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The influence of controllable task-lighting on productivity: a field study in a factory

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Abstract

This study examines whether or not a controllable task-lighting system that allows people to select high lighting levels will enhance productivity under real working conditions. For a period of 16 months a study was carried out in a luminaire factory in Finland in which such a task-lighting system was installed above 10 individual workstations. The illuminances selected by the users were recorded and productivity was monitored. Enhancing productivity can be relevant in industrial processes. The increase of productivity for the test group was +4.5% compared to a reference group, and statistically significant. The mechanism for this increase can be improved visual performance, biological effects of light, or psychological effects. Different dimming speeds were used to see whether the subjects' choices were based on illuminance or on the response of the control system. Decreasing the dimming speed of the system decreased the illuminance chosen by 13%. However, at slower dimming speeds the subjects took 55% longer to reach a given level, which suggests that they were aiming to set the lighting to their preferred level and not just pushing the button for a certain time.

Keywords: Lighting; Productivity; Industrial environment

1. Introduction

Controllable task-lighting is not standard in industry, and if a task-lighting system is present, the user can normally only switch it on or off. The investment costs of controllable task-lighting are always higher than the costs of fixed-level task-lighting. However, the extra investment could be justified were the lighting to have a positive influence on productivity, which is very important in industry. Productivity factors that can be measured are speed, quality (failure), delivery performance, absenteeism, etc.

Controllable task-lighting might influence productivity by way of performance in several ways. Most obvious are the effects of increased (or decreased) illuminance on visual performance and biological effects. The relative visual performance (RVP) model (Rea and Quellette, 1991) can be used to predict visual performance for specified tasks (Bailey et al., 1993; Eklund et al., 2001). The calculation is relatively complicated and entails the measurement of task contrast, task size and background luminance, which is almost impossible to do for assembly work that involves several actions.

Ocular light synchronises the biological clock and influences hormonal rhythms (melatonin and cortisol) and has a direct effect on brain functions (Küller and Wetterberg, 1993; Scheer and Buijs, 1999; Leproult et al., 2001). Melanopsin is found to be a light receptor for many of these light-dependent phenomena (Hattar et al., 2002; Berson et al., 2002). Studies (Brainard et al., 2001) in which melatonin suppression was measured show that the spectral-sensitivity curve of the photo-biological system peaks at around 460 nm. Biological effects can be expected to have a direct link to productivity, but the size of the effect is highly dependent on the type of work.

Not so obvious, but maybe just as important, are the psychological effects of light and lighting. The fact itself of being provided with a new lighting installation might give the employee the message that he and his job are

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important. And having a controllable lighting installation might increase the feeling of autonomy. These effects can lead to higher job satisfaction, which may positively influence performance. According to a meta-analysis made by Judge et al., (2001), job satisfaction correlates moderately well with job performance ($r = 0.30$). Job satisfaction also influences absenteeism and turnover. The average correlation is weak but significant, generally in the $r = -0.25$ range (Judge et al., 2001a). Studies that have been performed in office environments have shown that people like to have the possibility to control the lighting (Maniccia et al., 1999; Boyce et al., 2000; Escuyer and Fontoynont, 2001; Moore et al., 2002). It has been shown that the possibility to control indoor environments (temperature) can lead to an increase in self-estimates of productivity (Wyon, 1996). Also the way of lighting, like direct or indirect, influences the ratings of the working environment in offices (Hedge et al., 1995). Many field studies in industrial environments have shown large increases in productivity when the lighting level was increased, but the exact reason for this increase might be a combination of several mechanisms (Juslén and Tenner, 2005). Longer-term field studies with controllable task-lighting in an industrial environment are not available. A study was done before 8 August 2003 at the same location as this study, with the main focus on preferred lighting levels and possible daily, weekly or seasonal rhythms (Juslén et al., 2005).

Fig. 1. One of the workstations in the study area.

