found between the acceptance levels when dimming up without a change in occupancy and with a change in occupancy.

No significant difference is found between the acceptance level for a change in occupancy and the acceptance level for a change in luminance. This means that both the occupancy change and the luminance change are equally acceptable for co-workers.

Discussion

The participants seemed to find it more acceptable when the lights were dimmed down in 5 seconds without a delay when a person left instead of dimming down with the same dimming speed (46 lux/second) after a 5 minute delay. It might be that when dimming down 5 minutes after a person has left his or her workstation, these actions are not anymore linked to each other by the participant.

Daylight has been excluded from entering the experiment room when testing the different dimming speeds. These dimming speeds could probably be faster when the daylight level is sufficient, since people might not notice the artificial light changes.

Conclusion

It can be stated from this study that the minimal acceptable dimming behaviour of a lighting system with granular control in an open office is to dim lights down from 540 to 310 lux in 5 seconds, i.e. a dimming speed of 46 lux/second, with or without a delay when a person leaves his workstation. When a person arrives at his workstation the minimal acceptable fading time is 2 seconds when dimming up from 310 to 540 lux, resulting in a dimming speed of 115 lux/s.

Acknowledgements

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Enlightened thoughts: Associations with daylight versus electric light, preference formation, and recovery from stress

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Introduction

Light is often used as a metaphor for good versus bad in our daily language. Expressions like 'the bright side of life' and 'a bright or even brilliant person' illustrate that we often associate light versus dark with respectively the good versus bad. These associative patterns are an important component in theories explaining preference formation and evaluation, with associative processes affecting implicit evaluations. These implicit evaluations, in turn, form the basis of further evaluation (Strack & Deutsch, 2004).

In this paper, we investigated whether the type and valence of associations evoked by daylight differed from associations evoked by electric light. In addition, we investigated how these associations were related to both preference formation and restorative outcomes.

Several studies contrasting words and symbols in black versus white font indicate that light is associated with positive valence and dark with negative valence (Lakens et al., 2012; Meier et al., 2007; Okubo, & Ishikawa, 2001). In addition to more positive associations, people also generally *prefer* light over dark pictures and sunny environments over overcast environments (Beute & de Kort, 2013). One study even indicated that merely thinking of bright environments while under hypnosis resulted in remission of depressive symptoms for patients suffering from Seasonal Affective Disorder. These and other studies demonstrate that the light versus dark contrast is strong, meaningful, and reflected in associations, preferences, and generally beneficial effects.

The contrast between natural and electric light is also relevant to the lighting domain. Studies generally report more positive beliefs for daylight versus electric light with regard to mood, performance, and health effects (e.g., Veitch, & Gifford, 1996). These beliefs could be due to a naturalness bias (Haans, 2014), with natural light preferred over electric light because it is more natural.

In two studies, we investigated associations with, and preference for daylight versus electric light and we tested the relation between these and restorative outcomes. We employed words and images as stimuli rather than exposure to real daylight, to avoid confounds of view content and differences in temporal and spectral composition of the light, for which effects are already well established. Using words to evoke associations has been used extensively in earlier research concerning associations and meaning of concepts (see Osgood, 1957).

We hypothesized that daylight would generate more positive associations than electric light. We further expected that daylight would render more positive preference ratings and that this beneficial effect of daylight on preference would be mediated by the valence of association.

Study One

The first study tested the associations with, and preference for daylight versus electric light. We also explored the efficacy of words versus text to evoke associations, as we suspected that most people do not consciously perceive light in images and would therefore generate associations with features in the displayed environment rather than with the light setting.

Method

Design

A survey-based 3 (association generation method) x 2 (light source) mixed design was employed. Association generation methods between participants (words vs. images vs.

images with implicit instructions) was manipulated between groups, and light source (daylight vs. electric light) within groups.

Respondents

In total, 67 respondents completed the survey (30 females). Their age ranged between 18 and 52 (M = 25.24 (SD = 4.19).

Manipulations

Three different methods were used to evoke associations with daylight versus electric light. Two methods employed images of virtual office. Similar virtual environments -matched in overall brightness- were used, with only light source differing between the pictures, see Figure 1 for an example.

In the two Image methods, respondents received different association instructions. These instructions were either to associate with the images (Image Implicit), or with the light setting in the images (Images Explicit).

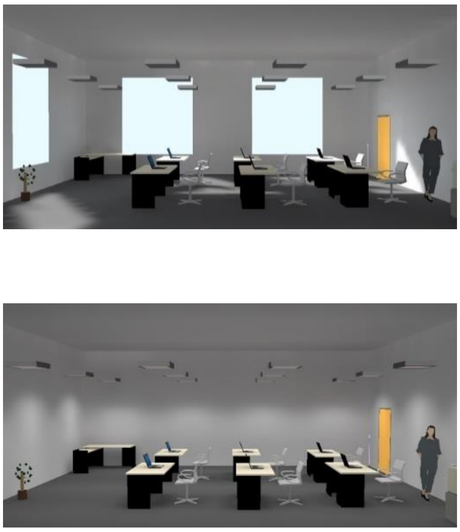

Fig. 1: Example images used

In the Text condition, respondents were asked to generate associations with the following words; *sunlight, daylight, lamp,* and *electric light*.

Task: Association generation

Respondents were instructed to write down all associations that came to mind, even if they were strange. For each word or image, they could generate between three and five associations. Table 1 displays some example associations generated in the text condition.

Table 1: Example associations in the text condition

Daylight	Electric light
'Sunshine' 'Vitamin D' 'No sleep' 'Need it' 'Yellow' 'Happy' 'Vampire' 'Morning' 'Freedom' 'Blue sky' 'Football'	*'Blue' 'LED' 'Street lighting' 'Philips' 'Not sharp' 'Cold light' 'Night table' 'Studying' 'Evening' 'Switch'*

Measures

Association ratings After the generation phase, participants rated each association on valence ranging from 1 (very positive) to 7 (very negative). Similar scores were obtained for health, energy, and relaxation. All scores were reverse coded for analyses so that high scores indicated more positive outcomes.

Preference was measured by asking participants how [pleasant, attractive, positive] it would be to spend one hour in the light setting (after Staats, Kieviet, & Hartig, 2003), on a scale ranging from 1 (not at all) to 7 (to a high degree).

Results

First, we investigated whether daylight induced more positive associations than electric light did, which appeared to be the case ($F(1,65) = 79.6$, $p < .001$, $\eta_p^2 = .55$)[1]. Similar results were found for health ($F(1,65) = 66.9$, $p < .001$, $\eta_p^2 = .51$), energy ($F(1,65) = 92.2$, $p < .001$, $\eta_p^2 = .58$), and relaxation ($F(1,65) = 41.6$, $p < .001$, $\eta_p^2 = .39$). On all variables, the text condition scored overall more positive than the image conditions ($F(2,65) > 5.4$, $p < .05$). No interaction between association generation method and light source was found, indicating that method of association generation did not affect the direction of outcomes.

Second, we established that higher preference ratings were found for daylight than for electric light ($F(1,64) = 191.5$, $p < .001$, $\eta_p^2 = .75$).

[1] Effect sizes are included. However, for space considerations, the means and SD are not included.

Third, mediation analyses were performed to see whether the valence of associations mediated the effect of light source on preference ratings, which appeared not to be the case (Indirect effect = .02, $p = NS$). No mediation effects were found for health, energy, and relaxation either.

Discussion

In Study One, we established that daylight generates more positive associations and higher preference ratings than electric light does. Counter to expectations, these associations did not mediate the effect of light source on preference formation.

Study Two

In Study Two, the first aim was to replicate the difference in valence of associations and preference between natural and electric light in a between subjects experiment, as associations have been found to depend on the context in which stimuli are presented (Gawronski & Bodenhausen, 2006). We further studied whether the associations influenced recovery of mood and cognitive performance after stress induction.

Method

Design

A between-subjects design was run with Light source (Daylight vs. Electric light) as between subjects variable.

Participants

In total, 64 participants (32 females) participated in the study, their age ranged between 18 and 35, with a mean of 22.41 (SD = 3.44).

Procedure

At baseline, mood and cognitive performance were measured, after which all participants completed a stress induction task. After completing the mood questionnaire for the second time, participants generated associations to daylight or electric light-related words. Participants then filled in their mood for the third time and cognitive performance was measured for the second time. Last, they rated their associations on valence, health, energy, and relaxation and the light-related words on preference, beliefs, and perceived restorativeness. After the experiment was finished, participants were thanked and paid for their participation.

Manipulation – Daylight vs. electric light

The following words were used to evoke associations for daylight: *daylight, sun,* and *sunlight*. For electric light, the words were: *electric light, lamp,* and *artificial light*. Words were presented in random order.

Manipulation – Stress induction

The retail task (adopted from Häusser, Mojzisch, & Schulz-Hardt, 2011) was used to induce stress. In this task, participants were required to compile a computer package consisting of a screen, desktop, and printer. For each component, three alternatives were given and they were instructed to make maximal use of a given budget. The time span for the trials decreased throughout the assignment. In total, they completed 35 trials.

Measures

Preference and association scores were measured similar to Study One.

Mood was measured with Visual Analogue Scales. On three scales ranging from 0-100 mm, participants were asked to indicate how they felt on three dimensions; tension, energy, and hedonic tone.

Performance was measured with the Sustained Attention to Response Task (SART). Digits ranging from 0 to 9 were displayed and participants were asked to respond as quickly as possible to the appearance of a digit by pressing the spacebar, except when the number ‘6’ was displayed.

Results

As in Study One, associations for daylight were more positive than those for electric light. Daylight scored higher on valence (F (1,62) = 39.4, $p < .001$, $\eta_p^2 = .39$), health (F (1,62) = 32.7, $p < .001$, $\eta_p^2 = .35$), energy (F (1,62) = 4.0, $p = .049$, $\eta_p^2 = .60$), and relaxation (F (1,62) = 16.3, $p < .001$, η_p^2 =

.22). Furthermore, higher preference ratings were again found for daylight than for electric light ($F(1,62) = 34.8$, $p < .001$, $\eta_p^2 = .36$). Again, the associations did not significantly mediate the effect of light source on preference.

Neither mood nor performance on the SART task was affected by our manipulation, so the association task with either daylight or electric light did not affect restorative outcomes.

General discussion

The aim of this research was to investigate whether daylight, in comparison to electric light, evokes more positive associations and receives higher preference ratings. Furthermore, we wanted to investigate whether the valence of associations predicts preference and restoration.

In both a within- and between-subjects study, we consistently found that associations with daylight received more positive scores on valence, health, tension, and energy than electric light did. These results corroborate previous research that reported more positive beliefs for the effects of daylight on mood and health than for electric light (Veitch, & Gifford, 1996).

Daylight also consistently received higher preference scores than electric light. However, no relation was found between associations and preference formation.

Thinking of daylight versus electric light did not appear to encompass restorative potential. This finding differs from results of Richter and colleagues (1992) who found restorative effects of imagining being in a bright environment while under hypnosis. However, we used a shorter and more subtle manipulation than they did.

To conclude, this research has indicated that besides biological relevance, light also affects us through psychological pathways. Extending association research beyond the comparison of light versus dark, we found that the light source, in particular the naturalness dimension, is also of central importance to this psychological relevance of light.

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How to create sustainable lighting for users? Psychological mechanisms underlying lighting effects

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Introduction

The ongoing discussion on sustainable lighting should not neglect a crucial dimension: sustainability for users. Sustainable illumination should not only protect our energy resources, but also their user's resources. In a similar vein, it has long been argued that high quality lighting does not merely prevent damage to health, but increases well-being and supports task completion (e.g., Veitch, 2001). In our knowledge society, this view becomes increasingly important because knowledge worker's performance largely depends on mental and psychological factors such as concentration, mood, and motivation.

Current psychological models distinguish environmental stressors and resources (e.g., Bakker & Demerouti, 2007) to describe potential psychological benefits and costs associated with contextual social, organizational, and environmental conditions. Lighting conditions can be experienced as stressful and deplete psychological resources, when glare impairs reading, reduces concentration, and promotes eyestrain and headache. In contrast, a view into nature and sunlight can help to recover. Lighting conditions can be viewed as an environmental resource (at the workplace) if they facilitate task performance or boost mental resources, for instance, if a pleasant lighting elicits positive mood and motivates to work perseveringly.

To describe and create psychologically sustainable lighting conditions, it is important to understand how lighting conditions impact user's performance and well-being. These routes of influence can be explained associating the different levels of comfort (extended model of the habilitability pyramid, Vischer, 2007) with well-established psychological mechanisms. Here, comfort is understood not merely as thermal or visual comfort. Instead, comfortable rooms or lighting conditions should support user's well-being, satisfaction, and performance. Although the habitability pyramid is not new, the current paper substantiates its theoretical grounding by identifying and detailing the underlying psychological mechanisms and relating the comfort generation to important psychological theories.

In this model, four levels of comfort are distinguished (Vischer, 2007): discomfort, physical comfort, functional comfort, and psychological comfort. In the following, section the comfort generation from one comfort level to another will be described via the psychological mechanism of resource depletion, facilitation through fit effects, and need satisfaction, and illustrated by recent lighting research.

Physical comfort: Preventing resource depletion

Uncomfortable rooms or lighting conditions can endanger user's health (e.g., vision), cause stress, and require that users invest energy (e.g., time, motivation) to cope with inconvenient conditions. This depletes the user's psychological and mental resources. Hence, the first psychological mechanism is resource depletion by coping with adverse ("stressful") lighting conditions which is frequently described as the main or only mechanism in environmental stress models. Generally, resource models (Baumeister, Vohs, & Tice, 2007) agree that individuals possess a finite amount of mental resources (e.g., concentration, willpower). High levels of resources are associated with feelings of vitality, persistence on tasks, and self-control, whereas depleted resources are signaled by mental fatigue and reduced performance on subsequent tasks. Hence, if lighting conditions create discomfort and individuals need to invest their energy to deal with this stressor, fewer resources can be invested in task completion and performance will decrease. Moreover, depleted resources require recovery (e.g., Baumeister et al., 2007). Accordingly, a recent study (Smolders, De Kort, Tenner, & Kaiser, 2012) showed that straining lighting conditions can increase people's need for recovery. People more frequently engaged in a number of recovery behavior when their offices were equipped with bare fluorescent battens than when the offices were equipped with low-brightness luminaires which prevent distracting reflections on computer displays.

Lighting standards determine how rooms should be lit in order to prevent discomfort, for example by setting a minimum horizontal illumination of 500 lux for office work (DIN-12464) or by recommending access to daylight. Current lighting standards are set to meet the visual requirements and first recommendations regarding the biological (circadian) effects of lighting are published. Following these regulations, lighting conditions should no longer steal resources from the users and, hence, provide physical comfort. From a resource-depletion perspective, lighting condition can either cause psychological costs or not, be a stressor or not, but it remains unclear how lighting conditions can create an added value.

Functional comfort: Conserving resources through facilitation by fit effects

Even within the levels of physical comfort, lighting conditions can either facilitate or hinder task execution. For instance, high levels of illuminance facilitate reading and reduce the time needed by a manager to read a report. However, the same lighting conditions create a rather cool, formal atmosphere which hampers a private conversation between the manager and an employee. If lighting conditions support user activities, this leads to functional comfort (Vischer, 2007) and users have to invest fewer resources to obtain similar results, for instance, straining their eyes or investing less time to create an informal atmosphere. Lighting standards consider the different visual task requirements and recommend, for instance, a brighter light for complex visual tasks like technical drawing.

Despite these physiological requirements, different work tasks pose various psychological (cognitive, social, and emotional) demands, which can be dealt with more easily at suitable (matching) environmental conditions. For instance, a dim, warm, or indirect lighting creating a cozy, informal atmosphere will ease an open conversation and talking about intimate topics. This kind of facilitation through fit emerges when the lighting conditions automatically activate associations to certain thinking styles, emotions, needs, or behaviors, which, in turn, facilitate meeting the cognitive, emotional, and social task demands and thus improve task performance. Fit effects have been described in basic and applied psychological research (e.g., Caplan, 1987; Higgins, 2005) and may work via conceptual or metaphorical priming effects that have been explored for many environmental qualities in the embodiment and grounded cognition research (e.g., Barsalou, 2008).

Recent studies showed these kinds of fit effects for various behaviors, such as creative performance (Steidle & Werth, 2013) and social interaction (Chiou & Cheng, 2013; Steidle, Hanke & Werth, 2013). For instance, a series of studies by Steidle and Werth (2013) revealed that illuminance impacts cognitive performance by changing the visual message (i.e. atmosphere). Participants were more original and generated more creative ideas at 150 lux, while their analytical performance was higher at higher illuminance levels of 500 or 1500 lux. This effect was mediated by differences in the visual message and associated information processing styles. Bright, direct lighting typically used in working contexts creates a rather formal atmosphere, which emphasizes following rules and being vigilant and detail-oriented and, thus, is beneficial for analytical performance. In contrast, dim light creates a more informal atmosphere and elicits a feeling of being free from constraints which allows for abstract information processing, thinking out of the box, and exploring new and original ideas. These results indicate that lighting conditions can increase cognitive performance if artificial lighting elicits a matching thinking style. In general, lighting can facilitate task performance and conserve mental resources, if lighting conditions fit to task demands and create functional comfort.

Psychological comfort: Boosting resources through need satisfaction

Independent of user's activities, lighting conditions can increase satisfaction, well-being, and performance, if they meet user's expectations, preferences, and needs. First, pleasant lighting conditions can trigger positive emotions. For instance, users generally prefer rooms with daylight (e.g., Farley & Veitch, 2001), which also has positive consequences for the emotional well-being (i.e. mood, satisfaction). Second, lighting conditions can contribute to the satisfaction of needs closely related to environmental design or workspace layout (e.g., privacy, control, and territoriality; Vischer, 2007). For instance, lighting control can increase perceived environmental control. Third, in line with other grounded cognition research (e.g., Kolb, Gockel, & Werth, 2012), lighting conditions may well serve as substitutes for satisfying associated social (e.g., social warmth by warm light), or personal needs (e.g., moral purity by clean, bright light) as well as synesthetically associated physical needs (e.g., physical warmth by warm lighting or silence by soft, "silent" light). A first study pointing in this direction showed that individuals concerned about their moral reputation preferred brightness including bright light (Banerjee, Chatterjee, & Sinha, 2012). In all this cases, lighting conditions satisfy user needs and thus create psychological comfort.

The psychological processes of need satisfaction which generate positive affect, intrinsic motivation, and vitality are widely researched (e.g., Deci & Ryan, 2008). Via this pathway, lighting conditions can boost positive affect and thus refill energy resources or even create new resources available to the self. Mood and well-being are particularly important in times of knowledge work, because happy and fit employees generally show more engagement, persistence, and creativity during task completion, which is crucial for successfully solving complex, open, and new tasks associated with a high degree of autonomy.

A recent study by Veitch, Stokkersmans, & Newsham (2013) showed the underlying route of influence. Participants worked for one day at one of 16 lighting conditions varying in type, direct proportion, and brightness and evaluated the lighting conditions, room appearance and their own mood. Work engagement was measured as persistence on an unsolvable task. Results showed that objective differences in the lighting conditions scarcely affected the evaluation of the room, emotional well-being, and task engagement. In contrast, the subjective evaluation of the lighting conditions had a strong influence, yielding the following linked mechanisms: The more pleasant participants evaluated the lighting conditions, the more positively they also judged the room appearance which increased the emotional well-being and, in turn, tasks engagement. Hence, this study revealed the importance of considering individual user preferences and subjective judgments to boost well-being and performance through psychological comfort.

Summary

The current paper proposes that lighting conditions can improve user's well-being and performance and thus support a sustainable management of user's psychological resources by three routes of influence:

- Uncomfortable lighting conditions deplete mental resources (resource depletion or physical comfort).
- The fit between lighting conditions and task demands determines, whether lighting conditions facilitate or hinder task completion (resource conservation by functional comfort).
- Depending on individual needs, lighting conditions can provide additional resources

in form of satisfaction and motivation (resource generation by psychological comfort).

