Publication II(A)

Juslén HT, Wouters MCHM, Tenner AD. (2005) Preferred task-lighting levels in an industrial work area without daylight. *Lighting Research & Technology*. 37,3, 219-233.

Lighting Res. Technol. 37,3 (2005) pp. 219–233

Preferred task-lighting levels in an industrial work area without daylight

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Received 23 April 2004; revised 1 October 2004; accepted 8 October 2004

In a luminaire factory an experiment was performed to determine the preferred lighting levels in an industrial work environment. A dimmable task-lighting system was installed above 10 individual assembly workstations. The illuminances selected by the users (regular workers) were recorded. The differences between the individual settings were large. Weak, but significant trends in using different lighting levels at different times during the working day were found. Subjects exhibited different weekly rhythms in their preferred illuminance, and as a group they showed a tendency to use lower lighting levels on Fridays than on Thursdays during the summer, and the reverse during the winter. There was also a trend towards using lower illuminances on the task in the summer than in the winter.

1. Introduction

During the past 10 years more research has been done on office lighting than on industrial lighting. In offices, the daylight contribution normally plays an important role. In office lighting studies, where people's control behaviour has been studied,[1–7] daylight was usually available. In industry, the daylight contribution is quite often missing. In the study described in this paper, located in a factory area, where the dimmable task lighting had been installed, there was no daylight.

The amount of daylight is not the only difference between offices and industry. A skylight instead of a window, the latter being more common in offices, is often used for daylight illumination in industry. So both the direction of the light and the view out are different. And the type of work in offices is different from that at industrial assembly tables.

Task lighting in industry is not normally dimmable. In those places where task lighting is present, the lighting is mostly controlled by an on/off switch. Table luminaires are sometimes used in very fine assembly work, giving the user the opportunity of influencing the direction of the light as well as its level.

2. Methods

2.1 Experimental set-up

A dimmable task-lighting system was installed at 10 assembly workstations in a luminaire factory in southern Finland. The dimmable system (4*49W T5) in these workstations replaced non-dimmable task-lighting luminaires (1*58W TLD). There was no daylight available in the test area.

The products assembled were different for the different workstations, but the tasks that had to be performed were similar for all workers. Subjects put together luminaire components such as a frame, the gear, and optical parts, and sometimes a cover. Connecting the

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 10.1191/1365782805li138oa

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) for this kind of work, the minimum illuminance required is 500 lux maintained.

Each workstation was equipped with two luminaires (IDMAN Aurea, lamps 2*49W Philips T5 840), which were installed 1.24 m above the table. These were controlled together with one two-button infrared remote control. The luminaires had glare control (less than 200 cd/m^2 65° above the downward vertical around the luminaire), and were also suitable for office lighting. Figure 1 shows an example of a workstation. The general lighting provided an even illuminance of between 100 lux and 380 lux, depending on the workplace.

Every hour, the dimmable task lighting was automatically switched off to force the users to reset (and reselect) the illuminance. To restore the lighting, the users had to switch it on again using their infrared transmitters, before setting the lighting level to their preference. They were free to readjust the level whenever they wished and the workstations were normal workstations. Before the test the subjects were informed how to use the transmitters, that they were free to use or not use the system in the way they wanted, and that there was no 'good' or 'bad' way to set the lighting. When the lights were switched on by using the transmitter the default level was approximately 100 lux on top of the general lighting (10% dimming level). To increase the level, the users had to press the button until the light level had risen to the level they wanted. It took 0.5 s before the dimming voltage started to rise, and to obtain the maximum light output the user had to keep the button pressed for more than 6 s. The luminaires were connected to a LON bus system (Local Operating Network), and the selected dimming voltages were monitored between 13 January 2003 and 8 August 2003. For every 10-min period, the maximum, the minimum and the average values were recorded.

Figure 1 One of the workstations in the study area

After the total test period, some users (25 employees) filled in a questionnaire, and only those who had been working most of the time (eight employees) at the experimental workstations were interviewed. During the interview, their visual acuity was tested using a simple short vision test (text of different sizes).

2.2 Subjects and work schedules

During the test period, a total of 37 persons worked in the test area, some for only a few days and some for almost every week. During the test period, 2–10 workstations were occupied simultaneously. Most of the subjects (31) were assembly workers, who had a long work experience. Some (six) younger and less experienced persons worked in the area during the holiday season. The 37 subjects was comprised of 31 females and six males. The average age of the workers was 42 years (minimum 18, maximum 59 years).