2. Method

2.1. Experimental set-up

2.1.1. Lighting

A dimmable task-lighting system was installed at 10 assembly workstations in a luminaire factory hall without daylight entrances in southern Finland. Seven other assembly workstations were used as a reference. The study started on 13 January 2003 and ended on 25 April 2004. Each workstation was equipped with two luminaires (IDMAN Aurea, lamps 2×49 W Philips TL5 840, colour rendering 85, colour temperature 4000 K), installed at a height of 1.24 m above the tables. The lighting could be controlled with a two-button infrared remote control. The luminaires had glare control (less than 200 cd/m^2 above 65° around the luminaire). Fig. 1 shows an example of a workstation. The task-lighting of a workstation did not influence the lighting conditions at other workstations. The general lighting in the industrial hall provided a constant horizontal illuminance of 100–380 lux, depending on the workplace. The task-lighting could add up to a maximum of 3000 lux on top of the general lighting. The dimmable system, which has been used in the reference area during the full test period, replaced a non-dimmable task-lighting system (white reflector luminaire, lamp 1×58 W Philips TLD 840, colour rendering index 85, colour temperature 4000 K) that created, together with the general lighting, an horizontal illuminance at the table of approximately 700 lux.

2.1.2. Lighting control

The luminaires were connected to a LON (Local Operating Network) bus system, and for every 10-min period between 13 January 2003 and 25 April 2004 the maximum, the minimum and the average values were recorded. Between 13 January 2003 and 8 August 2003, the dimmable task-lighting was automatically switched off every hour. After 08.08.2003, the lights were switched off at the beginning of the breaks (3 times per day). The users had to switch the lighting on again using their remote controls (infrared transmitters) and then set the level to their preference. They were free to readjust the level whenever they wanted. The default switch-on level was the 10% dimming level (approximately 100 lux on top of the general lighting). To increase the level, the users had to keep the button depressed until the light level had risen to the level they wanted. It took 0.5 s before the dimming voltage started to rise, and the longer the button was pressed the faster the lighting level increased.

During the test, three different dimming speeds were used. Before 8 August 2003, the users had to press the remote-control button for 6.5 s to reach the maximum illuminance. This was the “medium” dimming speed . After 1 September 2003, the dimming speed was alternated randomly between slow and fast, which meant that getting to the maximum illuminance took either 5 or 9 s. Dimming speed was always changed in the evening after work, and usually on Friday evenings. The users were not informed about these changes in dimming speed.

2.2. Subjects and work

The subjects could be divided into three groups:

- *Test group 1*: Fourteen persons; average age 50 years, age between 24 and 59 years. This group worked in the test area during 2002 and 2003.
- *Test group 2*: A sub-group of the "Test group 1" comprising eight persons; average age 51 years, age between 36 and 58. These were permanent employees, who were present almost continuously in the area after 1 September 2003 during the dimming speed changes.
- *Reference group*: Seven persons; average age 43 years, age between 25 and 58 years. These employees were working in the reference area during both 2002 and 2003.

The products assembled were different for the different workstations, but the tasks that had to be performed were similar for all workers. The subjects assembled luminaire components such as the frame, the gear, optical parts, and sometimes the cover. Connecting the wires was the most visually demanding part of the work. The tasks were mainly in the horizontal plane. In the European standard EN 12464-1 (2.6 electrical industry, 2.6.2 assembly work, medium) the minimum maintained illuminance for this kind of work is 500 lux.

The subjects manufactured standard products, which were the same during the whole measurement period. The subjects in the reference group produced the same kind of products, but they made significantly more special products. The productivity calculations for these special products were not as reliable as for the standard products. A 1-year measurement period was needed to filter out the effect of these products, as well as the effect of holidays, seasons, etc.

The workers had flexible working times, starting between 05:30 and 07:00 h and ending between 14:00 and 15:30 h, so that the total working time per day, including breaks, was 8.5 h. There were three scheduled breaks: 08:15–08:27, 10:15–10:45, and 13:30–13:42 h.

2.3. Productivity measurements

To determine the productivity, standard data from the factory have been used. That is to say, no extra productivity monitoring was performed during the test period. To quantify productivity independently of the product produced for each product, the "standard working hour" was introduced. In a "standard working hour", the standard output (number of products) is produced. The productivity of individual employees has been expressed in terms of this standard output. The productivity for a group of employees is the average of the individual productivity values. In this study, the values have been transformed in such a way that the value for the year 2002 was 100 for both test group and reference group. At the beginning of September 2003, the salary system in the factory was changed. From this date onwards, 10% of the salary was based on the productivity figures of the group one was working in. Before this date, the productivity figures did not directly influence the salary. This change in system should be considered as a problem for the experiment, that made the analysis more complex.