To provide psychologically sustainable lighting conditions, all three levels of comfort are important, but according to our view, they do not necessarily build on each other. Psychological comfort may also emerge at lighting conditions which do not provide functional comfort. Moreover, while functional comfort primarily depends on contextual and task demands, psychological comfort should depend more on individual needs and preferences. Hence, lighting conditions for functional comfort should vary across different tasks but be rather constant during one work activity, while lighting conditions for psychological comfort may be constant across different work activities but rather episodic depending on individual needs. From theoretical perspective, this differentiation between psychological mechanisms expands previous approaches (e.g., Veitch, 2001), helps to categorize and organize existing effects and solve apparent inconsistencies regarding the effects of certain lighting conditions. Based on the understanding of the underlying processes, customized lighting solutions and products for optimal functional and psychological comfort can be designed.

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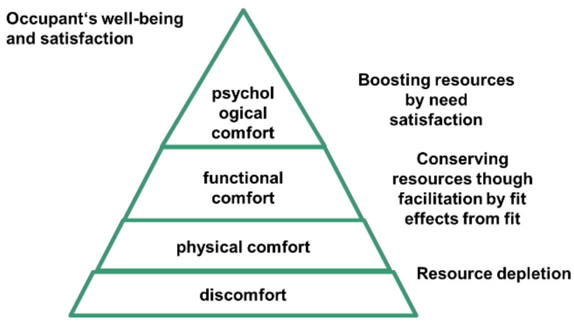

Fig. 1: Comfort levels and associated psychological mechanisms (adapted from Vischer, 2007)

Feeling the light? Impact of illumination on observed thermal comfort

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Introduction

The 'Hue-Heat Hypothesis' (HHH) states that light of wavelengths predominantly of the red end of the wavelength spectrum are felt as warm and those toward the blue end as cool(er). Manipulation of the ambient light colour could hence be a powerful tool for energy-saving in buildings if temperatures could be lowered under a reddish illumination in the heating season, or, conversely, be kept higher under bluish illumination in air-conditioned buildings. In the UK, space heating is responsible for about 53% of carbon emissions in domestic buildings, and for 46% of all carbon emissions in commercial and public buildings in which cooling and ventilation contribute another 7%; hence, the scope for energy saving is large.

However, whilst there is common agreement that blue stands for 'cold' and red for 'warm' - the colour coding of most bathroom taps as the prime example – research on the association between colour and thermal perception is less clear.

A series of studies have studied the Hue-Heat-Hypothesis, with about half finding an effect as hypothesized.

Mogensen and English (1926) asked subjects to judge which of two cylinders covered with one of six saturated coloured papers felt warmer. Red and purple were significantly less often judged as warmer than the other four colours, contrary to expectations.

Greene and Bell (1980) tested 72 students in rooms in which the walls were painted red, blue and white. Each student was exposed to one colour variation and one of four temperatures (18, 22, 29, and 35 °C). Amongst other tasks, students had to estimate the temperature of the settings, respectively. The estimations of temperatures did not differ significantly between settings.

Pedersen, Johnson, and West (1978) had per se identical rooms decorated and painted differently, i.e. with warm (red, orange, yellow), neutral (white), or cool (blue and green) hues. Using a between-subject design, 51 subjects estimated the temperature of the rooms. No significant differences between rooms emerged in temperature estimates.

Berry (1961) investigated whether the point at which people report experiencing heat discomfort depended on the colour of the illumination. He used five different lights, two "cool" colours (green and blue), two "warm" colours (yellow and amber), and white light. Subjects supposedly took part in a driving test in which it was supposedly important to know when subjects were too warm as that might interfere with driving performance. The colour of light did not impact on this judgement.

Bennet and Rey (1972) used yet another way of manipulating the colour experience: They provided participants with blue, red, or clear goggles. The investigators could not find observable correlations between hues and thermal comfort judgments.

Contrasting these null-results, the following studies all found an association between colour and thermal perception.

Johannes Itten (1961) showed that participants started to feel cold in a blue-green painted room at about 15 °C, but only at about 12 °C in a red painted room. Clark (1975) also tested thermal comfort in a design using painted walls. Employees of an air-conditioned factory reported feeling cold at 75 degrees F (~ 24 °C) when the walls of the cafeteria in the factory were painted in light blue. However, they were too hot at 75 degrees (~ 24 °C) when the same walls were painted orange.

Kearney (1966) exposed subjects to different combinations of hue, brightness, and temperatures (about 40°C, 16 °C, and a few degrees below zero, named hot, cool, and cold). Participants showed a higher preference for long wavelengths at cold temperatures, and for short wavelengths at hot temperatures.

Fanger, Breum, and Jerking (1977) used a within-subject design. In an environmental chamber, 88 subjects were exposed to two types of coloured light (extreme red or extreme blue) and two noise levels. One sessions lasted about 2 ½ hours. The ambient temperature was adjusted according to subjects' wishes. Subjects preferred a slightly lower temperature under the red ambient light than under the blue light; an effect of the magnitude of 0.4 °C. The physiological measurements of skin temperature, rectal temperature, and evaporative weight loss were not influenced by the light, and neither by noise.

A recent study varied colour temperature which is expressed in degrees Kelvin and ranges from about 1,800 K (light of a candle) to 15,000–27,000 K (clear blue poleward sky), i.e. from 'warmer' to 'cooler' light. Candas and Dufour (2005) exposed 48 subjects to a colour temperature of either 2700 K or 5000 K for two hours in "slightly warm environments" and asked them to judge their thermal comfort. Subjects preferred the cooler light; the effect was small but significant (~5 points on a scale from 0 to 100).

To summarize, existing research is ambiguous regarding a linkage between colour and perceived temperature / thermal comfort. The multitude of different ways of manipulating colour and response types complicate comparability between studies and drawing final conclusions. The positive findings of Fanger et al. (1977) and Candas and Dufour (2005) which warrant revisiting the Hue-Heat-Hypothesis, given that they are similar to how this effect could be used to realize energy savings, i.e. through varying illumination in a building.

We used an experimental approach in a climate chamber to test if light impacts on thermal comfort. The advantage of testing in a climate chamber was that research on thermal comfort shows that radiant temperature, air temperature, air velocity, and relative humidity impact on thermal comfort (in addition to level of clothing and metabolic activity); and the climate chamber allows exact manipulation of these parameters.

Subjects were exposed to either a 'warm' or 'cold' light while sitting in the climate chamber with temperatures decreasing from about 24 °C to 20 °C over the course of 60 minutes. To overcome limitations of self-report surveys, an observational design was used where the experimenter noted if and when participants put on additional clothing. We hypothesized that (a) under cold light, participants would put on more items of clothing than under cold light, and (b) under cold light, participants would put on clothes earlier than under warm light.

Methods

Participants.

Participants were recruited through the subject pool of University College London (UCL). The study was approved by the UCL Ethics Committee; all participants provided written informed consent. Payment was £8/hour. The sample consisted of N = 32 participants (23 female, nine male). The average age was M = 23.5 (SD = 2.51).

Experimental design and set-up.

Testing was carried out in the climate chamber which is an enclosed room of about 2.60 x 3.80m in which temperature, humidity, and air velocity can be controlled. The chamber was partitioned in two in order to prevent the two participants tested concurrently seeing each other. The observer was sitting in front of the participants.

A between-subjects design was used. Participants were randomly assigned to either participate under the 'warm' light (2700 K), or the 'cold' light (6500 K). Illuminance at reading level was 550 lux at 2700 K, and 495 lux at 6500 K. The light setting hence constituted the independent variable. Each light setting was tested equally often in the morning and afternoon.

A LED-based ceiling light ('ChromaWhite' from Photonstar) was used, equidistant to both participants at a height of about 2.20m. Figure (1) shows the spectral composition of the light.

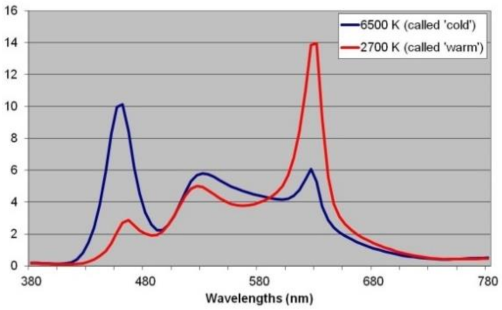

Fig. 1: Normalized spectral composition for the 2700 K and 6500 K light.

Experimental procedure.

During recruitment, participants were told what to wear during the experimental session to ensure the same level of clothing. In addition, they were instructed to bring a sweater / light jumper and a light jacket to the experimental session. Upon arrival, the participants were given information sheets, a consent form, and filled in a background survey about age, gender, clothing, activity prior to testing, etc. This pre-testing period ensured a somewhat comparable rate of metabolic activity, i.e. 20 minutes of sitting still. The experimenter positioned the clothing and a blanket in the climate chamber in the same location for all participants.

Participants were then led into the climate chamber; and instructions summarized, i.e. to sit and read, and if they should want to, to put on additional clothing or use the blanket. The experimenter was equipped with a stopwatch and recorded when participants put on clothing, and what they put on. In detail, the dependent variables were: (1) total number of clothing item put on, (2) minutes in climate chamber when first item of clothing was put on, (3) minutes in climate chamber when second item was put on, (4) minutes in climate chamber when third item was put on, and (5) the type of clothing put on and its respective insulation level.

Results

Analysis of confounding factors.

Besides room temperature, relative humidity and air circulation, which were controlled during the experiment, other factors that might impact thermal comfort are metabolic activity, type of clothing, gender and the Body-Mass-Index (BMI). We tested whether those factors differed between groups.

The reported metabolic activity was translated into ‘met’ values as given in Annex B of the EN ISO 7730:2005, separately for each of the four time periods enquired about. The values were then averaged across the four time periods. A *t*-test for independent samples showed that the metabolic activity over the last 10 minutes was not significantly different between the two experimental groups (M_{2700K} = 1.9; M_{6500K} = 1.7); neither was the aggregated value for metabolic activity. Clothing items were translated into a total score of ‘clo’ level as defined in Appendix C of the EN ISO 7730:2005. Each item was translated into its corresponding insulation value and those values were then summed up for each person. An independent samples *t*-test showed no significant difference in total clothing level between the two experimental groups (M_{2700K} = 0.59; M_{6500K} = 0.57)

Whilst the gender balance was unequal in this study, distribution across lighting setting did not differ significantly (2700 K: 5 males, 11 females; 6500 K: 4 males, 12 females).

The BMI was calculated for each person. An independent samples *t*-test confirmed that the BMI did not differ statistically in the two groups (M_{2700K} = 21.2; M_{6500K} = 22.2).

As the two groups did not differ in potential impact variables, they were not used as factors in further analysis[1].

Total items of clothing put on.

Figure 2 shows how many participants put on how many additional items of clothing. The categories are inclusive; i.e. a participant who put on two items of clothing will be counted both for the “1+” and “2+” category. More participants put on extra clothing under the cold light than the warm light. Only one person put on 2 or more items under the warm light but nine persons under the cold light. The observation of less clothing needed

[1] Of course, these factors can impact thermal comfort but the effect would occur in both groups.

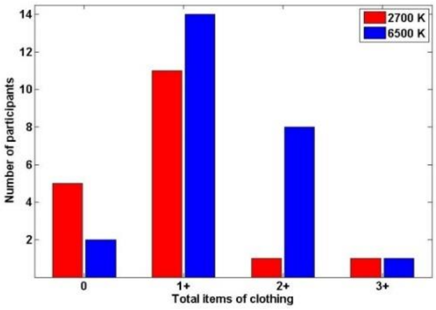

Figure 2. Total items of clothing put on under 2700 K ('warm') and 6500 K ('cold').

under warm light was confirmed through statistical analysis. Since the variable 'total_clothing' was not normally distributed, the non-parametric Mann-Whitney-U-Test was used to test for significant differences. We found a significant effect of lighting ($U = 70.5$, $p = .019$). More items of clothing were put on under the cold light than the warm light.

There was no difference in what item of clothing participants used first.

Minutes in the climate chamber.

We analyzed if participants put clothing on after fewer minutes under the cold than the warm light. This analysis is somewhat problematic because it needs to exclude those participants who did not put on any clothing and hence ignores that some people would have put on clothing only after more than 60 minutes. The average time before putting on the first item of clothing was 37 minutes under warm light and 34 minutes under cold light. This difference was not significant. For two or more items, statistical analysis was not possible because of too low numbers.

Discussion

Our study used an experimental design to test if apparent thermal discomfort, operationalized as putting on extra clothing at decreasing temperatures was impacted by the surrounding illumination. Participants put on significantly more items of clothing under cold light than warm light. The time when they put on extra clothing did not differ significantly between the two groups.

We conclude that the results show some support for the Hue-Heat-Hypothesis. Varying the illumination in a building could therefore be a tool for reducing energy consumption in buildings by off-setting changes in temperature and hence thermal comfort through changes in illumination. In particular for short-time power management applications, this could be of great benefit. The temperature range considered in this study is comparable to conditions in offices; a larger effect of light might be observed when lowering temperatures further; however, given the desired application in offices, those results might not be transferable into a real-world setting

Further research needs to test that the observed effect would hold up in a natural setting, and that performance / mood are not impacted by the lighting. Also, the potential energy savings need to be quantified.

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Atmosphere perception: combining lighting and fragrance

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Introduction

In this study we investigate if we can enhance the appreciation and affective evaluation of pleasant ambiences created with lighting by adding fragrances. Creating pleasant ambiences is considered beneficial for different applications, such as hospital rooms, care centres, and schools. For example a cosy ambience is expected to relax scholars that are stressed, while an activating ambience is expected to counteract feelings of sadness.

The focus of lighting research currently shifts from pure visual functionality of lighting towards biological and psychological effects of lighting. Effects of illumination level (McCloughan et al, 1999) and correlated colour temperature (CCT) (Knez & Kers, 2000) on people's mood are reported, often with complex interactions with gender, age and exposure time (Knez & Kers, 2000; McCloughan et al., 1999). We believe that the psychological effects of lighting are mediated by atmosphere perception. Atmosphere represents the affective state of the environment, and is known to be almost immediately recognized (Vogels, 2008). On the longer term perceived atmosphere is expected to change the emotional state of a person in the room towards the affective state of the perceived atmosphere. Consistent effects of lighting on atmosphere perception are found. Increasing the illumination results in a more lively, more stimulating, less tense and less hostile environment (Boyce & Cuttle, 1990; Vogels et al., 2008). Warm white light is more preferred (Nakamura & Karasawa, 1999) and perceived as cosier and less tense (Vogels et al., 2008) as compared to cold white light. Hence, by combining functional white lighting with coloured accent lighting pleasant affective ambiences may be created (Seuntiëns & Vogels, 2008), and are accordingly identified (Kuijsters et al., 2012).

So far, these atmospheres have been created using different light settings only. Our hypothesis is that the light induced atmospheres can be enhanced by adding ambient fragrances. Research revealed that ambient scents may improve the evaluation of brand names (Morrin & Ratneshwar, 2000) and of stores and their merchandise (Spangenberg et al., 1996). The type of scent or intensity did not in influence the enhanced perceptions (Spangenberg et al., 1996). Mattila and Wirtz (2001) showed that the presence of an ambient scent and/or music results in significantly more positive ratings for the perceived atmosphere. In their research the type of fragrance, however, seems to play a role, since the atmosphere ratings are most positive when the volume of the music and the arousing nature of the fragrance are congruent.

To test our hypothesis in the context of the findings of Mattila and Wirtz (2001), we evaluated two atmospheres created with lighting (i.e., a low arousing atmosphere referred to as cosy, and a high arousing atmosphere referred to as activating) in combination with two fragrances (i.e., a low arousing fragrance referred to as relaxing, and a high arousing fragrance referred to as exciting). We expect that ambiences which are congruent between lighting and fragrance are more appreciated than incongruent ambiences.

Experimental design

The experiment had a within-subjects design with lighting (2 levels: activating and cosy) and fragrance (3 levels: no fragrance, exciting and relaxing) as independent variables, while the scores on the atmosphere and appreciation questionnaire were the dependent variables. The appreciation was measured from 'dislike extremely' to 'like extremely'. The atmosphere questionnaire measured perceived atmosphere with 11 items based on four dimensions: cosiness, liveliness, detachment, and tenseness (Vogels, 2008). The scales ranged from 'not applicable at all' to 'very applicable'. In the first experimental week the participants evaluated the ambiences in a fully randomized order in different sessions, separated by at least one hour. They were immersed in the ambience and were asked to wait for two minutes before filling in the questionnaires. In the second experimental week the same participants evaluated both fragrances on pleasantness (from 'extremely unpleasant' to 'extremely pleasant'), intensity (from 'extremely weak' to 'extremely strong'), and familiarity (from 'unknown / unfamiliar' to 'well known / familiar'). All questions were rated on a 15cm continuous scale.

Participants: Thirty-five interns and employees (mean age 24.3 ± 1.97 years) from Philips Research in Eindhoven (The Netherlands) participated in this experiment. Eighteen of them were males. None of the participants had colour deficiencies as measured with the Ishihara test.

Experimental room: The experimental room had the dimensions L x W x H = 6.1m x 3.7m x 3.0m. The colour of the walls and ceiling was white. The floor consisted of dark grey carpet tiles. The windows were closed with a white shutter in order to prevent influences of natural light. The room was decorated with typical (achromatic) living-room furniture and accessories.

Functional white lighting was provided by six spots projecting towards the floor; 60W halogen lamp (Philips MasterLine TC 60W G8.5 12V 1CT), six spots projecting towards the left wall, and a diffuse light system containing six luminaires with fluorescent lamps; four lamps with a CCT 6000K (Philips Master TL5 HE 14W/865 SLV) and two lamps with low CCT 2800K (Philips Master TL5 HE 14W/827 SLV). Coloured accent lighting was provided by 6 RGB LED-spots (Philips Fiorenza Rainbow) high-power projecting RGB Luxeon LEDs towards the left wall, a RGB LED wall washer projecting on the opposite wall, and two LED Living Colours (Philips, model: Bloom Black). Finally, two RGB floor lights were placed against the left wall.

Ambient fragrances were diffused in the room with electric Ambi-Pur dispensers (model Electro). These dispensers were set at a diffusion speed level 3 out of 5 in order to have a moderate intensity level. Fragrances were introduced in the room at least 30 minutes before a session and at least 2 hours were scheduled between two scented conditions. The lab was fully ventilated with two exhaust fans to ensure complete removal of the fragrances. The room was sniff-tested before each session; no odours were detected to have remained in the room.

Stimuli: Six ambiences were created with two lighting setting and three fragrance levels. The lighting settings were based on previous research (Seuntiëns & Vogels, 2008), reflecting a low arousing pleasant lighting ('cosy') and a high arousing pleasant lighting ('activating'). The 'cosy' ambience had a low illumination (100lx), low CCT (2100K) and orange coloured accent lighting; the spots projecting towards the wall the diffuse lighting system and the floor lights were turned off. The 'activating' lighting had a high illumination (800lx), high CCT (4300K) and coloured accent lighting in the cyan/blue spectrum (see Figure 1).

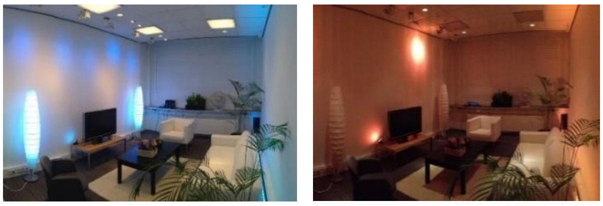


Fig. 1: Ambiances reflecting an 'activating' (top) and 'cosy' (bottom) atmosphere

The selection of the fragrances was entrusted to the company International Flavours and Fragrances (IFF) in Hilversum, The Netherlands. The fragrances were selected on their arousal and pleasantness properties. A high arousing pleasant fragrance (named: Refreshing passion) was selected as the 'exciting' fragrance, and a low arousing pleasant fragrance (named:

Sensolia) was selected as the 'relaxing' fragrance.

