Acceptable fading time of a granular controlled lighting system for co-workers in an open office

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.

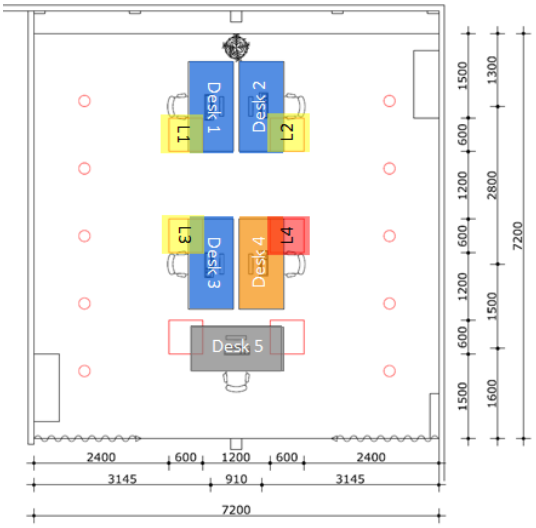

Fig. 2: Plan view of the experiment room.

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.

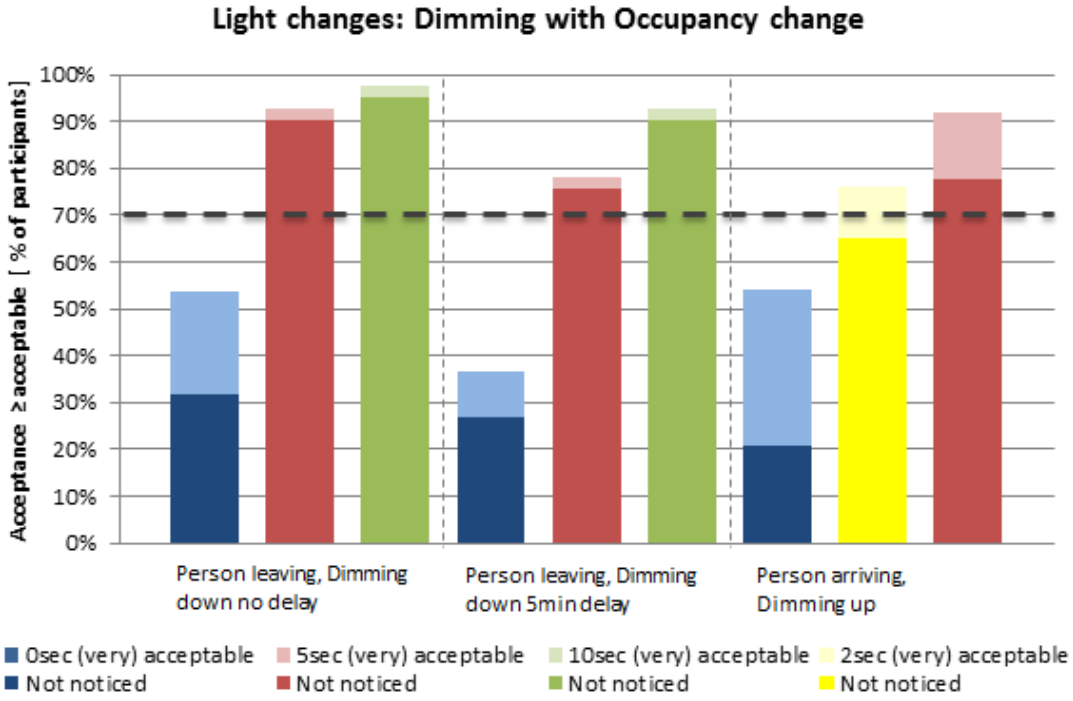

Fig. 3: Graphs of the acceptance level for the three fading times. The black dashed line - - represents the 70% boundary value for acceptance. N=41.

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.

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