3. Results

3.1. Productivity before and after for test and for reference group

During the year 2003, the test group 1 had a controllable lighting installation. Table 1 shows the productivity changes and standard deviations per year. Since standard deviations were different, Welch's test is used. There is a statistically significant difference in the productivity of 2002 and 2003 for test group 1 ($t(605) = -2.49$, $p < 0.05$). The difference for the reference group is not significant ($t(278) = -0.97$, $p = 0.33$).

3.2. Illuminances and dimming times during dimming speed changing

The effect of the dimming speed on illuminance and dimming time has been measured for those subjects who were present in the test area almost continuously after 1 September 2003 (test group 2). The dimming time is the length of time the subject pressed the button of the infrared remote controller while setting the lighting to the desired value. The means and standard deviations for dimming times are shown in Table 2. Factorial ANOVA (analysis of variance) has been used for the analysis of the data.

For the Illuminance (dependent variable: illuminance; factors: dimming speed and person), the ANOVA showed:

a significant main effect for the factor dimming speed: $F(1, 2521) = 82.6$, $p < 0.01$;
a significant main effect for the factor person: $F(7, 2521) = 141.1$, $p < 0.01$;

Table 1
Productivity figures and standard deviations (SD) for the "test group 1" and for the "reference group" (2002 and 2003)

	2002		2003	
	Productivity	SD	Productivity	SD
Test group 1	100	27	108.42	30
Reference group	100	29	103.82	21

Table 2
Means and standard deviations (SD) for the test group (test group 2) for the different dimming speeds

	Illuminance (lux)		Dimming time (s)	
Dimming speed	Mean	SD	Mean	SD
Fast	1359	691	3.3	0.65
Slow	1181	642	5.1	1.17

the interaction between person and dimming speed was also significant:
$F(7, 2521) = 4.3$, $p<0.01$.

When the dimming speed was increased from slow (9 s of pushing to reach the maximum) to fast (5 s of pushing to the reach maximum) the average illuminance chosen by the subjects of test group 2 increased from 1183 lux to 1359 lux. This increase was statistically significant.

For the dimming time (time for which the pushbutton of the remote controller was pressed) (dependent variable: dimming time; factors: dimming speed and person), the ANOVA showed:

a significant main effect for the factor dimming speed:
$F(1, 2521) = 2613.6$, $p<0.01$;
a significant main effect for the factor person:
$F(7, 2521) = 115.2$, $p<0.01$;
the interaction between person and dimming speed was also significant:
$F(7, 2521) = 12.0$, $p<0.01$.

When the dimming speed was increased from slow (9 s of pushing to reach the maximum) to fast (5 s of pushing to reach the maximum) the average dimming time used by the subjects of test group 2 decreased from 5.1 s to 3.3 s. This decrease was statistically significant.

Employees were working at different workstations during the test period and they used approximately the same illuminance at all workstations. Fig. 2 shows the effect of the dimming speed on illuminance. Fig. 3 shows the effect of the dimming speed on dimming times per person. Because of the differences in general lighting for the different workstations, the dimming times do not correlate with the illuminances.

Looking at the simple main effects, there was the significant effect for the dimming speed. When the dimming speed was slow, the selected illuminance was 13% lower than when the dimming speed was fast. This figure is statistically significant, however it is not significant in terms of visibility. The subjects pressed the button of the remote control significantly longer (55%) with the slow dimming speed. Nobody commented or complained to the management about the changing dimming speed.