Results

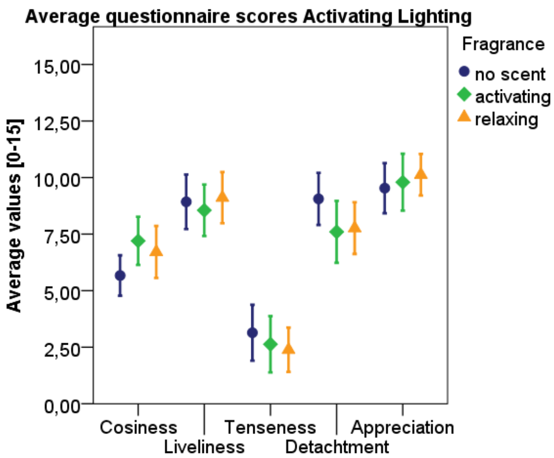
A principal component analysis with Varimax rotation revealed that the eleven items of the atmosphere questionnaire were indeed grouped in four underlying dimensions, explaining 74.9% of the variance. Two items on each atmosphere dimension had a high loading (above 0.8) with high inter-rater reliability (Cronbach's alpha): *Stimulating* and *Inspiring* for Liveliness (α = 0.78), *Threatening* and *Frightening* for Tenseness (α = 0.84), *Cosy* and *Intimate* for Cosiness (α = 0.74), and *Business-like* and *Formal* for detachment (α = 0.86).

The two fragrances were on average perceived as pleasant (scores on a 15-cm scale; relaxing: M = 10.0, SD = 3.2 and exciting: M = 10.4, SD = 3.1), intense (relaxing: M = 10.3, SD = 2.6 and exciting: M = 10.8, SD = 2.4) and moderate familiar relaxing: M = 9.2, SD = 3.7 and exciting: M = 9.9, SD = 3.3). Eleven participants, however, evaluated one or both fragrances as unpleasant. These participants were removed from further analyses because we want to investigate if adding a pleasant fragrance may enhance the affective evaluation of an ambience, and not if these two specific fragrances may.

The ambiences with a cosy lighting setting received higher cosiness scores than the ambiences with an activating lighting setting (see Figure 2. Indeed the analysis of variance (with lighting and fragrance as factors) revealed a significant effect of lighting on cosiness, $F(1, 23) = 43.17$, $p < .001$, $\eta^2 = .65$. Significantly higher liveliness scores were given to the ambiences with an activating lighting setting than to the ambiences with a cosy lighting setting, $F(1, 23) = 5.69$, $p = .026$, $\eta^2 = .20$. Also the detachment scores were significantly higher for the activating lighting setting than for the cosy lighting setting, $F(1, 23) = 42.79$, $p < .001$, $\eta^2 = .65$.

Fragrance significantly affected appreciation, $F(2, 46) = 6.64$, $p = .003$, $\eta^2 = .22$, cosiness, $F(2, 46) = 10.88$, $p < .001$, $\eta^2 = .31$, and detachment, $F(2, 46) = 5.49$, $p = .007$, $\eta^2 = .19$. Post-hoc tests revealed that the relaxing fragrance was more appreciated than the no fragrance condition ($p = .004$, d = .58). The no fragrance condition was less cosy than both the relaxing ($p = .001$, d = .38) and exciting fragrance conditions ($p = .003$, d = .41). Lastly, the detachment scores of the no fragrance condition was significantly higher than both the relaxing ($p = .012$, d = .30) and exciting fragrance conditions ($p = .023$, d = .30). An interaction effect between fragrance and lighting was found on the liveliness dimension, $F(2, 46) = 3.71$, $p = .032$, $\eta^2 = .14$. As can be seen in Figure 2, adding a fragrance (exciting or relaxing) increases the liveliness scores for the cosy lighting, but not for the activating lighting.

The congruency effect was tested by comparing the congruent conditions (cosy lighting with a relaxing fragrance and



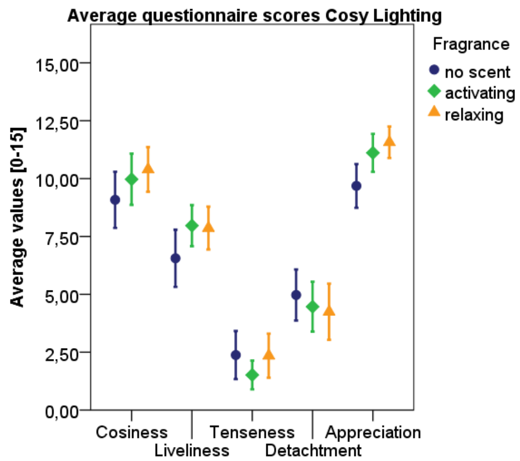


Fig. 2: Average atmosphere and appreciation scores, separated by activating lighting (left) and cosy lighting (right). The different markers reflect the three fragrance levels. Error bars represent the 95% CI.

activating lighting with an exciting fragrance) with the incongruent conditions (cosy lighting with an exciting fragrance and activating lighting with a relaxing fragrance). No significant effects of congruency were found.

Discussion and Conclusion

In line with previous research, we found that the cosy ambience (low illumination, low CCT and orange accent lighting) was cosier, less lively and less detached than the activating ambience (higher illumination, high CCT and cyan/blue accent lighting) (Kuijsters et al., 2012). Adding an ambient fragrance enhanced the appreciation and cosiness scores and decreased the detachment of the ambiences.

In contrast to the lighting, the arousal properties of the scent failed to influence the affective evaluation. No significant difference between the fragrances nor a congruency effect with lighting was found. This finding is in line with previous research stating that the presence of a scent is more important than its nature (Mattila & Wirtz, 2001; Spangenberg et al., 1996). On the other hand, it may also be that the two fragrances were not accurately enough selected. The two fragrances were reported orally by participants to be both very sweet, which suggest a more relaxing nature of the fragrances. This may be the reason why both fragrances failed to enhance the liveliness scores.

Eleven participants rated one or both of the fragrances as unpleasant. This suggests that smell is highly sensible to inter-individual variability, especially on pleasantness (Rouby, Pouliot, & Bensafi, 2009). It might also be that the diffusion level of the fragrances in the experiment was too high, resulting in a too intense perception of the fragrances, and as such reducing the perceived pleasantness (Rouby et al., 2009). Indeed the group that rated the fragrances as unpleasant also rated the fragrances as very intense.

We may conclude that adding ambient fragrance is a promising way to further enhance pleasant affective ambiences. The scented ambiences are more appreciated, cosier and less detached than the unscented ambiences. Additional experiments are needed in which we pre-test the type of fragrance and the diffusion level to ensure the selection of an arousing and relaxing fragrance with a perceived moderate intensity level. Also personalization can be investigated for an optimal effect on atmosphere perception.

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Experiencing Adaptive Retail Lighting in a Real-World Pilot

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Introduction

In this paper, we present a qualitative exploration of customers' experiences of adaptive retail lighting, reflecting on the evaluation results of three lighting schemes for the same retail space. Furthermore, we describe the innovative real-world research setting.

Adaptive lighting (AL), which brightens and dims slowly according to the presence of customers, has been commonly implemented in retail spaces in order to reduce energy consumption. Optimally, lighting control for this purpose is normally designed so that the customers are not able to notice changes in light levels. However, lighting adaptations can also be intentionally designed to be noticeable and to influence customers' shopping experience and behavior. The experience of light in retail spaces can be approached from several viewpoints.

Lighting can be used to create an attractive atmosphere in retail environment, thus creating an experience that can positively influence customers' mood and behavior (Quartier *et al*. 2008). Customers perceive the ambiance of the retail environment as less tense, and more lively and stimulating when the stores' spatial lighting pattern contains contrasts and sparkle, a desired and pleasant form of glare, attributes as opposed to overall brightness. (Custers *et al*., 2010). Architectural lighting can also be used for brand communication (Schielke 2010). By applying dynamic lighting settings and different lighting scenarios, retailers are able to provide changing visual stimuli to revitalize and increase customers' affect to the store (Parsons, 2011). Furthermore, dynamic changes in light provide strong attention catching stimuli. Even peripheral cues of dynamic changes of light attract our interest and make us examine the reason for the changes that are occurring (Reisinger, 2009).

Our research aims to understand experiences of AL as part of the shopping experience. For the research, a temporary pilot installation of intelligent and AL was designed and built in an existing retail environment. The aim was to design, develop and test a system of AL which can attract customers to a certain store section and serve their visual needs while they browse the merchandise. In addition, lighting dynamics could be used to focus customers' attention on certain products, and to lengthen the time they spend in the store browsing products. The pilot project had several development targets concerning the intelligent lighting control system, people tracking, as well as a design tool for AL. In this paper the focus is on the experience, thus results concerning development are not presented.

Research setting, process and methods

The research environment was a part of a ladies' clothes section with a rather low ceiling height for a commercial space: only 2.4m. To create visual, illuminated focal points in the area, five mannequin figures were placed in front of white background boards. The existing luminaires for general lighting were changed to controllable LED luminaires with neutral white light (4000 K). New controllable target lighting in tracks, with a warm white tone (3000 K), were attached under the false ceiling. The white LED spotlights were directed towards mannequin figures and to garments hanging from the racks on the walls and on the floor. In addition, RGB spotlights were installed under the ceiling in strategic positions for colour effects, pointing towards the backgrounds of the standing mannequin figures and wall leaning torso figures. These luminaires were used to produce both warm white light and colours. However, on some occasions a slightly visible pastel violet hue could not be prevented in the white light.

In order to gain knowledge of the effects of AL on customers' experiences, three different lighting schemes were created. One scheme, **“Static White” (SW)**, was created to provide a point of comparison: a good, basic retail lighting situation. For dynamic and AL schemes we created both a scheme containing only changes in light levels, **“Adaptive White” (AW)**, and a scheme containing light level and colour changes, **“Adaptive Colour” (AC)**. This was done in order to see if there were differences in experiences and shopping behavior between the dynamic scheme with only white light and the scheme with added colour effects. For effect colours, shades of warm red and magenta were selected after in-situ testing, to match with the colour palette of the clothing collection of the late autumn and Christmas. The test area with the lighting schemes and information of the used light levels and colours are presented in fig. 1.

Fig. 1: The tested lighting schemes: Static, Adaptive White and Adaptive Colour.

The intelligent control of AL was based on tracking the customers' position and movement in the test area and its access points with networked depth camera sensors. The design for the lighting adaptation followed a three-mode strategy of responses to customers' movements in the pre-defined sections of the test area and its surroundings. This three-mode strategy was created in a research by design process, i.e. by simulating and testing different scenarios, and it was based on scenarios elaborated and theorized in an earlier Master's thesis conducted within the research project (Markkanen 2013). The adaptation modes were **“Attract”, “Focus”** and **“Keep in the area”**. The “Attract” mode was intended to draw the attention of customers in the vicinity of the test area, in order to attract them into the area itself. Customers walking towards the test area triggered a brightening of the spotlights and a lively rhythm of altering light levels on the back wall and on the background panels of mannequin figures. On AW scenario days this light dynamic was achieved using only warm white light and in AC days with warm white and shades of warm red and magenta.

When a customer stopped in front of the site, she triggered the “Focus” mode. The design aim was to focus customers' attention to products in the front area of the site, and to make her enter for a closer look. In this phase, the spotlights pointing towards the garments in the front section of the area and on the side walls were brightened with slow dynamic changes. Light colours followed the same logic as in “Attract” mode.

Finally, when a customer entered the test site, “Keep in the area” mode was launched. In that mode, lighting was intended to serve the customer by increasing the illumination of the products near the customer to enhance their visibility. Simultaneously, a few spotlights illuminating merchandise further away were brightened in order to make her notice other products and stay longer in the area browsing them. In this mode, the light triggered by a person moving in the area was 3000 K tone in the RGB spotlights also in AC scheme, so that the customer could detect the clothes' colours naturally.

The site was set up in October 2013 and taken down in February 2014, and the test ran during that time in a three-day rotation of SW, AW and AC schemes.

In order to evaluate visitors' experiences of the different lighting schemes, we used a probe-inspired method. We refer here to the Cultural probes methodology introduced by Gaver, Dunne and Pacenti (Gaver et al. 1999), which employs visually enticing and playful material to engage participants in reflection without direct researcher presence, and to self-report their thoughts. The benefits and limitations of the method are discussed in a further paper (Luusua et al. 2014)

The study was conducted in five weeks in October and November. Our participants (19 persons) were females (from 35 to 55 years). They were recruited through various professional and non-professional organizations' email lists, our personal networks, and through the snowball method, i.e. referred through participants' friends.

The evaluation probe consisted of a probe package with three custom-designed notebooks, and a preliminary, 30 minute semi-structured interview. The notebooks included relevant information concerning the assignment, a floor plan of the department store and the test area, and several open-ended questions that were meant to foster participants' reflection on their experiences. Each participant filled out three notebooks; one for each visit in the department store. Participants were instructed to explore at least the women's clothing department, but otherwise they were given free reigns to wander around the store as they pleased. On each occasion, a different lighting scenario was in operation. Due to commercial reasons, the clothing collection changed somewhat during the study period. The colour palette of the clothing remained similar, however.

Both the interviews and notebooks provided us with a wealth of valuable qualitative research material for further analyses. The aim is to publish the wider account of the results in a journal article. The preliminary key findings are presented and discussed here in the following section.

Results: Experiences of adaptive lighting

The analysis was conducted through a grounded theory approach informed by the preceding research by design process. The analysis indicates that the participants had *varying and personal attitudes* to AL. The idea was seen mostly as interesting, favourable and adding many positive aspects to shopping experience. Only a few clear rejections to the idea occurred in answers. Interestingly, similar features could be read in different responses both as positive and negative. There are personal differences in the ways lighting is experienced, and also the complex research setting in the real-world with many changing factors causes variation in lighting situations.

Those aspects, which were the guiding principles in designing adaptations, emerge in many responses. These themes were *attracting*, *focusing* and *guiding the eye* further. Especially the AC scheme was found to be effective as an *attention* catcher and attractor even from longer distances. Both of the adaptive schemes were mentioned several times as a feature that made the area more attractive, and which gave it an *identity*, which distinguishes it from surrounding areas in a positive way. One part of the attraction was also the *atmosphere* which the changing warm (AW) and coloured (AC) light created.

Observers mentioned several times that the changes of target lighting made them focus on a certain product, and guided their gaze to other products that would perhaps otherwise go unnoticed. Nevertheless, some of them felt that the products which were emphasized with light should be somehow special, not ordinary products. Especially the use of changing light and colours in focal points – the mannequin figures and their background panels – was considered a beautiful and attractive effect.

Many observers noticed *the relation of the changes of light to their own movements* in the space. All of them found it interesting as an idea. It facilitated their seeing and brought products to their attention. However, there were also several observers who did not mention that the lighting responded to their movements or who described the changes of light as *random*. One observer said she got tired because of trying to analyse the *logic and pattern of light*, partly due to her commitment to the task of observing. The variety of these comments can easily be understood while reflecting the adaptation design. The concept combined three modes so that a part of the dynamic changes of lighting resulting from a person's movements did not happen near her. In addition, the amount of customers in the area and its access points had an effect, as all of them caused adaptations. This created a mixture of logical but also seemingly illogical patterns in the dynamics of light, depending also on what part of the space the observer is looking at. The multi-user aspect can be seen as a further design challenge.

Seeing the colours of products in a realistic way was an important aspect to many observers. This caused some criticism towards the use of colour in the AC scheme. Nevertheless, some observers had noticed the whitening of light while approaching a product. Some mentioned the change of light level and colour also as a positive feature regarding colour detection: it showed the customer how the garment looks like in different conditions of light.

Many *meanings* were linked to adaptive and dynamic lighting and especially to the scheme which contained also colours, for example in connection to the season with forthcoming Christmas and period of many festivities. In addition, the AL schemes altered the *brand image* of the store and the products for some of the observers.

Furthermore, detailed aspects of visual experience were brought up, concerning, for example, the perception of the dynamics of light (rate of changes, timing) and light levels (contrast in space and in different moments).

To conclude, the evaluation of experiences reveals that AL has promising potential for design concepts as it can attract, tempt and guide customers, facilitate their seeing and make their shopping more experientially rich. Additionally, it can enhance identity and influence brand image. The results show that a careful design of detailed aspects of adaptation patterns and light dynamics is very important in creating pleasant environments, as dynamic light is a powerful tool for future designers. Further research is deemed necessary.

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De-escalate: Defusing escalating behaviour through the use of interactive light scenarios

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Introduction

Almost on a daily basis, the media report of behaviour escalation: situations run out of control because individuals or groups become frustrated, agitated, often resulting in verbal or physical acts of aggression. Such situations may occur in crowded outdoor situations (public events, urban night life) as well as in small-scale indoor settings (prisons, service & help desks, psychiatric wards). Defusing escalation in any of these situations is no mean feat and generally requires the presence and active intervention of experts trained specifically for this purpose. A recent project studies the utilisation of interactive lighting design in de-escalation, by examining psychological pathways through which exposure to dynamic lighting might defuse escalating behaviour. Based on a review of the current literature, we present our vision and theoretical framework, which should provide the basis for empirically exploring light as a means for de-escalation.

Aggressive escalation

Aggression is defined in the literature as behaviour intended to hurt another person (Berkowitz, 1993). This need not necessarily refer to physical acts of violence, but may also pertain to verbal abuse. Escalation refers to "an increase in severity of aggressive means used in a given conflict" (Winstok, Eisikovits, & Fishman, 2004, p284).

Escalation of behaviour can occur anywhere and its extent may range along a dimension of intensity, from frustration and annoyance to rage. In the majority of cases, aggression and escalation occur not because they were intentionally planned (i.e., premeditated aggression), but because people respond to perceived stress, become ignited by autonomic arousal and anger and in this process break personally held norms and revert to things they might not do otherwise (i.e. impulsive aggression; Siever, 2008). As Potegal and Stemmler (2010) argue, people themselves often experience these acts as at least partially involuntary.

Escalation typically involves a narrowing of attention and progressive failure of cognitive and executive functioning, potentially resulting in risk taking and "commitment to aggression" (Potegal & Stemmler). It consists of distinct components including patterns of peripheral physiological responses and brain activation, physical sensations, feelings, cognitions, and action tendencies. Important components often implicated in aggressions and escalation include:

Negative affect. Anger and escalation involve negative emotions, but, in contrast to for instance sadness and fear which implicate inhibition and avoidance motivations, anger and aggression involve an active approach (e.g. Litvak et al., 2010).

High arousal. On the physiological level, anger and escalation involve increased blood pressure, total peripheral resistance, and facial warming (Stemmler, 2010).

Egocentric/antisocial focus. Novaco (2010) reports that one function of anger is defensive social distancing. Escalating persons are therefore less likely to take a communication partner's perspective or have a collaborative attitude.

Narrow attention focus. Litvak and colleagues review: "Anger makes people indiscriminately punitive, [..] optimistic about their own chances of success, [..] careless in their thought, [..] and eager to take action" (p288). Others also report on extremely emotional individuals' selective attention; they tend to attend to and recall stimuli that have content similar to the emotion they are experiencing (e.g. Tavris, 1989), and are likely to engage in heuristic rather than systematic information processing (e.g.,Tiedens & Linton, 2001)

Loss of self-control and self-awareness. The essence of (unintended) escalating behaviour is that people fail to control their emotions and emotion-driven urges as a function of both internal state (stress, arousal, ego-depletion) and/or external cues (time, place, audience). Conflict, escalation, and aggression are all context-dependent. Decreased self-awareness is characterized by lowered attention to one's inner states and traits (Carver & Scheier, 1978). This prevents individuals from examining their personal norms regarding the relevant actions or behaviour (Duval & Wicklund, 1972).

Defusing escalating situations

Although there is an abundant literature on aggression and escalation, empirical work in the area of de-escalation is in fact quite scarce. The majority of this work is geared towards situations in which a professional tries to intervene in escalating situations and to manage potentially aggressive events.

Contextual and/or technological means to defuse escalation have only received scarce attention, even though current theories of aggression such as Berkowitz's cognitive neo-associationist model and Anderson and Bushman's general aggression model (GAM; 2002) assign a crucial role to situational stimuli determining whether or not an individual will engage in an aggressive response. Similarly, the Biopsychosocial Model of Arousal Regulation explicitly acknowledges the role of external affective cues in appraising situations as threat or challenge (Blascovich & Tomaka, 1996). Moreover, research on environments and anger has focused primarily on ambient characteristics of public spaces as triggers or catalysts of aggressive escalation. However, these theoretical models also imply that the presence of pleasant, positive situational cues may attenuate the readiness to engage in aggression, and possibly buffer the adverse effects of concurrent negative stimulation.

Light as a de-escalating stimulus

Light presents a potential contextual means to impact mood, arousal and many of the components of escalating behaviour. In general, there is a remarkably universal symbolic connotation of darkness as evil, threat, and danger (e.g., Lakens, Semin & Foroni, 2012). Darkness is said to facilitate aggression against other individuals (Page & Moss, 1976), although absolute darkness was also reported to facilitate affection and sharing of intimacy between complete strangers (Gergen, Gergen & Barton, 1973). But there is more.

Light and affect. The strongest link between light and affect has undoubtedly been demonstrated in relation to seasonal depression disorder. But also outside the clinical realm light has often been related to affect and mood. Research has demonstrated that colour is a very influential attribute of lighting (Küller et al, 2006) and that especially colour evokes affective responses (Knez, 2001). Moreover, light as an affective cue may impact cognitive appraisals in stress and coping. As such, light may be employed to induce more positive affect, or to serve as a positive affective cue, in escalating situations.

Light and sociality. Very recent research has indicated that beyond influencing affect, light settings can also impact social behaviour. For instance Steidle and colleagues (2012) demonstrated that brightness influenced cooperative behaviour. Similarly, light may impact an escalator's antisocial or egocentric focus and induce a more social orientation.

Light and attention. Shifts of visual attention can be goal directed or stimulus driven. Stimulus-driven attention shifts are independent of the individual's goals or actions: they capture attention due to specific attention-driving (bottom-up) characteristics of the stimulus. Light has since long been employed as a means to direct attention: consider for instance the use of stage and spotlights in theatre. But also outside the theatre, dynamic and static characteristics of light may inherently capture the attention of escalating groups or individuals and direct it to external cues or objects, making them more aware of for instance bystanders, social norms, or the consequences of their actions. In addition, directed light on the escalating situation could heighten self-awareness, which is characterized by greater attention to one's inner states and traits (Carver & Scheier), which subsequently triggers individuals to examine their personal norms regarding the relevant actions or behaviour and behave more accordingly to these norms.

Light and self-control. Research has demonstrated that light increases alertness and performance on cognitive tasks (e.g. Smolders, de Kort & Cluitmans, 2012). Neuroimaging has indicated that light during daytime increases activity in the thalamus and prefrontal cortex (Vandewalle et al., 2006). Crucially important, the prefrontal cortex is the area where executive functioning is said to reside, and perhaps also self-regulation.

Light and arousal. Although empirical proof is scarce, light has since long been related to arousal and relaxation. In fact, lighting is already successfully employed in for instance scanning practice in hospitals for lowering patient arousal during MRI scans or during PET uptake (e.g. Philips Ambient care concept, e.g., see Vogel et al., 2012). Typically, dim and warmer colours are associated with lower autonomic arousal.

Light and safety in outdoor environments. The relationship between light and perceived safety at night is intuitively strong and well established empirically (e.g., Welsh & Farrington, 2008). As such, street lighting is essential for the freedom to go out at night, in particular to those vulnerable to or fearful of personal attacks (e.g. Keane, 1998). Research has only recently started to investigate how dynamic lighting affects safety perceptions; demonstrating for example that providing light in pedestrians' immediate surroundings is more important than illuminating the road that lies ahead (Haans & de Kort, 2012). Although subject to debate, street lighting is also generally accepted as an effective means for crime prevention. Particularly important in this regard is that physical barriers such as for instance fences or the visual presence of police or MPs have been shown to act as cues for aggression and may thus facilitate escalation rather than defuse it (Carlson et al, 1990). Lighting, in contrast, does not throw up a physical barrier and may therefore be more successfully applied as a soft – non-aggressive – means to manage mood and behaviour in escalation.

In sum, the literature described above suggests several pathways for light to target emotional and/or behavioural components of escalation. Light could facilitate the reduction of arousal and negative affect, and induce a more positive and social orientation, function as an affective cue in situational appraisal, increase awareness of personal and social norms, and enhance self-control. Moreover, it may increase perceived safety in urban areas and increase the beneficial effect of restorative mediated content in ambient experience and support rooms.

Innovation potential

The use of dynamic lighting for defusing escalating situations is new and innovative. The application of dynamic coloured lighting has only recently become available, with the development of LED technology and its enhanced controllability. LED's main characteristics such as its energy efficiency, its dynamic controllability in colour and intensity, its robustness, all play a crucial role in opening up this new use potential.

The ideas and insights generated in the current project will not only be tested in controlled laboratories. Light principles tested and deemed successful in the laboratory need to be carefully and sensitively integrated in their contexts of use and tested there. The current project will therefore make use of experiential design landscapes, which means that investigations and experimental manipulations will be implemented while regular life continues. The first is 'Stratumseind' a popular, yet aggression-prone downtown area with numerous cafes and bars. The second is a mental care facility.

At the conference, we hope to present this theoretical framework and vision, and discuss it with the experts present, to explore the potential for the present project and related goals.

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Cross Modal Associations between Aggression and Light

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Abstract

Connotative meaning and associations of light may present a pathway to influence emotions and behavior. In this abstract, we will describe theoretical work on cross modal associations between light and aggression. We present findings on a first empirical test of explicit associations between two characteristics of dynamic light – brightness and the rate of change in brightness – with aggression. Furthermore, we give a detailed overview of an experiment to test the implicit association between dynamic light and aggression to be performed this month.

Introduction

Aggressive incidents around bars and clubs at night are a problem in Eindhoven, and lead to great personal and social costs. When aggression occurs, a common response of the police is to turn on bright illumination to enhance visibility. Intuitively, light is associated with positivity, whereas darkness is associated with negativity. Therefore, turning on the light could have positive effects on people's behavior. However, an important aspect of turning on the light is the dynamic increase in brightness. This sudden increase in light could be associated with activity and arousal. If an increase in light is associated with an increase in activity, turning on the lights when aggression occurs could potentially have undesirable behavioral consequences.

People have the tendency to associate stimuli in one dimension (e.g., brightness) with stimuli in a second dimension (e.g., valence). We believe that such cross modal associations could also occur between aggression and light. In their seminal work Osgood and colleagues (1957) examined cross modal associations between concrete and conceptual dimensions. They developed the affective meaning theory, which holds that people evaluate the meaning of concepts on three features: Evaluation (good-bad), Activity (active-passive) and Potency (strong-weak). Words have different factor loadings on these semantic scales (E, A, P). These features can vary in dominance: GOOD is for example E-dominant, but STRONG is P-dominant. Furthermore, Osgood et al. suggest parallel polarity: when connecting different concepts, the diverse dimensions are related in parallel, positive endpoint with positive endpoint, and negative endpoint with negative endpoint. The parallel polarity predicts that GOOD and STRONG are related because they are both associated with positive polar endpoints on their dominant dimension.

According to a parallel polarity account an association between aggression and brightness is not likely to emerge. Anger and White have opposite loadings on the Evaluation dimension, and we could therefore expect that people evaluate WHITE as CALM instead of AGGRESSIVE. Indeed, Adams and Osgood (1973) found that people, across 23 cultures, associate white with positivity, low potency and moderate activity. Black on the other hand is bad, strong and passive. Research has repeatedly confirmed the association of white with positivity and black with negativity (Meier, Robinson, Crawford, & Ahlvers, 2007; Meier, Robinson, & Clore, 2004; Lakens, Fockenberg, Lemmens, Ham, & Midden, 2013; Sherman & Clore, 2009).

However, it might be important to differentiate between achromatic brightness differences (white vs. black) and luminous brightness differences (bright vs. dark). Most studies have examined white-black difference. Dynamic luminous intensity differences have rarely, if ever, been used as stimuli in such cross-modal matching tasks. The dynamic nature of a light stimulus could affect which dimension is salient. For example, Eitan, Schupak, and Gotler (2013) found that cross modal associations between pitch and size can change depending on whether the stimuli are dynamic or static. Counterintuitively, they found that whereas people associate a high static pitch with a small object, and a low static pitch with a large object, when pitch dynamically rises, the object grows rather than shrinks. Therefore, when light is turned on, it could be that the *increase* in light changes the salient dimension. Instead of associating an increasing light with the Evaluation dimension, the Activity dimension might become salient.

Based on this line of reasoning, we predict that, when stimuli are static, people are likely to associate white with positivity and black with negativity on the Evaluation dimension. Because of the salience of the Evaluation dimension, black is more likely to be associated with aggression, whereas white is associated with calmness. Furthermore, people will associate an increase or decrease in achromatic brightness with the Activity dimension, and perhaps more so as the rate of change increases. Depending on the relative salience of the features brightness and rate of change of brightness, dynamic brightness may be associated with a decrease or an increase in aggression.

To investigate this, we have planned 2 studies. The present paper reports the results of Study 1, examining the effects of dynamic achromatic brightness on explicit associations. In addition, we will describe the planned Study 2, exploring implicit associations. Furthermore, follow-up studies will use luminous intensity (light vs. dark) allowing us to compare different brightness manipulations.

Study 1 Method

In this first study, we explicitly asked participants how they perceived static and dynamically changing screen brightness. Twenty university students (14 males) volunteered to take part in this experiment, which followed a 2 (target color: white vs. black) x 5 (rate of change: static vs. changing in 2040 ms, vs. 1020 ms, vs. 510 ms, and 255 ms) within groups design. The experimental stimuli consisted of a set of 16 short animations in which the entire screen changed in brightness, and 3 static stimuli (white, perfect grey, and black). The increasing white stimuli increased in brightness from 0 to 255 (the maximal brightness), gradually over time. The decreasing black stimuli decreased in brightness from 255 (white) to 0 (black), the decreasing grey stimuli from 128 (grey) to 0, and the increasing grey stimuli from 128 to 255 in brightness. The animations varied in rate of change and in brightness starting points (i.e. black, white and grey). After each animation, participants answered on a 9-point Likert scale how negative/positive, passive/active, weak/powerful, and calm/aggressive they thought the animation was. In view of space considerations, we only report the black-white stimuli in this manuscript.

Procedure

Participants were approached in the lunch facility of the Eindhoven University of Technology. They completed the experiment in an Authorware questionnaire on the experimenter's laptop.

Results

To investigate the associations people have with static white, we conducted a paired samples *t*-test. Paired samples *t*-test showed that static white (M = 6.30, SD = 1.56) is perceived as more positive compared to black (M = 3.50, SD = 1.76), $t(19) = 4.35$, $p < .001$, and less aggressive compared to black, $t(19) = 1.94$, $p = .07$. Means and standard deviations of the scores on Aggression for the different speeds are shown in Figure 1. There were no significant differences between black and white for the scores on potency and activity.

To investigate our hypothesis that people associate dynamic brightness with the Activity dimension as well as the Evaluation dimension, we conducted a linear mixed model with participants as random intercept, and Target color (i.e., towards black or towards white) and Rate of change (i.e.,

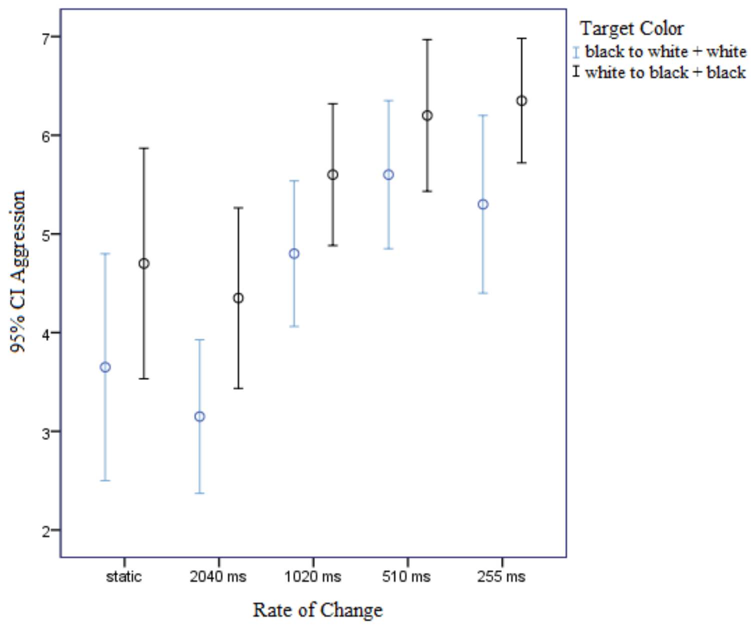

Fig. 1: means and standard deviations for Aggression scores for the Rate of change.

Tab. 1: Numerator df, Denominator df, and F value of the main effects of Target color and Rate of change on Aggression, Evaluation, Activity and Potency.

	Aggression		Evaluation		Activity		Potency	
	df	*F*	df	*F*	df	*F*	df	*F*
Target color	-1,18	14.44**	-1,2	93.01**	-1,18	0.525	-1,18	.99
Rate of change	-4,18	12.32**	-4,2	1.68	-4,18	33.33**	-4,18	3.91*

Note: *p<.01, **p<.001

static, 2040 ms, 1020 ms, 510 ms and 255 ms) as fixed factors.

First, in 4 separate models, we included aggression, evaluation, activity and potency as dependent measures (for results; see Table 1). The main effect of Target color was significant for Evaluation, and the main effect of Rate of change was significant for Activity and Potency. Both effects of Target color and Rate of change were significant for Aggression.

Second, we tested whether Activity and Evaluation mediated the main effects of Target Color and Rate of change on Aggression[1]. Specifically, we tested the model with Aggression as dependent measure, Rate of change and Target color as fixed factors, and Positivity and Activity as covariates. The results showed significant effects of both covariates: Activity (F (1, 200) = 84.18, $p < .001$) and Evaluation (F (1, 200) = 29, 37, $p < .001$). The main effect of Rate of change decreased, yet still remained significant (F (4, 200) = 6.24, $p < .001$). The main effect of Target color disappeared, F (1, 200) = .12, p= .73. Analyses[2] suggest that Evaluation fully mediates the effect of Target color, and Activity (partially) mediates the effect of Rate of change. Data for the grey stimuli revealed a similar pattern.[3]

Discussion

The results suggest that both the Evaluation and Activity dimension may become salient when people evaluate dynamic chromatic brightness, and therefore

[1] Due to large correlations between Potency and Activity, we excluded Potency from the model.

[2] Not fully reported for space considerations.

[3] Not fully reported for space considerations.

an association between brightness and aggression emerges for rapidly changing brightness, even if it becomes lighter. The main effects of Target color and Rate of change on Aggression are mediated by Positivity and Activity, with Activity being the strongest predictor. These results suggest that fast color transitions are not perceived as more negative, but mainly as more active and therefore as more aggressive. The target brightness (white vs. black), also contributes to the association, yet only modestly in comparison the stimulus' rate of change.

Study 2

In study 1, we explicitly asked people for their associations. In Study 2, we investigate implicit associations with brightness and the rate of change in brightness. Employing an implicit association test, we will test the hypothesis that a fast increase in achromatic brightness will affect the saliency of the dimension on which people evaluate the stimulus – activity becoming more salient than positivity - which will make the association with aggression more likely.

We will conduct two Implicit Association Tests. First we test, within subjects, whether people associate white and black stimuli with valence or activity. The stimuli will consist of words related to aggression and calmness and brightness stimuli (i.e. white and black filled squares). Participants will categorize the word stimuli and light stimuli into categories (i.e. aggressive, calm, brighter, and darker). In the second IAT we will use dynamic achromatic stimuli: participants will categorize increasing and decreasing brightness stimuli (i.e. squares which rapidly change from black to white, and from white to black). We expect that the response times will be the smallest when the stimuli are congruent (i.e. aggressive with black, calmness with white; aggressive with increasing white and calmness with decreasing white).

In a second series of studies we plan to replicate the studies with actual light (LED-based) stimuli instead of screen-based stimuli. This is relevant as pilot studies indicate brightness may be more explicitly associated with activity for light than for color. We also hope to be able to present these findings at the conference.

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A future in Sustainable lighting using lighting controls: A study into pedestrian street lighting analyzing user comfort, perception and safety

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Introduction

With the world moving towards the idea of sustainable and energy-efficient solutions, the field of Lighting is no different. Advanced technology, energy and economic issues are slowly paving the way for the use of intelligent lighting systems using lighting controls. With people increasingly becoming energy conscious, using lighting controls in indoor environments has gained momentum in the last few years, but implementing the same in an outdoor urban environment hasn't been taken up extensively in spite of its potential; probably because of the ambiguity regarding the response of the people towards it. The aim of the research was to experiment with energy-efficient lighting systems using lighting controls and discover if the people warm up to this idea - by not jeopardizing with their road user comfort. Thereafter, depending on the results, see if the concept of intelligent outdoor lighting solutions can be encouraged for wider implementation.

Previous studies list detection of obstacles, visual orientation, facial recognition and pleasantness & general comfort as the crucial factors for the users with respect to urban pedestrian lighting (Davoudian and Raynham, 2012). All these factors together have been summarized as visual comfort, safety and perception for the paper. This was determined through study and analysis of the user responses of a pilot lighting installation with five different test scenarios in an outdoor environment using lighting control systems. Energy savings were also an integral part of the research. However, this paper will primarily focus on the results of three identified factors with respect to the lighting installation – visual comfort, safety and perception of the users. Energy savings for the different test scenarios were also calculated in order to draw some conclusions on if the varying degrees of energy-efficiency affected the visual comfort, safety and perception of the users. It could also help finding a balance between the energy usage and user comfort in the space; which may serve as a reference for the development of comprehensive outdoor lighting control strategies in the future.

Method

Design

The study was a field experiment involving investigation of a pedestrian and bicycle pathway in the city of Stockholm, by analyzing a temporary test street lighting installation using presence control over the users, both pedestrians and cyclists. The focus of the study was based on evaluation of data from five different test scenarios in a period of five consecutive weeks during October and November.

This field study was carried out in two ways:

- The Visual evaluation- Evaluation of the users' responses which they answered based on their visual experience in the form of questionnaires,
- The Technical evaluation- Calculation of the energy consumption values for each scenario.

Lux level readings to see the distribution of light on the horizontal surface of the road and Luminance data in the form of photographs to mostly understand the vertical light distribution in the space were also processed for the research, although this paper would exclude the discussion for the same.

Installation and Participants

The test stretch was 750 meters long, with a total of 34 new LED fixtures equipped with individual sensors for each pole. The lowest acceptable light level[6] for the installation (in absence of people) was predefined by discussion with a test group[7] prior to the interviews with the users. The light levels for the light poles could vary within a range of level 1 (light output 0%) to level 10 (light output 100%). The lowest light level was chosen as level 5 (light output 50%) based on the visual judgement by the test group. Five different scenarios were designed to be implemented over a period of 5 weeks; ranging from the most basic scenario of static lighting (constant maximum light level of 10) to the extreme scenario with dynamic lighting and short timer settings in order to compare and evaluate the extreme contrasting conditions of lighting situations on the stretch. Table 1 shows the five scenarios along with the variables.

Table 1. Five scenarios with the variables

Scenario	Low light level	High light level	Number of poles	Timer setting (seconds)
# 0	10	10	All	- No -
# 1	5 (7 for end 3)	10	All	120
# 2	5 (7 for end 3)	8	All	120
# 3	5 (7 for end 3)	10	7 (3+1+3)	120
# 4	5 (7 for end 3)	10	7 (3+1+3)	60

In scenario #1, #2, #3 and #4, 'Low light level' (Refer Table 1) for the end 3 poles on extreme ends of the stretch were constantly maintained at Light level 7 for avoiding sudden change in visual light perception for the users approaching the area. For scenario #3 & #4, only 7 poles (3+1+3; 3 succeeding

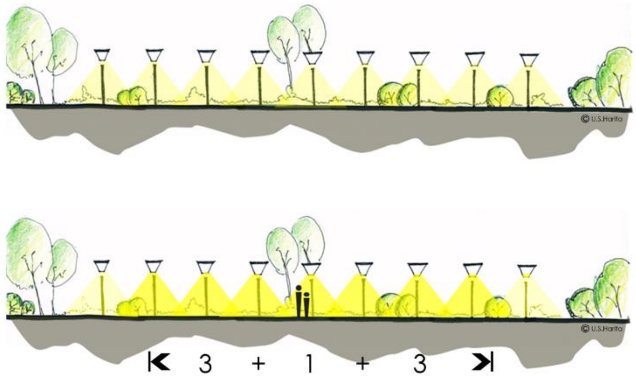

Fig.1. Illustration depicting the lighting scenario #3; without the presence of users (above) and with the presence of users (below).

poles, the pole at the current position of the user and 3 preceding poles from that of the position of the user lit up to the maximum light level on the stretch (Fig.1). Feedback was obtained from 21 people per scenario per week, making it a total of 105 people (41 female and 64 male) for 5 weeks. The percentage of men using the stretch was comparatively higher than women. The pathway was actively used during the stipulated time of the survey (20.30hrs- 23.30 hrs), though the traffic does vary from working days to weekends; high to low respectively. From the comparison of statistical data for the different scenarios, results were derived and conclusions were established.