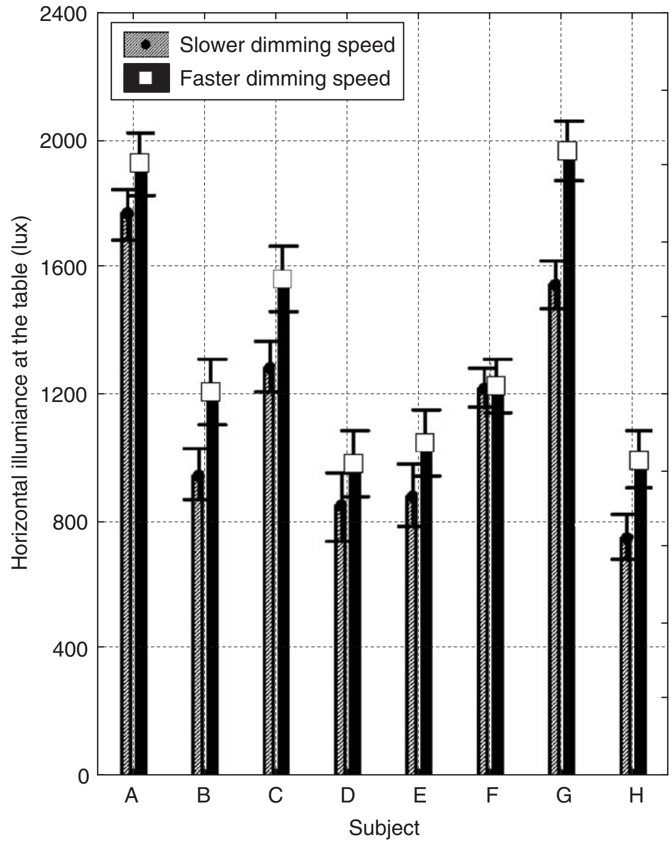

Fig. 2. The influence of the dimming speed on illuminance per person (vertical bars denote 95% confidence intervals).

3.3. Productivity and illuminance

Fig. 4 shows productivity as a function of selected illuminances for the group of subjects who were working almost continuously in the area after 1 September 2003 (test group 2). There is weak but significant positive correlation between illuminance and productivity ($r = 0.14$, $p<0.05$). The difference in productivity for different dimming speeds is not statistically significant.

4. Discussion

4.1. Methodology

Productivity is influenced by a number of factors, some of which cannot be controlled in a field study like the one described here. Also, the motives of the subjects in selecting certain illuminances are not known. Possible motives could be visual, such as the need to see better and be more productive, or psychobiological, such as mood. It was not possible to gain knowledge about these motives in this study. To reduce the influence of other factors, a reference group, working in the reference area, which is fully isolated from the test area, has been used. By alternating the dimming speed, we could be sure that the subjects had the

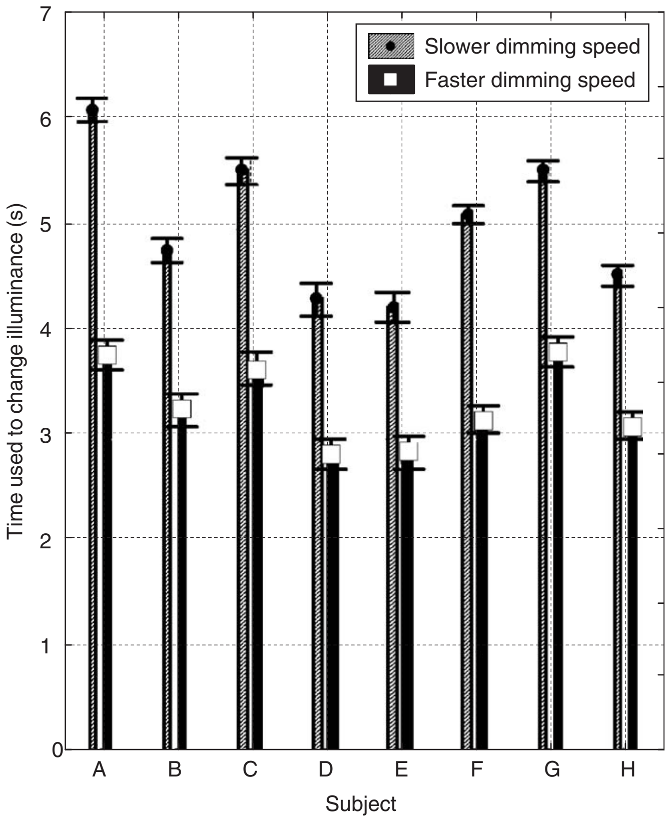

Fig. 3. The influence of the dimming speed on dimming times per person (vertical bars denote 95% confidence intervals).

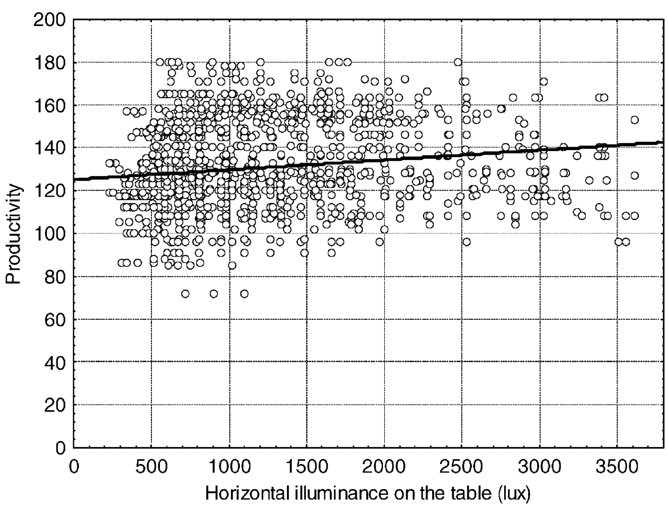

Fig. 4. Productivity as a function of selected illuminance for those eight subjects who were in the area almost all the time between 1 September 2003 and 25 April 2004 (test group 2). Productivity "100" refers to the year 2002 (productivity is measured per 2-week salary period).