T he questionnaire was formulated addressing the three identified factors of the evaluation – Visual comfort ('Is the light here enough for what you need to see?'), Safety ('Do you feel safe walking this road?') and Perception ('How do you judge the lighting situation?' & General comments regarding the installation). It also included range of ages, genders and the mode of transport by the users to provide comparisons in relation to the lighting situation.

All the data collected through the questionnaires was interpreted in the form of percentages.

Results

Since the study also covered the energy consumption values, it was necessary to have Scenario #0, with static lighting in order to make a comparison with those of the

[6] In this paper, 'Light level' corresponds to a certain Light output (in %) of the luminaire.

[7] The 'test group' comprised of 10-12 lighting engineers and specialists from the related industry.

scenarios with dynamic lighting using lighting controls. This also helped in making an objective comparison of the factors of visual comfort, safety and perception between static and dynamic lighting scenarios in an urban environment. The study showed some very interesting results, favouring the dynamic lighting scenarios over the static lighting. Static lighting (Scenario #0) was found out to be the least preferred scenario considering each one of the aspects of visual comfort, safety and perception both exclusively and cumulatively. Except for Scenario #1, all the other scenarios with dynamic lighting were equally preferred by the users when all the identified factors of visual comfort, safety and perception were considered together. However, while addressing each of the factors independently, Scenario #2 was considered to be the safest among others with 81% of the respondents feeling 'absolutely safe' in it, where as Scenario #1 was perceived to be the best (95%). Scenario #4, which was also the most efficient scenario in terms of energy consumption, proved to be the most visually comfortable scenario (86% of the users being able to see absolutely clearly). Surprisingly, the most energy-efficient scenario with the least timer settings of just 60 seconds before the light levels dimmed down to the lower limit of level – 5, was found to be the most successful scenario in terms of visual comfort, safety, perception along with the energy savings.

Discussion

The results of the current study were encouraging. It certainly indicates that there is untapped potential in using advanced lighting control systems, which proves to be more compliant with the users' need of visual comfort, safety and perception when compared to the static lighting in an urban environment. Although a positive response has been drawn from the study, there are reservations that need to be made. Since the study was limited to a small number of participants from a certain geographical location and socio-cultural background, caution is required in generalizing the results to a larger population and developing standardised global lighting solutions using lighting controls for the future. For e.g., different studies by Keane (1998), Listerborn (2000) and Johansson (2003) show how the perception of safety varies in different countries. Also, the context of the site is an important factor which is believed to influence the response of the users. People's perception of safety, general perception of environment and degree of visual comfort can significantly change from that of a busy place in a city with surrounding external light influence with that of a more isolated environment. Weather conditions, time of the year showed to have an influence on the responses of the users regarding visual comfort, subjected to the light levels. It was also found that the adaption of the eye from 50% light output to 100% light output was comfortable. It was interesting to find out that people could not perceive the difference in the light levels among Scenario #8 (maximum light level-8) and rest of the scenarios (maximum light level-10), providing a scope for further research if the maximum light levels could be dimmed to a lower level. Time of the day & week and isolated/ closed stretches on the installation affected the responses of the people with respect to safety. Some of them admitted that 'feeling safe' was associated less with the light levels and more with the surroundings, people and area, although many of them felt higher light levels propagated higher feeling of security. Colour of the surfaces, vertical illuminance are some of the significant factors which contributed to the responses regarding the perception of space. Presence of ample surrounding light and avoiding too bright light levels of light in the installation were the common factors which seem to influence all the three factors of visual comfort, safety and perception.

Due to the positive response from this study, another study has been proposed to be carried out later this year in Stockholm, but in a more isolated environment, in the outskirts of the city, in order to compare the two environments.

While the current study was carried out in order to be sure that the road user comfort was not compromised at the cost of sustainable, energy-efficient lighting, there was a risk that controlling the environment in itself defeats the purpose of creating a secure and transparent environment. This study project provided some useful inputs on how should the governance (using controls) should be designed so as not to jeopardize with the users comfort. The results and inferences serve as a reference for design, helping designers, technicians and manufacturers develop more standardized solutions using lighting controls. The study provides a very optimistic result, and indicates that urban lighting using controls if designed carefully could shape environments in a better way; economical and environmental benefits following as a bonus!

Acknowledgements

The pilot installation was a project proposal at the Swedish Energy Agency and was funded by the same organization. This was a collaborated project by KTH University, Stockholm Municipality, Sust (Sustainable Innovation AB), Fagerhult and Tritech and I would like to extend my gratitude to each one of them for their contribution in the study.

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Using lighting to make pavements safer for pedestrians

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Introduction

This article presents research which investigates how road lighting might be used to make pavements which are safer for pedestrians when walking after dark. Eye-tracking was used to record the items fixated by pedestrians walking along an urban route: a novel dual-task was used in parallel to identify which of these fixations were critical to the task of safe walking. This work confirmed that detection of irregular pavement surfaces and obstacles is a critical task. Experimental studies were hence carried out to identify how detection of typical obstacles is affected by the illuminance and spectral power distribution of road lighting. Initial results suggested that higher S/P ratios improve detection; higher illuminances also improve detection but a plateau is reached beyond which further increases have negligible effect. This apparatus is being used to explore the impact on detection of natural eye movements and cognitive distraction.

One reason why this work is needed is because current recommendations for illuminances on subsidiary roads are not based on robust evidence (Fotios and Goodman, 2012). The findings of this work will contribute to improving guidance for pedestrian lighting, a step toward reducing the frequency of tripping accidents after dark.

Identifying critical visual tasks

Previous assumptions about the critical visual tasks of pedestrians were reported by Caminada and van Bommel (1980), who suggested perceived safety, obstacle detection and recognition of the intent or identity of other pedestrians were the primary tasks. However, these assumptions did not have a firm empirical basis. Eye tracking offers one method for investigating the fixation behavior of pedestrians and the relative importance of different tasks, thus to clarify Caminada and van Bommel.

While mobile eye-trackers allow eye-tracking research to be done in real-world, outdoor situations, only two studies have done this to date (Foulsham et al, 2011; Davoudian & Raynham, 2012).

One issue associated with eye-tracking in real-world situations is the difficulty in controlling the type and frequency of external variables encountered. For example Foulsham et al (2011) and Davoudian and Raynham (2012) report very different rates of fixation on other people (21% and 3% respectively) and this discrepancy may have been in part due to the frequency with which other pedestrians were encountered by participants in their studies.

A second issue with real-world eye-tracking is the potential dissociation between what is being fixated and where attention is focused. Objects can be fixated without being processed (Triesch et al, 2003), particularly if our mind is wandering and considering other things (Foulsham et al, 2013).

To overcome these potential problems with real-world eye-tracking we developed a novel method for identifying the critical fixations of a pedestrian. A concurrent secondary task is used to highlight when attention may be focused on something significant in the environment. Fixations at these 'critical moments' were analysed to

Fig. 1: SMI mobile eye-tracker system (inset) and screenshot from recorded video (main). Red cursor shows current point of gaze.

identify what was being observed, and this information used to draw conclusions about the important visual tasks of pedestrians.

Method

Forty participants (53% male, 58% in 18-29 age group) with normal vision were asked to wear a mobile eye-tracker (SMI iView X HED, see Fig. 1) whilst walking a short route 900 m in length near to the University campus (see Fig. 2). Participants walked the route during daytime and after-dark, with the order and direction of the route being counterbalanced.

Fig. 2: Photographs taken from different sections of the route

Whilst walking the route participants also carried out a concurrent secondary task of pressing a handheld button in response to an audible beep emitted from a speaker on the underside of the eye-tracking helmet. The beeps occurred at random intervals between 1 s and 3 s, and reaction times to each beep were recorded. The purpose of the dual task was to identify ‘critical’ moments, instances when the participant’s attention may have been distracted by something in the visual environment. Such instances were identified by examining their reaction times. Slow (2 standard deviations greater than their mean reaction time for the whole route) or missed responses were labelled as critical moments and the eye-tracking video was investigated at these moments to determine what the participant was looking at. The rationale for the secondary task was that reductions in performance on this task could indicate cognitive resources had been allocated to visual stimuli (Pashler, 1998), suggesting whatever was being looked at during instances of poor performance are more likely to have been attended to and to have been of some importance to the participant. This concept was demonstrated in a pilot study in which visually distracting images displayed on a computer monitor produced slower reaction times to an auditory stimulus (Fotios, Uttley & Hara, 2013).

Critical observations were determined by examining the eye-tracking video for a 1 second period either side of each slow reaction to determine what was the most significant item or area being fixated. This ‘critical observation’ was placed into one of eight categories (Fig. 3): the frequency of observations in each category, as a proportion of all critical observations, was used as the dependent variable for analysis.

Results

Twelve participants were excluded from data analysis due to poor eye-tracking quality on one or both of their sessions. Data from the remaining 28 participants was not normally distributed so median values and interquartile ranges are reported, and non-parametric statistical tests have been used.

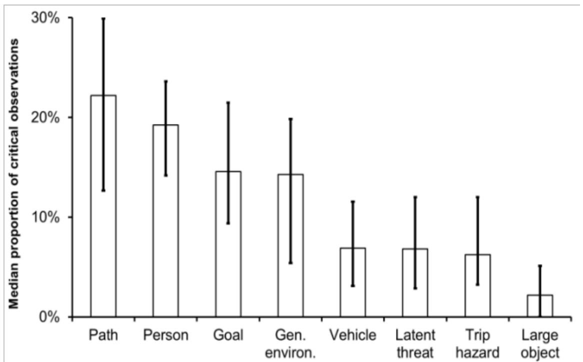

Fig. 3: Median proportions of critical observations in each item category

Figure 3 shows the median proportion of critical observations in each of the eight item categories, combined across both day and after-dark sessions. The Path and Person categories have the highest proportions of critical observations, suggesting these are important items that pedestrians look at. Further analysis of these two categories examining the distance at which they were fixated at critical moments suggested the path was more likely to be fixated in the near environment (< 4 m away, p<0.001) whilst other people were more likely to be fixated at a greater distance (> 4 m away, p = 0.04). Observing the near path and distant people appear to be important tasks for pedestrians.

We can have some confidence in this conclusion because of the identification of critical moments through the secondary task. This is an improvement from previous methods of analysing eye-tracking data, which have been based on all fixations not just those at critical times. To demonstrate the improvements offered by the dual-task approach we compared the proportions of all fixations and critical fixations for the People category. The all fixations data had a significant positive correlation with the frequency of other people encountered ($r = 0.58$, $p<0.01$) but the critical fixations showed no correlation ($r = -0.04$, $p = 0.87$), suggesting it was not influenced by the number of other people each participant encountered.

Obstacle detection

Fixation on the path ahead is carried out in order to identify obstacles and pavement irregularities for which changes in gait and/or direction may be required to avoid a trip accident. Prior to identification, a potential trip hazard must be detected, and this task occurs predominantly through peripheral vision (e.g. Marigold et al, 2007). A standard approach to assessing obstacle detection is by having participants fixate a static point ahead and indicate if they detect an item as it appears in their periphery (Fig 4). The participant is usually stationary and focused only on the detection task (e.g. He et al, 1997).

This approach was used by Fotios and Cheal (2013) to examine the effect of illuminance and spectral power distribution (SPD). With fixation maintained on a static location, peripheral vision was permitted for 0.3 s, after which test participants reported which, if any, of four obstacles were raised. This work demonstrated that SPD had an effect, with lighting of higher S/P ratio (ratio of scotopic and photopic luminances) improving the rate of detection. Higher illuminances also increased detection, but after a given illuminance, the rate of increase in detection probability diminished. These results also raised the discussion needed for interpretation of an optimum illuminance and how this decision affects also whether age and SPD have significance.

However, this standard approach does not provide realistic conditions if results are to be related to pedestrians in a real environment, for 3 reasons: (1) pedestrians do not look at a fixed point ahead of them, their gaze is constantly shifting as they fixate different areas of their environment as demonstrated by our eye-tracking data. (2) pedestrians are generally not stationary, they are walking, which demands cognitive resource. (3) pedestrians are likely to be thinking about things other than just looking out for obstacles.

To address these issues the obstacle detection apparatus used by Fotios and Cheal (2013) has been extended to investigate obstacle detection in more realistic conditions than previously. The task is similar to that used by Fotios and Cheal (2013), using raised cylindrical objects as target obstacles, but is now of a realistic scale with the obstacles appearing approximately 2.5 m in front of participants. In addition, participants walk on a treadmill, at a comfortable but realistic pace, to simulate a pedestrian walking down a street, as it is not clear from previous research how locomotion may affect obstacle detection ability. The locomotion will also add cognitive load, again making conditions more realistic.

A concurrent dual task is employed, involving a moving fixation target on a vertical surface facing the participant. This target randomly and briefly changes to a number which participants are instructed to report. This dual task has three purposes: to simulate eye movements that might be found in a real pedestrian; to use cognitive resources, again making it more comparable to a real situation; to encourage use of peripheral vision for the obstacle detection task. Previous detection studies have not been able to guarantee that only peripheral vision was used; the dynamic fixation target encourages constant fixation and thus it is more likely that peripheral vision is used for the detection task. Illuminance levels (within mesopic thresholds) and SPDs are varied to determine the effects of lighting characteristics on obstacle detection under conditions that are more analogous to a real pedestrian situation than has previously been carried out.

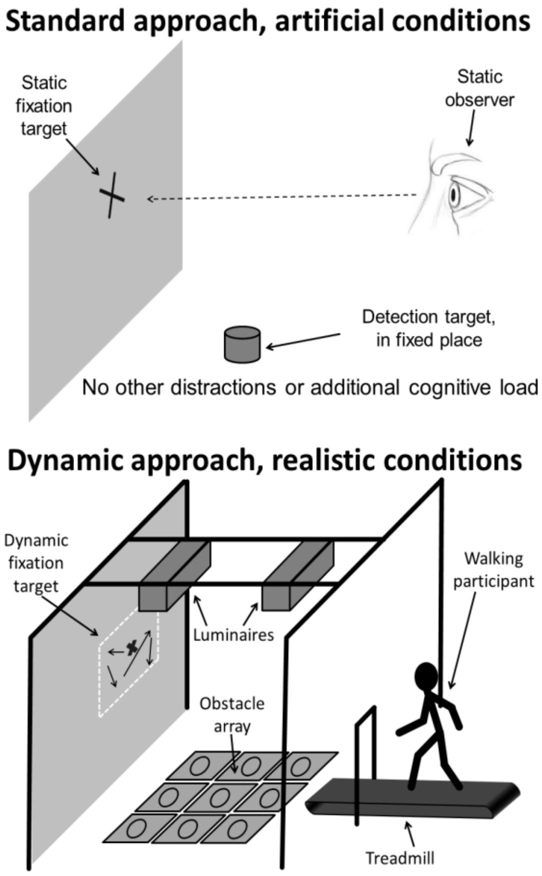

Fig. 4: Standard approach to assessing peripheral detection (above) and new approach with more realistic conditions (below)

Summary

Eye-tracking was used to identify the critical visual tasks of pedestrians. A novel secondary task was employed alongside the eye-tracking to overcome issues with standard analyses of eye movement data. This enabled the identification of critical fixations, which suggested viewing the near path and distant people are important tasks, confirming for the first time empirically the assumptions about pedestrian visual tasks outlined by Caminada and van Bommel (1980).

Viewing the near path is likely to be for the detection of obstacles and trip hazards. Previous research into obstacle detection has taken place in abstract laboratory conditions. We are now investigating obstacle detection in a more realistic situation.

The data collected during this study can provide information about optimum light levels for obstacle detection by pedestrians, contributing towards any update of the current guidelines for pedestrian road lighting.

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Perceived and Measurable: Lighting of Cambridge King's College Chapel for concerts as a case study

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Introduction

Measurable factors alone cannot fully account for lighting perception which often addresses social dimensions, such as personal expectation, emotion and experience. In this paper, we present an experimental method for developing an analytical framework to link perceived parameters with physical measures. Cambridge King's College Chapel is used as a case study. Key initial findings obtained from 624 responses will be presented and discussed.

Perceptual and objective attributes

Our approach to linking subjective parameters with objective measures is borrowed from the field of acoustic research. Beranek (1962), Barron (1988) and others developed perceptual frameworks to evaluate acoustics for concert halls. They established a mathematical procedure that evaluates subjective attributes with objective parameters, concluding with a rating of perceived sound quality. Recognising similarities between sound and lighting perception, we identified seven subjective attributes for lighting: 1) visual clarity, 2) visual uniformity, 3) visual balance, 4) spatial intimacy, 5) brightness, 6) appropriateness/comfort and 7) overall lighting impression.

Visual fields and working illumination of occupants were sampled at six positions (Fig. 1) under four artificial lighting conditions (Table 1) using a fish-eye lens and High Dynamic Range (HDR) photography. Each HDR image was created by merging fifteen RAW images captured at shutter speeds ranging from 1/1000 to 15s. To relate facts about human vision with luminance and photometric data, we superimposed onto the images the structure of the visual field and histological details of rods and cones, and then analysed the images in Matlab. Twenty-two mathematical functions were tested to describe the lit appearance of the visual scenes.

Experimental scene

One of the major pitfalls in lighting experiments is that they often entail the use of highly controlled laboratory environments, empty spaces, scaled models and/or virtual environments, where the presence of occupants is omitted. Light and shadow patterns created by luminaires can potentially change the appearance of surfaces, objects and occupants, thereby changing the overall impression. Taking physical measurements

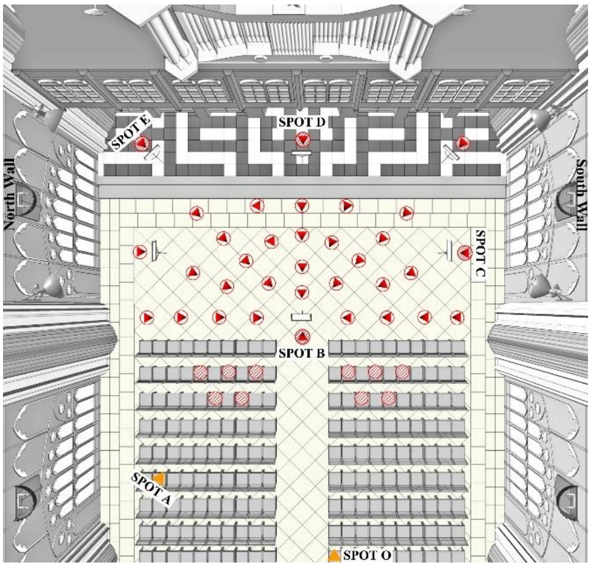


Fig. 1: Six positions in the antechapel of King's College Chapel - Spot O (Audience member), Spot A (Audience member), Spot B (Conductor), Spot C (Musician), Spot D (Musician) and Spot E (Musician)

Tab. 1: Four artificial light settings

I.	'Interim Lighting': Four sets of light fixtures were mounted on the North and South Walls. Each set consisted of a 320w energy-saving florescent lamp and two supplementary 16w spot light units.
II.	'Interim Plus Lighting': Setting I + A 320w energy-saving florescent lamp was suspended above the performance area.
III.	'All Lighting': Setting I + Setting IV
IV.	'Rig Lighting': Twenty-eight spot light units and a 320w energy-saving florescent lamp were suspended above the performance area.

and conducting field experiments during rehearsals or concerts would cause excessive distraction. Similarly, inviting groups of musicians to help recreate a concert atmosphere would give rise to security concerns and cause disruption for college members. Recognising the importance of studying light in an occupied space, we adopted the idea of replacing the occupants with dummies. Using dummies as a tool in lighting research is not new. In the early 1970s, the classic work of Cuttle (1971) on the 'flow of light' used objects and dummies to study the effects of directional lighting on appearance. This approach, however, is limited to street lighting, and uses dummies as a substitute for pedestrians during visibility measurements for night driving.

To recreate a realistic visual scene in a concert setting, we built thirty musician dummies and ten audience dummies (Fig. 2). The musician dummies were placed in the centre of the performance area and were arranged in a concentric pattern facing the conductor and audience members (Fig. 1, Fig. 3). Music stands, music sheets, chairs and a conductor's podium were also in place to ensure that the final experimental scene matched as closely as possible that of real concerts with regard to light reflection and scattering. Detailed physical lighting measurements and photographs were taken prior to the experiment. Our experimental method shows that the use of dummies is an effective and economical alternative to the use of real people.

Field experiment

Several trial runs were carried out to test the questionnaire design and the logistics of the experiment. Taking into account the feedback received from pilot subjects, we restricted the experiment to fifty minutes and the questionnaire to a single page for each setting. This was done to minimise fatigue and/ or boredom in the participants.

The questionnaire was structured into five sections: i) Visual clarity, ii) Distribution of light, iii) Spatiality, iv) Overall impression, and v) Further comments. In the first three sections, responses were collected through a

Fig. 2: Dummies for the lighting experiment

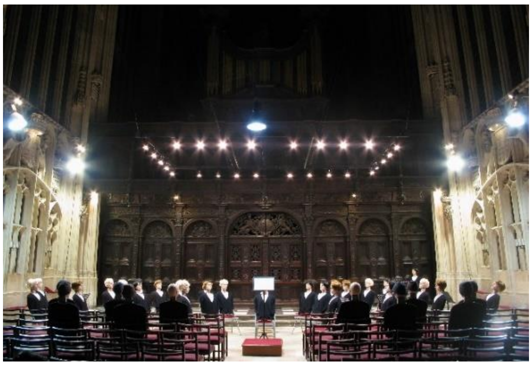


Fig. 3: The experimental setup

combination of factual, semi-subjective and subjective questions. With this method, we were able to justify subjective judgments based on objective assessments of light. Similar to acoustic research, the questionnaire concluded with a question related to the overall lighting impression and an open-ended section for additional comments. To provide a complete picture of our method, an example of the questionnaire for the audience member (at Spot A) (Fig. 1) is presented in Fig. 4. The questions for the performers were slightly different and were dependent on the occupants' roles. For instance, we asked the conductor and musicians whether the visual environment was appropriate for their roles.

Seventy-eight participants were recruited from across the University to take part in the experiment in the evenings, when the sky was completely dark. They were instructed to compare three test settings (I, II and III) against a control setting (IV) (See Table 1). The presentation sequence of the settings was randomised as a means of experimental control. Each test setting was followed by the control setting, the ratings for which were used as reference points. Time was given for the participants to adapt to each new setting. Twenty-six responses were collected at each position, resulting in a total of 624 responses (i.e. 6 positions x 4 settings x 26 responses).

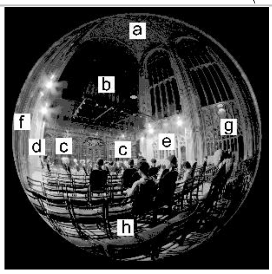
1) Visual Clarity:	
A. How well can you read the programme? *(Very poor □□□□□□□ Very well)*	
B. How well can you see the facial expressions of the musicians? *(Very poor □□□□□□□ Very well)*	
C. How would you rate this lighting environment? *(Hazy □□□□□□□ Clear)*	
2) Distribution of Light:	
A. Is this lighting environment providing a good view of the conductor/ musicians? *(Not at all □□□□□□□ Definitely)*	
B. How well can you see the architectural features? *(Very poor □□□□□□□ Very well)*	
	a. □□□□□□□
	b. □□□□□□□
	c. □□□□□□□
	d. □□□□□□□
	e. □□□□□□□
	f. □□□□□□□
	g. □□□□□□□
	h. □□□□□□□
C. Do you think the balance between light and dark is appropriate? *(Not at all □□□□□□□ Definitely)*	
D. How would you rate this lighting environment? *(Non-Uniform □□□□□□□ Uniform)*	
3) Spatiality:	
A. How appropriate is this visual environment for your enjoyment of the concert? *(Inappropriate □□□□□□□ Appropriate)*	
B. How would you rate this lighting environment? *(Dim □□□□□□□ Bright)* *(Confined □□□□□□□ Spacious)* *(Intimate □□□□□□□ Public)* *(Uncomfortable □□□□□□□ Comfortable)*	
4) Overall Impression	
A. How satisfied are you with the overall lighting experience? *(Dissatisfied □□□□□□□ Satisfied)*	
5) Further Comments	
--	

Fig. 4: Sample of the questionnaire

Findings and Discussions

Throughout the experiment, we were not allowed to interfere with routine activities in the antechapel, including regular organ practice. Among the fourteen experimental sessions, seven were conducted when there were Organ Scholars practising on the organ. Although the participants were asked to focus on the visual elements only, on-site observations and written comments prompted speculation that the subjective responses might have been affected by the unplanned music. When the antechapel was quiet, some of the participants questioned the absence of music, commenting that *"I became gradually more tired from focusing on the visual aspect of the environment"*. In contrast, when there was music playing, none of the participants complained about boredom, eyestrain or tiredness. Ordinal regression analysis indicates that the estimate coefficient of "Music_on = 0" (i.e. when there was no music) is negative (*sig*. =.003), implying that when there was music in the background, the participants were likely to assign a higher score to the overall impression scale. In other words, the presence or absence of music was of some importance.

A closer examination of the overall ratings revealed two additional observations (Fig. 5): a) the direction in which the occupant was facing, and b) the occupants' roles were the major factors that affected the overall lighting impression in the antechapel.

Next, the rating scales in the questionnaire were combined as summated rating scales in accordance with the subjective attributes. The independent relationship among the six attributes and the dependent relationship with the overall impression were then tested for the 624 responses. The Pearson correlation coefficients (Fig. 6) for the relationship between the attributes reveal that all of them were significantly correlated with each other ($\rho < .01$). Multiple regression analysis shows that all the subjective predictors together account for 74.5% of the overall lighting impression in the antechapel. However, 25.5% of the variation cannot be explained by this model, possibly because of factors such as personal expectation and experience.

154 correlation tests were performed to test the relationship between the subjective attributes and objective measures. The most highly correlated measures include, for example, average luminance (L_{avg}), relative mean of pixel intensity (RIM_{whole}), standard deviation of pixel intensity ($RISD_{whole}$), relative standard deviation of relative luminance (RL_{std}), 'Light : Dark' ratio (L:D),

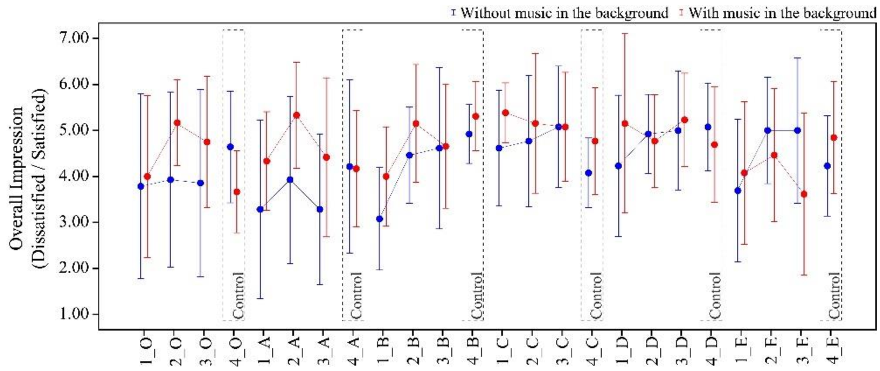


Fig.5: Comparison of subject's overall impression ratings (1_O = Setting I, Spot O)

	Visual Clarity	Visual Uniformity	Visual Balance	Brightness	Spatial Intimacy	Appropriateness + Comfort
Visual Clarity	1					
Visual Uniformity	.284**	1				
Visual Balance	.541**	.542**	1			
Brightness	.705**	.297**	.408**	1		
Spatial Intimacy	.541**	.324**	.280**	.714**	1	
Appropriateness + Comfort	.357**	.514**	.708**	.236**	.163**	1
Overall Impression	**.320****	**.517****	**.679****	.203**	.142**	**.853****

**. Correlation is significant at the 0.01 level (2-tailed).
Bold text indicates r ≥ 0.32, i.e. at least 10% of the overall impression can be explained by an attribute

Fig.6: Correlation matrix between subjective attributes

average relative luminance (RL_{avg}) and total area of light patches. 84 of these correlations were significant at the 0.01 level and 13 were significant at the 0.05 level.

A further multiple regression analysis was performed to derive a set of equations. We regressed all the ratings for the subjective attributes against the objective measures. The result shows that a combination of the significant measures is able to account for the variance in visual clarity (28%), visual uniformity (7%), visual balance (4%), brightness (26%), spatial intimacy (26%) and appropriateness/comfort (6%).

The percentage of variance for appropriateness/comfort, however, increases to 53.3% when we take into account the subjective ratings for visual clarity, visual uniformity, visual balance, brightness and spatial intimacy only. This indicates that objective measures only explain a small part of appropriateness/comfort. The regression equation for visual clarity (r = 0.53), for example, is: Visual Clarity = 3.920 + (0.093 x L_{avg}) + (0.317 x $RISD_{whole}$) + (-0.039 x L_{var}) + (-0.491 x $VA_{Musicians}$) + (-0.076 x VA_{Sheets}), where L_{var}, $VA_{Musicians}$, VA_{Sheets} are defined as luminance variation, visual acuity to discern details of performers' appearances and visual acuity to discern details of music sheets/ programme, respectively.

Despite the limited range of lighting conditions tested, our initial findings suggest that this subjective-objective framework can be used to evaluate lighting quality.

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Poster

An Investigation on Mirror Lighting

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Abstract

A research project (2012-03-01-YL04) entitled "Investigation of Mirror Lighting" is being performed in Yıldız Technical University and is supported by YTU Scientific Research Project Coordination Office. The aim of this project is to determine the preferred luminaire positions and the vertical illuminance for mirror lighting through experiments. For this purpose, a mirror was fixed on a wall of a 1/1 scale mock-up room and three linear luminaires were placed around the mirror; two on both sides and one above the mirror. The position of each luminaire around the mirror ensured that the angle between the line of view and the reflected image of the luminaire in the mirror was over 45^0. By using three luminaires around the mirror for local lighting (LL) and four suspended indirect luminaires providing general lighting (GL) in the room, 27 lighting scenarios have been created. Lighting scenarios are based on six different lighting arrangements (LA) and a range of vertical illuminances between 300 lx and 2000 lx. Surveys have been performed to determine the judgments and preferences of the subjects about which lighting scenarios cause glare or create shadows on the face and whether they provide sufficient illuminance.

Results

Lighting scenarios with 'the indirect general lighting in addition to the local mirror lighting' were more favourable than the scenarios with 'only the local mirror lighting'. The rank order of the lighting arrangements from the most preferred to the least preferred was LA-6, LA-3, LA-5, LA-4, LA-2, and LA-1. Preferred vertical illuminance ranges according to the age groups 18-25 and 26-60 were 500 lx-750 lx and 750 lx-1000 lx, respectively. For each lighting arrangement, the impression of direct glare is increased as the illuminance is increased. The preferred rank order of the lighting arrangements concerning glare was LA-4, LA-6, LA-5, LA-1, LA-3, and LA-2. Considering responses of the subjects where they did not notice any shadows or did not feel disturbed from the produced shadows, the preferred rank order of the lighting arrangements regarding shadows was LA-5, LA-2, LA-6, LA-3, LA-4, and LA-1. The responses received separately for illuminance, glare, and shadows are integrated and according to the integrated results the most favoured lighting arrangement by the subjects is the one in which three luminaires were placed around the mirror and the mirror lighting was accompanied by the indirect general lighting (LA-6). Lighting arrangement LA-6 was followed by the arrangements LA-3, LA-5, LA-2, LA-4, and LA-1. In terms of the vertical illuminance on facial plane, the age group 18-25 preferred 750 lx in the first place, which was followed by 500 lx. The first preference of the other age group was 1000 lx, followed by 750 lx. 300 lx and 2000 lx were the least preferred illuminances.

LA-1, LL *LA-2, LL* *LA-3, LL* *LA-4, LL+GL* *LA-5, LL+GL* *LA-6, L+GL*

Fig. 1: Six lighting arrangements providing 750 lx vertical illuminance on facial plane

Poster

How to Present Physical Activity Feedback on a Point Light Bracelet

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Introduction

In the last years, everyday wearable devices such as smart watches and fitness wristbands became widespread. Some of these devices present information via abstract point light displays. These should integrate easily and unobtrusively into everyday life. So far, research is missing that investigates the everyday life suitability and effectiveness of these light displays. In this work, we addressed the question how information on physical activity behaviour should be presented on a point light bracelet with respect to everyday life suitability and a mapping that is easy to understand.

Methods of inquiry

We built a light bracelet which consisted of a digital RGB LED stripe with a waterproof casing that we curved to the form of a bracelet. The bracelet provided six visible LEDs that were covered with semi-transparent film to diffuse the light. We controlled the lights with a LilyPad Arduino microcontroller, that we sewed on an additional armlet, together with a battery power supply and a button to activate the lights.

To investigate the question how the information should be presented on the point light bracelet, we conducted a user study with seven volunteers. First, each participant designed light patterns that represent information about their recent physical activity behavior. The activity information that had to be mapped to light patterns were the overall daily progress, the time elapsed since the last activity, the current performance compared to that of the week before, and the challenge to move. For the light design the participant could vary the light parameters colour and brightness, which included blinking patterns. After the design session, we programmed the light bracelet with the participant's light patterns. Then, the participant was instructed to wear the bracelet, testing the light patterns in their daily life for three days. In a post-hoc interview we asked about the overall experience and acceptance of the bracelet and light patterns.

Main findings of the study

Overall, the light bracelet was accepted for various everyday situations. Each participant followed an overall principle when designing the light patterns for the different types of information. We assume this was done to facilitate the learning of the information mapping. Participants preferred to use colours to represent different levels of information. Although many participants used a traffic light pattern (red, yellow, green) to encode rating information, they in general wished for customizable colours. Blinking was chosen only to present information of urgent or important character that really needs to arrest the user's attention. The parameter brightness was found to be unsuitable to encode information, as participants were not able to distinguish different brightness levels by daylight. From the study results, we derived central implications for the design of light patterns on a wrist-worn point light display.

In future work, we will upgrade the bracelet by integrating a light sensor to automatically adjust the point lights' brightness to ambient lighting conditions. We will investigate in how far the everyday suitability and user acceptance can be improved by using a context-sensitive light design.

Poster

The impact of illuminance and color temperature on social interaction

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Introduction

The existing embodiment and grounded cognition research shows that physical environment, particularly light, impact cognition, affect and behavior (Steidle, Werth, & Hanke, 2011; Chiou, & Cheng, 2013; Zhong, Bohns, & Gino, 2010). Social interaction in cooperation and negotiation situations depends on various lighting conditions. For instance, Steidle, Hanke, and Werth (2013) investigated the effect of light and darkness on cooperation in social dilemmas and showed that darkness activates interdependent self-construal, which in turn promotes social cooperation. Baron, Rea, and Daniels (1992) showed more tendencies for collaboration and less tendencies for avoidance strategy in conflict resolving situations under warm color temperature.

Although first evidence indicates the importance of light in social situations (e.g., Zhong et al., 2010), the nature of the underlying grounded and embodied processes is largely unknown. Theoretical accounts such as the notion of implicit affective cues (Friedman & Förster, 2010) proposes the effect of light on motivation, emotion, cognition and behavior are automatic. Thus, the very nature of automatic light associations (content, motivational tendencies, procedures) and their situated emergence can determine the effect of light on cognition, social interactions, and negotiations processes.

The aim of the study

With the aim of clarifying the underlying role of grounded and situated cognition and of explaining the effects of lighting conditions, we conduct a study with different scenarios of illuminance and color temperature. We aim to investigate their impact on social motivation, social interaction, and negotiation.

Method

We use four light and color temperature conditions, bright condition (1000 lx), dimmed condition (300 lx), cold temperature condition (4300 K) and warm temperature condition (2800 K) for a 2x2 between subjects design. The participants (n=120) are recruited via university mailing lists and receive research credits for the participation.

Expectations and current stand

Based on previous research, we propose that persons in dimly and warmly lit room would show more cooperative and collaborative behavior than those in other conditions. The study is currently being implemented as a laboratory experiment.

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Poster

A single light therapy session does not alter mood and empathy in premenstrual women

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Introduction

Most menstruating women experience psychological or somatic symptoms during the premenstrual phase, including irritability. Some of these women can be diagnosed with premenstrual syndrome (PMS) or premenstrual dysphoric disorder (PMDD). In these groups light therapy is considered a potential alternative to pharmacotherapy. As the speed of the therapeutic effect remains unclear, we studied the effects of a single morning light therapy session on mood and empathy in 48 premenstrual women.

Methods

Using a single-blind between-groups design, at about 9.30am 23 participants underwent a 30-minute light therapy session (4,500-5,000 lux with blue-enriched light, 17000K) and 25 participants underwent a sham session (150-200 lux polychromatic light, 5000K). According to the Premenstrual Symptoms Screening Tool (PSST), 17 participants met criteria for moderate to severe PMS and 1 participant also met criteria for PMDD. To assess light-induced changes in mood, we administered the Positive Affect and Negative Affect Schedule and the Affect Grid right before and right after the session as well as 60 minutes later, upon completion of a computer task. This task involved watching video clips of individuals recounting personal emotional events and rating how positive or negative the target individuals felt while recounting the events. We used the correlation between participant and target ratings as a measure of empathic accuracy.

Results

Positive affect decreased and negative affect increased over the course of the morning. There were no significant effects of light condition on any of the affect variables, nor on empathic accuracy.

Conclusion

The single light therapy session did not alter mood and empathy compared to the sham session. Future studies might consider a longer session, or focus exclusively on women with a diagnosis of PMS or PMDD.

Acknowledgements

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Poster

Relating physical and visual global light field structures

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The structure of a light field in a scene is dependent on the illumination, materials and scene geometry. We adapted the method for measurement and reconstruction of the physical light field introduced by Mury (2009) to cubic illuminance measurements using a device with a mini receptor head at each surface of a cube (Cuttle, 2014). Since human observers are sensitive to the properties of the physical light field, it is possible to measure the visual light field using probing methods (Pont, 2013). We will investigate the relation between physical and visual light fields in order to reveal possible (in-) congruencies between them.

Physical measurements and stimulus generation

We photographed and physically measured a scene that was similar to a common living room. We used three light configurations: a visible light source in the middle of the room, three aligned diffuse light sources on one side of the ceiling and four collimated light sources in the corners of the ceiling. These conditions form light fields of increasing global complexity.

Illuminance measurements were taken over a matrix of points using a cubic illuminance meter on the basis of a Konica Minolta T-10MA. The light fields were computed by means of linear interpolation of the coefficients of the first order spherical harmonic approximation between the neighbouring measurement points.

Psychophysical experiment

In each trial a "probe", i.e., a white Lambertian sphere on a black monopod, was superimposed on a predetermined location in the image. The monopod end was always grounded on a surface defining the location of the probe in the scene. The observer's task was to change the parameters of the probe's lighting (direction, intensity, diffuseness) in order to make it appear like it fits the scene.

Fig. 1: An example of a trial for three aligned diffuse light sources on the right side of the ceiling. For the current parameter settings the probe clearly does not fit the scene.

Results of the research will be presented on the conference.

Acknowledgements

We thank the Visual Experiences Group, Philips Research Europe, for the use of their light lab. This work has been funded by the EU FP7 Marie Curie Initial Training Networks (ITN) project PRISM, Perceptual Representation of Illumination, Shape and Material (PITN-GA-2012-316746).

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Poster

Towards an interactive material probe for visual perception studies

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Introduction

As part of the EU-funded project PRISM, of which the aim is to understand the perceptual representation of illumination, shape and materials, we want to measure and model the relations between perceived material qualities and factors such as light, shape and other physical properties of real objects. We hereby propose an interactive interface as a material probe and conduct a series of experiments to study (1) whether the perception of four basic BRDF modes (matte, velvety, specular and glittery) are independent from each other and (2) how well can people match material qualities under different lighting conditions?