intention to set the illuminance to a certain value and had not just pressed the button for a certain length of time.

The normal procedure in the factory was to calculate the productivity rates per salary period. Because of the random alteration of the dimming speed, the productivity had to be calculated per day to enable us to estimate the effect of the dimming speed. The uncertainty of the productivity figures was increased by the fact that the employees only wrote down the completion of whole orders, which consisted of a number of products. Sometimes an order had been started on one day and completed the next day.

During the measurement period, two main changes occurred. The salary system change was not planned, but changing the switching-off schedule was. It is important to note that the illuminances before and after 8 August 2003 are not comparable. Before 8 August 2003, when the lamps were switched off every hour, they were normally warm when they were switched on again. After 8 August 2003, the switching off was reduced to the beginning of the breaks. Consequently, when lamps were then switched on again after the break, they had cooled down, and the illuminance selected by the users might have risen when the lamps warmed up again.

4.2. *Productivity of the test and reference groups*

The main problem in comparing the productivity figures for 2002 and for 2003 was the salary system change in September 2003. Separating the effects of the new salary system and the controllable lighting is difficult. The reference group did not have the controllable lighting, but did have the effect of the salary system change. The difference in productivity between the reference group and the test group was 4.5%. This result indicates that having controllable task-lighting, which allows subjects to use much higher lighting levels, increases productivity. The effect is important for industry, where possible new ways to increase productivity are attracting much attention. It is not possible, however, to say whether this is attributable to improved visual performance, biological effects of light, or psychological effects. One of those possible psychological effects is the so-called Hawthorne effect. The Hawthorne effect (Mayo, 1933; Bloggs and Draper, 1996) is the effect that the study or evaluation itself has on people; the feeling of being observed and cared for can lead to improved performance. The limited size of the reference group (eight persons) increases the uncertainty of this result.

4.3. *Dimming speed and illuminance*

Even though the dimming speed had an influence on the selected illuminance, the effect was relatively small compared to the influence this had on the dimming times. The result shows that subjects had preferred lighting levels and were able to recall them after a long break, with the general lighting as a reference. They were not just pressing the button for a certain period. The illuminances chosen with the low dimming speed were only 13% lower, a difference that is hardly perceptible. It is remarkable that with the slower dimming speed, the subjects really wanted to press the button for almost 2 s longer than with the faster dimming speed to get approximately the same lighting level. When the dimming speed was set low, some subjects pressed the button for longer than 5 s, which is quite long for setting the lighting.

4.4. Productivity and illuminance

The correlation between illuminance and productivity is weak, but statistically significant. This indicates that there is a connection between lighting level and productivity.

The influence of the dimming speed on the illuminance selected was small. At around 1500 lux, a change of 13% should not have a strong influence in terms of visual performance or biological effects. This, together with uncertainties in the daily productivity measurements, can explain why there was no significant difference in productivity for the different dimming speeds that were in use. In future research, to be able to detect possible productivity differences, the difference in unconsciously selected lighting levels should be greater. One way could be by alternating illuminance from general lighting together with dimming speed.

5. Conclusions

The results of this study show that:

- the selected illuminances had a weak but significant positive correlation with productivity.
- changing the dimming speed of the lighting control system did not greatly influence the illuminance selected.
- with lower dimming speed, the subjects pressed the button on average 55% longer than with the faster dimming speed to get practically the same lighting level.

The results suggest that workers have certain preferred lighting levels, and that they put some effort into setting these levels. This study also indicates that giving assembly workers a controllable task-lighting system that allows them to select higher lighting levels than usual, increases their productivity under the circumstances described in this paper. However, when it comes to the reasons of this productivity improvement we invite the reader to draw his/her own conclusions. It is difficult to say whether this is attributable to improved visual performance, biological effects of light, or psychological effects.

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