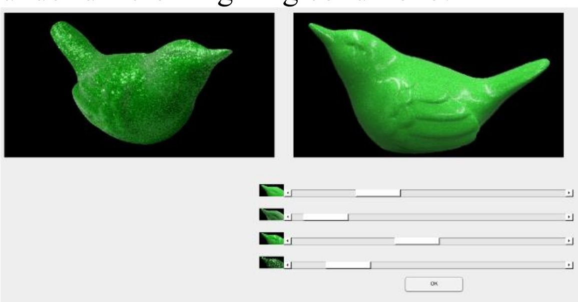

Fig. 1: The interface of the material probe

Methods

In previous research (Pont et al, 2012), we optically mixed matte, velvety and specular bird-shaped objects in real scenes, and found that the mixes looked realistic and perceived qualities depended systematically on the weights of the mixes. Here we want to demonstrate how four materials can be combined into a material probe for perception research and industrial design uses. We propose an interface (Figure 1) that integrates the material probe. There are four sliders under the probe image, representing matte, velvety, specular and glittery contributions. Images cropped from original photos were set in front of each slider as reminders. We conducted matching experiments with the probe to test its usability.

We firstly took photos of matte, velvety, specular and glittery bird-shaped objects under two lighting conditions. By weighted linear superposition of the photos under the same lighting condition, we generated a stimulus set of controlled stimuli (left image in the interface), which varied parametrically in material appearance. Then we implemented the photos under the same (Exp 1) or different (Exp 2) lighting condition as the probe (right image in the interface). In both experiments, for each stimulus, participants are asked to manipulate the probe by moving the sliders until they perceived the materials to be as similar as possible in both images.

Results

The data of Exp 1 fitted the linear model quite well, indicating that the task is doable and the interface is workable for the participants. There were slight interactions between matte, velvety and specular modes, while the glittery mode was quite independent from all others. Results of Exp 2 will be presented at the conference.

Acknowledgements

This work has been funded by the EU FP7 Marie Curie Initial Training Networks (ITN) project PRISM, Perceptual Representation of Illumination, Shape and Material (PITN-GA-2012-316746)

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Poster

The sensitivity of observers to light field in real scenes

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Introduction

Humans are able to perceive and adjust the intensity, the primary illumination direction, and the diffuseness, which are basic (low-order) properties of a light field (Koenderink et al, 2007). However, most research on the light field was based on photographs or synthetic renderings on a computer screen. We developed a method to investigate the visual light field in a *real scene* by using a novel experimental setup (see Figure 1), with which a real gauge object can be optically mixed into a real scene (Xia et al, 2013). The results of that study showed that observers can also judge intensity, direction and diffuseness (in)congruencies in real scenes. Here we address how sensitive observers are to the properties of the light field in real scenes and whether they can estimate three properties simultaneously.

Methods

The experimental setup is shown in Figure 1. The lighting characteristics in cube B and C were varied by changing the displayed images on the two LCDs covering these cubes. We tested observers' sensitivities for lighting intensity, direction and diffuseness by varying the pixel values, position and size of a white disk on the LCDs. The task of the observer was to adjust the lighting on the gauge object in cube C to fit the lighting on the scene in cube B. In the first experimental session, nine directions (a 3 by 3 array), five levels of intensity (28, 37, 47, 60 and 77 cd/m2), and five levels of diffuseness (diameter of white disk being 7, 10.5, 14, 17.5 and 21cm) were tested separately. In the second experimental session, 3 directions (in the center and in two opposite corners) were combined with 2 levels of intensity (37 and 77 cd/m2) and 2 levels of diffuseness (diameter of 7 and 10.5 cm) and observers had to adjust all parameters simultaneously.

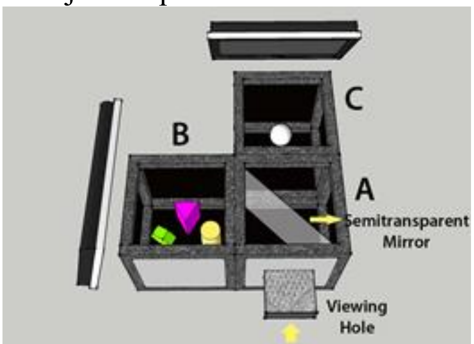

Fig. 1. Experimental setup: in cube B, five geometrical shapes form a simple scene; in cube C, a white sphere serves as the gauge object; in cube A, a semitransparent mirror optically mixes the scene and gauge object together; two LCD screens covering the top of cube B and C provides the lighting.

Results and conclusions

We found that human observers were quite good at fitting the lighting intensity on the gauge object to that of the scene in both sessions. The estimated lighting direction on the gauge object correlated to that of the scene, but also showed systematical deviations from the veridical directions. In another study these deviations were found to be due to the scene layout and content (Xia et al, 2014). The estimated diffuseness tended to be overestimated and the participants were able to distinguish only three of the five levels of diffuseness.

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Poster

Spectrum and Scene Brightness Perception

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Introduction

Studies of scene brightness have led to recommendations suggesting that "cool-appearing" sources achieve higher brightness at lower illuminances than "warm-appearing" ones. And while a sense of safety appears to be correlated to perceived scene brightness in outdoor environments, a "warm" appearance might be preferred for certain scenarios. With light emitting diode (LED) sources being customizable in spectrum and light level, targeted research can lead to user-oriented, energy-efficient solutions. A metric to design spectra according to brightness could help in optimizing preferred spectral appearance and perceived brightness for different conditions.

Several experiments were conducted to assess whether scene brightness perception at low-to-moderate photopic levels (~ 3-150 lux) could be partially explained by the contribution of intrinsically photosensitive retinal ganglion cells (ipRGCs) to brightness perception, and to test and refine a metric for scene brightness.

Experiments 1 and 2

Experiments 1 and 2 utilized an LED light box in controlled laboratory conditions. Ten participants compared two stimuli sequentially for brightness at two different light level ranges (low ~3-20 lux, and high ~20-150 lux), and at two different spectral power distributions (Green vs. Fuchsia, and Amber 1 vs. Amber 2). The results suggested an increase in short-wavelength spectral sensitivity at increasing light levels. The results also confirmed that a metric of spectral sensitivity for scene brightness perception that includes ipRGC contributions, in addition to incorporating a shift in short-wavelength sensitivity at higher light levels, was able to predict the experimental data with significantly less error than a metric using cone input only.

Follow-up Experiment

A follow-up experiment was conducted using two off-the-shelf 4-channel color changing LED outdoor fixtures to illuminate a spatial scene. Ten participants adjusted the light from one spectrum to match the brightness of the scene illuminated by another spectrum. The results confirmed that scenes lighted by two similar-looking amber sources (~600 nm vs. ~520 nm + ~630 nm) were evaluated differently in terms of brightness. The evaluations were consistent with predictions using a brightness metric that includes ipRGC contributions.

The study also evaluated the overall preference of the spectra at equal brightness, to assess further effects of spectral composition and aesthetics on preference. The results suggested that participants largely agreed on which stimulus would be preferable for a given scenario, and that different spectra would be preferred for different scenarios (i.e., unfamiliar/dangerous locations vs. familiar/safe ones).

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Poster

Timelight – Using Light to Keep Track of Time with Children

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Introduction

In today's daily life parents are often sidetracked by other events or devices when really they promised their children to spend some time with them, e.g. playing or reading. While being sidetracked, it is easy to lose track of the time intended to be dedicated to interaction with the child.

We are introducing Timelight. A means to help parents and children keep track of time dedicated to interaction and play. Timelight is a tangible, portable timer displaying the progress or remainder of time in a quiet, unobtrusive way by using light. We plan on investigating the design space present our initial research questions.

Related Work

Ever since Weiser and Brown reported on the concept of "Calm Technology" (Weiser & Brown, 1996), scientist have tried to develop systems displaying information in the periphery of the user's attention to assist people in an unobtrusive way (Ishii, et al., 1998). Light has recently been used to display upcoming events in the office environment (Mueller, Kazakova, Heuten, & Boll, 2013) as well as to display spatial information in control room tasks (Loecken, Mueller, Heuten, & Boll, 2014).

The Design Space

We envision Timelight to be a tangible device emitting light to show the progress or remainder of time periods that parents and their children dedicate to playing. Timelight could be anything from a "magic wand" to an illuminated "hour-glass". The lighting design is meant to display either the progress or remainder of dedicated time. Over the course of our investigations we will need to answer the following research questions:

1. What is a child's intuitive understanding of light to show the progress of time?
2. Can the time duration displayed with light be variant or does the time period have to be fixed?
3. Does the form factor play a role and are there gender-specific differences to be accounted for when designing the light?

With these questions in mind, we aim to construct a number of prototypes designed to answer the individual questions as well as help solve the problem overall.

We plan to evaluate various parameters of light such as hue, saturation or brightness for their suitability to convey information as well as evaluate the use of single or uniformly controlled light sources over a multitude of individually controllable light sources to create more complex lighting patterns to show the progress of time.

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Poster

Effects of artificial lighting on cognitive performance in elderly night shift workers: The role of well-being.

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Purpose

In particular night shift work leads to reduced cognitive performance and consequently decreased work productivity, especially in elderly people. One well documented method to maintain or improve cognitive performance during night shift work is the exposure of bright artificial light (Santhi et al., 2008).

According to previous research, the purpose of the current study was to examine whether there is a direct positive bright light effect on cognitive performance in elderly persons and whether and to what extent well-being plays a mediating role in the relation between artificial lighting and cognitive functioning.

Methods

A random sample of thirty-two test persons (16 women, 16 men, 48-68 years) worked in three consecutive simulated night shifts. Treatment group (N=16) was exposed to bright light (3,000 lx) and control group received normal room illumination (300 lx). The cognitive performance variables divided attention, working memory and concentration were assessed by computerised tasks. The variables sleepiness and mood were applied as indicators of well-being and were recorded by well-established German questionnaires.

Results

Mediation analyses according to Baron & Kenny (1986) were conducted. In addition, the bootstrap method was deployed to detect mediation effects. Results illustrate that sleepiness and mood could completely be excluded as mediators in the relation between lighting and cognitive performance. Sleepiness caused an underestimation of the enhancing bright light effect on concentration performance. Mood produced only a random effect concerning the improving bright light effect on working memory (Kretschmer et al., 2013).

Conclusion

This investigation underlines that well-being of elderly persons is not a critical influential variable in the treatment of bright artificial light on cognitive performance in the night shift workplace. It becomes evident that bright light has a strong direct and independent enhancing effect on cognitive functioning, particularly on working memory and concentration, in elderly persons during night shift work (Kretschmer et al., 2013).

We recommend to provide higher illumination levels for visual tasks in the night shift workplace to improve cognitive performance and to maintain or increase work productivity of older night shift workers.

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Poster

Solar fictions : A practical approach to simulate the sun's path around a white cube

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The objective of the research was to provide a device where the viewer can perceive the sun's path corresponding to the rotational motion of the Earth in a white cube. Projection of light through apertures on the walls was the symbolic image of this movement. How to design a device with parallel ray of light and a single rotating source to simulate the sun's path?

Technical and aesthetic challenges were:

- The creation of a light spot with parallel rays. The sun's rays appear parallel to our eyes due to the distance; the rays of artificial light diverge due to diffraction. The aesthetic intuition in the project is that the parallelism of rays suggests the distance of the source.
- The creation of four synchronized moving lights to have the impression of the rotation of a single sunlight around the white cube.

After testing several systems, four movable mirrors seem to be the best solution for both purposes.

To design a spot with approximately parallel rays of light, the first idea was to create a light with a big parabolic mirror in order to have parallels rays like in the optical theory, but it was too complicated to realize and to motorize. The optical project manager has pointed out that only 5 meters away from the projection surface, the rays seem quite optically parallel to our eyes. Two meters away from the source the reflectance on a plan mirror multiplied the length of the ray before it passes through the slit in the wall and touch the projection surface, which is equivalent to the length of 5m recommended.

The second objective was to design a system with four rotating lights sources, the solution found was to place an articulated plan mirror at a distance of two meters from the light source and to articulate this mirror. The mirror was powered by 2 axes; one for the height of the azimuth and another for the East-West direction. The first motor was located around the X-axis and placed horizontally in the middle axis of the mirror, the second motor was located around the Y-axis and placed vertically in the center of the source at two meters away from the mirror.

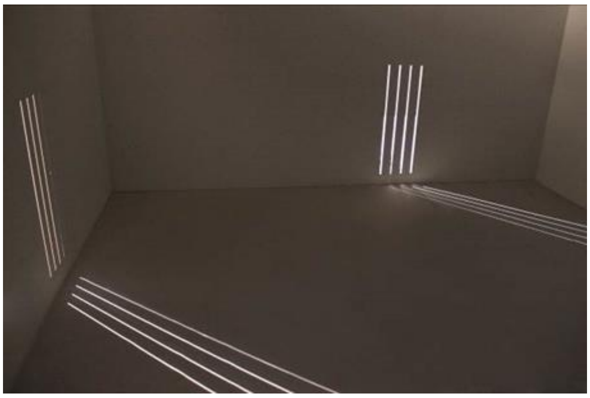

Fig. 1: Parallels installation, 2012

The feeling of a unique mobile source rotating far away around the installation seemed to give the viewer the illusion present in the white cube of the simulation of the sun's path. The synchronization of the mirrors gave the viewers the sensation that they were embedded in the device like in a space and time continuum.

Parallels is an artistic installation created by Marie-Julie Bourgeois, artist researcher, in the EnsadLab research group from 2009 to 2012 and presented during the exhibition "leurs lumières"[1] in 2012.

[1] "leurs lumières" (Their lights) Catalogue of the exhibition from October 13rd to December 16th 2012, Centre Culturel de Rencontre, Abbaye de St Riquier, Baie de Somme, France, Curating by Jean-Louis Boissier

Poster

Non-visual aspects of light: a proposal for a practical procedure in lighting design for wellbeing

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Introduction

In lighting design great emphasis is put on quality. Wellbeing has increasingly become the key element in the design process, considering not only visual comfort but also non-visual aspects such as the interaction of light with the circadian rhythms in humans.

Notwithstanding the lack of standards dealing with calculation models or specific requirements for circadian light, some researchers have proposed advanced models (CIE 158, 2004; Rea, Figueiro et al, 2010) approaching to circadian photometry. (Bellia and Bisegna, 2013)

Referring to fresh research, this work aims to propose a practical approach to compare lighting design solutions, optimized for circadian lighting requirements and based on simple tools used by lighting practitioners.

Methodology

This work was focused on providing early indication on circadian effects of light using two parameters: illuminance on visual task and the circadian action factor relative to a light source.

The lighting simulation of an office space has been chosen as case study, in order to assess a lighting profile that should be able to satisfy both requirements for visual and non-visual aspects.

Traditional light sources and LEDs with different correlated colour temperature have been characterized by their own circadian action factor, measuring their spectral power distribuition. Illuminance has been assessed on the visual task (desktop) and at observer eye level (semicylindrical illuminance) to verify the circadian light received by users during an established lighting profile. This last parameter has been assessed by means of one of the most complete circadian models available today. (Rea, Figueiro et al., 2010)

Photometric quantities have been simulated by means of a commercial software developed for light planners.

Conclusions

In the future lighting designers will have to deal with new requirements for wellbeing, considering both visual and non-visual aspects that should be included in a specific standard framework. A standardized circadian action factor is needed, that should be provided by lamp manufacturers, so that designers are able to classify and compare different light sources for their biological effect. Moreover calculation methods defined by standards should be easy to apply, in order to not radically change the workflow of lighting practitioners and make them aware on the importance of non-visual aspects in the lighting quality assessment.

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Poster

Prototyping interactive lighting for a musical installation

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Introduction

The Music Room is an interactive installation that allows couples to compose original piano music by moving throughout a physical space (Morreale, 2013). Couples can direct the emotionality of music by changing their distance and speed: distance influences the pleasantness of the music, while speed influences the intensity. During the two first public exhibitions we opted for a static and minimalistic setting to avoid distractions from the musical cue. However, in-situ observations and visitors' comments suggested adding interactive lighting to enrich the experience. This poster describes the process of prototyping a lighting system for The Music Room. The prototype consists of an interactive light composition which couple with the emotional connotation of music. This prototype was designed to increase the perception of control while avoiding distracting participants from the music. After an initial conceptual design phase, five possible scenarios were developed and iteratively tested using prototypes of increasing fidelity. This iterative prototyping methodology resulted particularly efficient in terms of costs and time, and it might be useful for researchers, artists and practitioners that wish to pre-test the effect of different lighting conditions when designing artistic or entertaining experiences.

Related Work

Existing research on colour and emotion (Kaya, 2004) was used to design the mapping between the interactive light composition and the emotional connotation of music. Although colour preferences tend to be deeply connected to personal experiences, some studies suggest that red is generally connected to negative emotions, blue to positive emotions, and low lighting to intimate and positive experiences.

Scenarios

These findings, combined with authors' experience and creativity, contributed shaping five possible scenarios:

S1. Physical distance between couples is dynamically mapped into brightness levels.

S2. Physical distance between couples is dynamically mapped into hue filters (blue when they are close, red when they are far) and average speed into brightness levels.

S3. A wavy line connecting the two people is projected into the floor. Average speed is mapped into wave frequency and physical distance determines the waveform.

S4. A light pulse is emitted every time one of the visitors steps on the floor.

S5. A light pulse is emitted to simulate the heartbeat of each visitor.

Results

The scenarios were sketched and rated by 15 participants. The three scenarios which obtained the highest ratings (i.e. S1, S2, S3) were transformed into high fidelity prototypes. The high fidelity prototypes consisted in four videos recorded during a public exhibition of The Music Room manually manipulated for brightness and hue filters. High fidelity prototypes were evaluated by 50 participants. Results disclosed that the first two scenarios were considered the most intuitive and less distracting.

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Poster

Daylight Openings: The Impact of Permeability Effects on the Perceived Creative Potential in Offices

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Introduction

Physical environments can elicit different subjective evaluations, atmosphere perceptions, and moods in individuals. Depending on the office design, a creativity-supporting atmosphere can be created which, in turn, improves creative performance (McCoy & Evans, 2002). From a psychological perspective, the subjective assessment whether an office would facilitate or hinder creativity describes the creative potential of this environment. The present research focused on the impact of one physical feature which acts as mediator between inside and outside and is closely related to lighting aspects such as amount of daylight and view: the facade permeability. The facade's specific structure, in particular its permeability, strongly influences the space perception (Stamps, 2010). Openness, transparency, the strength of room-boundaries, lightness, space, and light itself constitute essential characteristics of facade permeability. Previous studies indicate that elements of facade permeability (e.g., luminosity) can influence creativity (Ceylan et al., 2008). The present research investigated the effect of facade permeability in offices on their perceived creative potential and explored the role of light, window size, attractiveness, and creative atmosphere in the permeability-creativity model.

Method

We conducted an online-study in a two-step procedure: In a pilot study, 42 pictures of office rooms varying in facade permeability were identified. A sample of 19 participants rated the perceived permeability on a newly developed scale with seven semantic differential items (e.g., intransparent – transparent, $\alpha = .95$). A second sample of 152 participants assessed the room's attractiveness, creative atmosphere (McCoy & Evans, 2002), and creative potential. Moreover, the window size and the luminosity of the window space in the pictures were measured via Photoshop.

Results and Discussion

As expected the results showed that facade permeability increased the perceived creative potential ($r = .70$), creative atmosphere ($r = .75$), and attractiveness ($r = .73$) of offices significantly. Partial correlations revealed that the creative atmosphere and attractiveness mediated the influence of perceived permeability on a room's creative potential yielding to a subjective evaluation chain: permeability → creative atmosphere → attractiveness → perceived creative potential. Results showed that the subjectively perceived permeability was significantly influenced by light-related parameters including window size ($r = .59$) and luminance of window area ($r = .45$).

Overall, facade permeability cannot only shape daylight in an office, but also its perceived creative potential. Further research is needed to provide concrete guidelines for practitioners how to create facades and daylight openings for optimal creativity.

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Poster

Shifting Daylight Patterns: Daylight in Retail Spaces

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Introduction

Light being the quickest and the most direct form of non-verbal communication, plays an indispensable role in retail spaces. It is the single most important design element for attracting customers, creating or manipulating atmosphere and affecting consumer‘s visual appraisal of everything in a store (Summers & Hebert, 2001; Gobe, 1990; Rea, 1993; Lopez, 1995). Furthermore, daylight, to all cultures in all times, connotes positive feelings and values; and apart from having such strong emotional effect on people, is also embedded in a larger spatial context. Research by Heschong et al. (2003) suggests that daylight in retail stores might positively influence the visual perception of the store and also the sales. Hence, daylight could be used to influence the subjective and emotional response as well as the behaviour of people in a retail space. The question to be addressed however is which properties and characteristics of daylight can be used to bring about these positive behavioural responses. Moreover, how can daylight be used to present products and therefore what will be the impact of various fenestration designs, their location, and visual contact/noise on product presentation.

The aim of the study

The current study looks at the relationship between different fenestration designs and consumer behaviour in a retail space. Investigating how does the design of daylight openings influence the perception of the store and in turn affect the emotions and behaviour in that space. Subjects rate a retail space with different fenestration designs based on the pleasantness of light and the willingness to explore and evaluate the products in that retail space.

Method

Seventy-eight participants (44 females, M_{age} = 23.4 years) were asked to evaluate set of 61 simulations of an abstract retail space, generated using Autodesk 3ds MAX rendering software. The simulations were shown on a 46-inch LCD television in a controlled experiment. Participants had to rank a set of four images based on two separate tasks. First task involved ranking the images based on “in which image they find the lighting situation most pleasant”. The second task required the participants to rank the same set of images based on “in which space will they prefer to spend time, explore and evaluate the products the most”.

Analysis and Results

Initial analysis reveals that position and shape of the fenestrations influences the perceived pleasantness of the lighting situation. Further, the willingness to explore and evaluate products in retail spaces with small window sizes is dependent on the position of the windows. In general, spaces with vertical openings are perceived as having more pleasant lighting situation when compared with spaces with similar size skylights. Final results will be presented and discussed.

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Poster

The Effect of Media Facade on Physical, Mental, and Cultural Health of Society

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It is globally believed that the usage of digital technology in façade design, or in other words digital and media façade is increasing significantly. Indeed, there are advantages as well as disadvantages in using these recent types of façades.

Several reasons have been mentioned that shows the eagerness of the society and also the media industry to expand various aspects and usages of this technology but up to now no guideline is provided neither to ensure the visual outcome of digital facades, nor to control the unity of these facades with each other as a whole concept. Without considering visual outcome of these digital facades the result would sure be a chaos of lights and colors changing the whole atmosphere of urban spaces. This issue can easily be seen in cities like Shanghai in China and Tokyo in Japan. In addition, the fact that urban spaces affect the formation of the culture of society and art, like the effect of Paris's urban changes and modernized in impressionism movement, it's necessary to control the outcome of these media architecture.

There are several aspect which need to be considered in the design of a media façade. Apart from technical considerations in architecture which would focus on the architectural design of the shape, type and placement of the façade, not to block the daylight and view from indoor, communicational aspects of media façade are to be considered carefully.

Media façades being the same all over the world, in the case of advertisement, would convey a placenessness feeling to people.

From health and safety point of view, the placement of media facades, can cause distraction and accidents especially in case of highways. Furthermore, rapid changes in color, brightness and contrast can attract the attention of pedestrians and drivers to a noticeable extent and cause accidents consequently. In addition, the culture of society is affected as every urban space in which the façade is installed, is transformed into a public space which communicates with people in the neighborhood. Hence, the content of a media facade should be designed according to the society, culture, and context within which it is going to be presented.

In the current study, the effect of media facades on physical, mental and cultural health of a society is analyzed and investigated. Several case studies were taken into account and recommendations and design considerations with respect to limitations and possibilities were presented.

Poster

Colour temperature influencing space perception

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Introduction

Variations in colour of light influence the impression of the room (Flynn, 1977), and Manav (2007) also found a correlation between the correlated colour temperature (CCT) and the perception of spaciousness. Billger (2006) concluded that the perception of spatiality and proportions are influenced by the colour combinations of the surfaces.

This study investigated if artificial light sources with two different CCTs, 2800K and 6500K could influence perceived spatial volume.

Methods of inquiry and measures used

The study was an experimental study using room scale models 1:10, see Fig.1. Four models in three different sizes were used; one small model (Box A), two medium size models (Box B1 and B2) and one large size model (Box C). The participants were 21-62 years old, 8 men and 7 women.

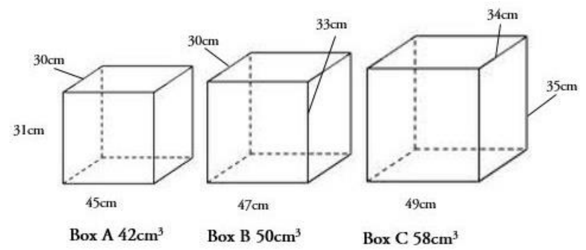

Fig. 1: Metrics for scale models

LEDs (Philips retrofit LED ”Hue” 9W, 360 lm) hung from the ceiling and shone into the models through holes in the top. CCT 2800K and 6500K were set using a spectroradiometer. The average illuminance in the 2800K box was set to 1000 lux and in the CCT of 6500K it was set to 1200 lx in accordance to a pre-study estimating equally perceived brightness. The CCT 4000K was chosen for the ambient room lighting as being neutral compared to the CCTs in the models. Existing windows in the experimental room were blocked.

Procedure

The participants looked into the models, shown two at a time, with different or the same CCT and size, through a slit in a screen. They were asked to name the most spacious model or to decide if they were the same size. The procedure was repeated 15 times according to a protocol.

Analysis

A Chi-square analysis using SPSS, with the level of significance set to $p = 0.05$ was used.

Results

The result shows a tendency for a higher CCT to enhance the perceived space inside the model as compared to a lower CCT. The participants estimated the volume to be larger than in real life in 39% of the cases in 6500K as compared to 29% of the cases in the 2800K illumination. The largest model (Box C) was the only size where a significant correlation in estimated size and CCT could be shown.

Conclusion

This study could not show that CCT has an influence on perceived volume.

Acknowledgements

Kjellberg and Stormvern originated the study and assisted in data collection.

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Poster

Exploring light and darkness: collective interventions in urban spaces

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Introduction

This work is about a collective light festival created by the students of a bachelors' degree lighting course conducted by the authors. The idea of planning and performing a lighting festival was connected to the concept of reflective practice as a learning method. The interventions had the goal to bring some quality to urban spaces in the inner city. The formal question of this study was: how do people coming from different cultures understand the relations between light, dark and urban spaces and give meaning to their installations?

The Taschenlamp Festival

The light festival format, developed for the Taschenlampe Festival event acted as a vessel that transports the ideas of the theme and installations. Using the documentary "The City Dark" from Ian Cheney (2012) as an inspiration, the "just born lighting designers" went deeper in the light pollution issue to create their installations that aimed to give meaning for commonplaces in the city of Detmold without spilling more light in the sky. The students created installations around three central themes: environmental impact of light pollution, magic of low light in dark settings and perception of public space using light. All themes wanted to bring a new atmosphere, and awareness towards the action that ultimately presented a changed condition in the space.

Methodology

The students used small hand held torches and light sources to give them the freedom to explore space without the need for large scale infrastructure planning. The low impact method fitted all materials into a backpack and were easily transportable. Filters were added to hand held torches to create effects that were quickly realised. Considering that the learning process includes improving your action each time you think and do it again, there were at least three steps to produce the final lighting installation action: first to test it, reflect on the problems and achievements with professors and colleagues and then, go to practice again. The test night preparation involved prior site investigations during day and night conditions and a gathering of materials. All materials were salvaged from the University, borrowed from the lighting laboratory or brought from home.

Discussion

Lighting has the fantastic capability of creating different atmospheres and it is always interpreted and related to our cultural experience. Having students from all around the world, as Brazil, India, Serbia and Germany was responsible for making the experience full of richness and complexity at the same time. Language and different working methodologies were great challenges for all. The result was a festival with different and very sensitive approaches to light and darkness.

Conclusion

This poster is the documentation of the results from this intercultural lighting experience. Registering all the actions of each participants let us perceive the potential of light installations in the urban space.

Acknowledgements

The authors would like to thank to the German Academic Exchange Service (DAAD), to the Ostwestfalen-Lippe University of Applied Sciences' (HS-OWL) and to Universidade Federal do RS (UFRGS).

Poster

Visual comfort of Luminescent Solar Concentrators in Offices

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Introduction

The need for energy conservation in buildings has spurred innovations in (window) technologies. One of these innovative technologies is the Luminescent Solar Concentrator (LSC). The LSC is a device, employing a polymeric of glass waveguide and luminescent molecules to generate electricity from sunlight when attached to a photovoltaic cell. Such a device has the potential to find extended use in an area traditionally difficult for effective use of regular photovoltaic panels: the built environment.

However, a major issue in the use of LSC as a window technology is the color of the dye on the glass essential for the energy performance of the device. The colored glass alters the daylight penetrating into the room in terms of wavelength, distribution and luminous flux. All this affects the perception and quality of a space and therefore the acceptance of the user.

The objective of this research is to find the optimum percentage of LSC in terms of energy efficiency related to the preference and acceptance of the user. A sub question is whether the tolerance of people towards colored glazing changes when they are aware of the fact that the colored glass is part of a sustainable device.

Methods

Furnished scale models (1:6) of a day lit office room are made and evaluated (Figure 1), using different percentages of colored glass in the transparent façade (Dubois et al., 2007). For this evaluation, 40 test subjects in the age between 21 and 28 are asked to complete questionnaires. The subjective ratings obtained from the questionnaire responses are analyzed statistically with SPSS statistics.

Different light measurements are done to assess the illuminance, luminance and spectral irradiance inside and outside the scale model and to link the subjective ratings to objective light values.

Fig. 1: Scale model, shown with 50% colored glass

Results

The pilot studies demonstrate that in general the visual impression is scored increasingly positive in linear proportion as the percentage of colored glass decreases. Surprisingly, people valued the transparent façade with 25% of colored glazing as more comfortable than a fully transparent façade (0% of colored glazing). When people are informed about the energetic aspect, 1/3 accepts a higher percentage of colored glass in the transparent façade than without knowing.

The full experiment is planned in September and October 2014. Results will be presented in December at the Eindhoven University of Technology.

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Poster

Reassurance in the dark: Effects of personality and environmental factors on critical distances between pedestrians

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Introduction

Guidelines for pedestrian lighting are formulated in terms of the tasks that lighting is to support. The crucial task for safety perception is taken to be face recognition at a distance of four meters (see, e.g., Raynham, 2004). Whether this is indeed most essential for safety perception is subject to debate, as is the critical distance of four meters (e.g., Fotios et al., in press). We contribute to this discussion by investigating critical distances between pedestrians, and by exploring how these distances are affected by personality and environmental factors.

Method

Thirty-three students participated (22 men; average age: 20.7 years, SD = 1.85). With each participant critical distances were assessed at four different locations on three sites (counterbalanced): bicycle path with vegetation on the sides, underground bicycle parking, and an open pedestrian area with few trees. We expected these sites to differ on three environmental features: prospect, concealment of possible criminals, and escape possibilities (e.g., Haans & de Kort, 2012). At the pedestrian site—with adaptive street lighting—two locations were included: each matched to the color temperature of the lighting at one of the other sites. The same confederate, wearing a hoodie, was used with each participant. $L_v \approx 6$ lux at their position. Participants approached the confederate and stopped at the distance at which they felt they normally would like to be reassured about the other person being a threat or not. Next, they rated the location on the three safety-related features. Finally, they completed a survey assessing two personality characteristics: power to avoid assaults, and attractiveness to criminals (e.g., Haans & de Kort, 2012).

Results and discussion

The three sites differed on all three environmental features in the expected manner, with $t(32) \geq 3.0$, and $p < .01$. The average critical distance obtained at the four locations ranged from 8 to 10 meter, but only the difference between one location on the pedestrian site and the bicycle path was significant, with $t(32) = 2.3$, and $p < .05$. This difference was mediated by prospect and escape as indicated by significant Sobel tests ($p < .05$). Critical distances increased with lower escape and prospect. Finally, we found that more attractive ($r = .35$; $p < .05$) and less powerful people (power; $r = -.41$; $p < .05$) maintained larger distances. Consistent with recent eye-tracking studies (e.g., Fotios et al., in press), our results suggest that critical distances may well exceed four meters. They also suggest the importance of considering not only personal, but environmental factors in pedestrian lighting research.

Acknowledgements

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Poster

Framing the Study of Pedestrians' On-Going Experience of Safety in Dynamically Lit Urban Environment

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Introduction

This poster presents work-in-progress to investigate subjective lighting-related safety as experienced by pedestrians with the intent to optimise the energy efficiency of street lighting. This is increasingly pressing as the influence of lighting dynamics to the experienced safety remain still largely unknown. Experienced safety associates to how people perceive their possibilities to act in a particular environment and shapes people's willingness to utilise outdoors environments. Hence it is important to understand how different lighting setups influence on people's experience of safety.

The experience of safety

The experience of safety can be understood as people's anticipation of potentially harmful events to themselves or to their belongings. We have identified 1) assaults, 2) vandalism, and 3) accidents to be aspects that are related to this experience. Earlier studies of experience of safety have addressed these aspects separately, but we seek to bring these together in a holistic appreciation of safety in natural settings. Moreover, we aim at getting hold of dynamically evolving experience of safety as people move through space.

The dilemma

Even though the notion of experience of safety would be conceptually clear, measuring it is difficult for many reasons. First of all, it is very much likely that the study procedure influences on how people perceive their surroundings. Moreover, it may be problematic to get people to report on their experience of safety in an accurate and clear fashion notwithstanding the changes that take place during live experiencing. And, lastly, it may be challenging to distill, which features of the surroundings influenced on the experience. This is especially important when addressing real-life conditions where the full control of environment is not possible.

Suggested approach

We propose 3-part procedure for collecting data about the experience of safety. The *first part* is a questionnaire for collecting background information, briefing about the experiment, and then learning the use of an experience tracker that enables the input of a linear measure. On user-input the tool records time, GPS location, and a measure (positive/negative). A small video camera will be attached on the head of the participant so that it may record roughly the visual area that the participant is attending to. The time code of the camera will be synced to the experience tracker in order to combine these later.

The *second part* is the recording of the experience while walking through an area that is studied. And the *third part* is a post-experience interview about the locations where the participant recorded changes with the experience tracker.

The results

The experience data will be plotted on a 3D model of the environment where the video camera data is projected on the model. This produces a summative experiential result of the data processing, which may assist in lighting design. The tracker enables also crowd sourcing based experiment setups.

Acknowledgements

This work was supported by the Aalto University AEF research programme.

Poster

Music Visualisation with Colored Ambiance Lights

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Introduction

The listener's presence during music listening is the key condition for perception of a musical piece. Classical music may sometimes, due to structural complexity or greater length of pieces, appear difficult for comprehension to a listener with no formal musical education. The research shows that emotional, rather than structural aspect of music, is more appealing to an average listener. Thus, creating the right atmosphere is an important pre- condition for an enjoyable listening experience - whether it comes to a live performance or listening to a recording at home, the degree of enjoyment depends on many factors, starting from a good performance, performers' charisma, concert hall acoustics, quality of instruments and the general atmosphere, to name but a few.

Comprehension of music is just as important pre- condition for an effective music therapy, since music listening forms a basic of a Receptive method of music therapy. Through researching impact of music on cognition, we have come to a proposal on how to enhance the effect of music on an average listener by bringing out structural elements of music into the field of vision. We have designed a prototype based on an example of a classical music piece mapped into the Philips ambience lights. Following harmonic and formal analysis of the musical example, we have mapped each tonality to a certain color of the lamp. By creating such kind of music visualization, we have sought to suggest similarity of relations between musical tonalities and relations between colors.

We hope to prove by further studies that our design successfully reflects emotional aspect of music, since it visualizes, and thus underlines, a tonal aspect of music which is already an expression of emotions in itself. Our main research questions for the future studies are measurements of the physiological effects of the proposed combination of ambience lights and music on the listener, as well as the application of the product in entertainment and healthcare.

Poster

Finding "pleasing" illumination conditions in outdoor environments using an intelligent lighting installation

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Introduction

Kruithof (1941) delineated the regions of correlated colour temperatures (CCTs) and illuminances, at which the illumination is to be considered "pleasing". Most of the further attempts to validate Kruithof's rule were conducted in office conditions (above ~100 lx) under different lamps and with subjective evaluation using discrete scales. These attempts resulted in controversy that has not been completely resolved so far. In outdoor conditions (~5-50 lx), where Kruithof predicted very low CCTs (1800-2300 K) and narrow intervals (typically, 100-200 K), the available experimental data is even more scarce. Meanwhile with the penetration of highly versatile solid-state lighting technology into outdoor lighting, the optimization of CCT received much interest due to the possibility of balancing energy-saving, photobiological, task-performance, environmental, and well-being needs.

Here, we present an approach to finding subjective preferences to outdoor lighting conditions using an intelligent lighting installation with continuously tuned CCT and with the controlled photobiological effect.

Method and results

Different nigt-time environments (old town courtyard, concrete scene of modern city, and botanical garden corner) were illuminated by a tetrachromatic (red-amber-green-blue) light-emitting diode based light engine. The engine consisted of two street luminaires wiressly connected to a smart phone with a controll app that allowed for precisely tuning CCT in the range of 1850-6500 K by moving back and forth a non-graduated slider on the graphical interface, while maintaining a constant luminous or circadian flux with the general color rendering index in excess of 92.

After adaptation to the illuminance level, subjects were asked to select "most pleasing" lighting conditions. Two selections were made at the constant illuminance of 5 lx and 50 lx and the other two selections were made at the constant circadian irradiance corresponding to 5 lx and 50 lx illuminance at the CCT of 1900 K.

In the constant illuminance regime, the results showed statistically significant increase of the mean selected CCT with increased illuminance (typically, about 3200 K and 4000 K at 5 lx and 50 lx, respectively) and very broad distributions of individual selections (standard deviations of ~1000 K). In the constant circadian irradiance regime, the obtained CCT values were lower (typically about 2700 K and 3800 K, respectively) due to the dimming with increasing CCT.

Conclusions

Intelligent lighting installation with of continuously tuneable CCT was proved as a versatile tool for finding the most "pleasing" illumination conditions in outdoor environments. It allowed for the qualitative validation of the Kruithof's rule in that "pleasing" illumination at lower illuminances requires lower CCTs. However, the intervals of "pleasing" CCT were found to be substantially broader and shifted to higher values than those predicted by Kruithof.

References

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Poster

Neutral Daylight Illumination with Electrochromic Windows: Theory and Validation

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Electrochromic (EC) glazing can enable users to control glare from windows with less reliance on window blinds or external shading devices. The ability to control tint dynamically can give users more access to daylight and a continuous view through the window, whilst decreasing energy consumption through the reduction of cooling loads and electric lighting usage. Studies of fixed-tint glazing have shown that the colour of the tint can have a significant affect on occupants' perceptions of room interiors. Although EC glazing is a variable tint material, it is nonetheless important to investigate how the colour of the tint might affect the quality of daylight when it is filtered through tinted EC glass.

As part of a case study into the application of EC glazing in a UK office, the effect of window tint on daylight colour was investigated. The glazing in this study is capable of four states: Un-tinted (T_{vis} = 62%), fully tinted (T_{vis} = 2%), and two intermediate states (T_{vis} = 20% and 6%). The EC glazing takes on a blue appearance when tinted, with a deeper colour in the fully tinted condition. When tinted, the view to outside remains sharp, albeit darkened. The windows consist of multiple panes, and the control system has been zoned to enable different parts of the window to be controlled independently.

A key finding of the case study is that occupants preferred to leave the window panes in their eye-line un-tinted, except when direct sun was visible through those panes. There are likely to be several factors at play in this preference, including a desire for an 'un-darkened' view to outside, and/or a perception that daylight that is not filtered through tinted glass is more natural.

To explore the second issue in more depth, a hypothesis was put forward: If at least one pane of the EC windows is not tinted, the resultant spectrum of daylight in the room is close to that of a room with completely un-tinted windows. A set of field measurements was made of daylight spectra in the case study room under various tint-pane combinations. This was compared with a set of theoretically modelled spectra, with very good agreement, thus supporting the hypothesis.

This poster gives an overview of the EC window case study and outlines the daylight spectra field measurements and theoretical model. The results are presented in the wider context of the case study, including early findings with respect to the experience of the room occupants. In conclusion, the wider implications of the study outcomes are explored.

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