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

3. Results

3.1 General

Unless stated otherwise, the illuminance is the sum of the horizontal general illuminance and the adjustable local horizontal illuminance in the middle of the empty working table. The illuminances were calculated from the dimming voltages, which had been recorded. The calibration had been performed by measuring the illuminance on the empty tables without the user present. The presence of the user at the workstation was monitored by the work registration forms and the data for unused tables were removed from the database. The average illuminance on the main horizontal working area was approximately 0.9 times the illuminance at the centre of the table. The total average values of the illuminance as presented are calculated from the average values per person.

The general illuminance on the tables was between 100 lux and 380 lux. On top of this the users were able to add task lighting up to a horizontal illuminance of approximately 3000 lux.

After 15 April, the average outdoor temperature was almost always above 0°C (one exception being on 24 April: −0.6°C), and practically all the subjects were able to experience natural daylight before their workday started. In this paper, the periods before and after 15 April are called winter and summer, respectively.

The weather data (average temperature for each day, temperature in the morning, and rainfall for each day) were received from the Finnish Meteorological Institute. The temperature data were measured by an automatic weather station approximately 15 km from the test site and the rainfall data from the rain station 3 km from the test site.

The significance level used in all the tests was 5% ($P<0.05$).

3.2 Questionnaires and interviews

The questionnaire was filled in by 25 subjects (two male, 23 female, average age 48). Table 1 shows the average score and the standard deviation for each question (on a 5-point scale), and indicates that the respondents recognized that good lighting is important (question 8, score 1.4).

In the interviews, the respondents said that they liked the dimmable system and that they

Table 1 Questionnaire results—25 completed papers

	Mean	SD
1. I adjust the light level depending on the task	3.04	1.51
2. I use more light in the afternoon than in the morning	3.84	1.34
3. The minimum lighting level is too high	4.08	1.19
4. I am often tired in the afternoon	2.76	1.51
5. The maximum lighting level is too low	4.24	1.09
6. I try to use always the same light level	2.16	1.18
7. I am bothered by glare from luminaries	3.44	1.39
8. Good lighting has positive influence on my work	1.42	0.93
9. I use more light in the morning than in the afternoon	3.44	1.16
10. Controlling the lighting is too complicated	3.76	1.27
11. I am often tired in the morning	3.25	1.45
12. Working in the test area is better than before because of the different lighting installation	2.5	1.41

Scale: 1 strongly agree, 2 agree, 3 no opinion, 4 disagree, 5 strongly disagree wanted it to be installed for the other workstations. The dimming range was rated to be suitable.

The controlling of the lighting was rated to be not too complicated (question 10, mean score 3.8). Some respondents commented on the automatic switching off every hour and the malfunctioning of the system this caused.

Those interviewed were not able to say whether they used more or less light during the summer or winter, or they guessed that their preferred lighting level was always the same because there was no daylight. Five of the eight subjects who were interviewed said that the general lighting level was too low.

There was no significant correlation between the visual acuity needed for the task and the average illuminance the subjects chose.

3.3 Average illuminances

For the statistical analyses three groups of users were distinguished: 'All users', 'Main users' and 'Main users total period'.

All users. The group 'All users' consists of all the subjects who have been working in the test area (37 subjects). Only when the lights were on during a whole measurement period (10 min), were the illuminance values used in the analysis.

Main users. The majority of the users had worked in the area for only a few days or a few weeks. The 'Main users' group consists of the subjects who worked in the area for more than 2 months during the total measurement period from January to August (11 subjects).

Main users total period. The dataset of the subjects who worked in the area during both seasons, and therefore provided data from all weekdays and seasons, forms the group 'Main users total period' (seven subjects).

Table 2 shows the mean illuminances and the number of subjects in each dataset. The mean illuminance of the dataset 'All users' is higher than the illuminance in the other two groups. A comparison of the subjects who do not belong to the group 'Main users' ('All users' – 'Main users') and all the values from those who belonged to the group 'Main users' showed a significant difference ('Main users' 1408 lux, 'Others' 1978 lux, t-test for independent samples $t(27317) = 42.4$ $P < 0.001$)). The subjects in the group 'Main users' were more familiar with the tasks in these test workstations than the others.

Table 2 Mean horizontal illuminances and the average ages of the different groups

	Mean illuminance (lux)	Number of subjects		Average age (years)
		female	male	
All users	1752	31	6	42
Main users	1405	9	2	45
Main users total period	1479	6	1	48

3.4 Individual differences in preferred illuminances

The mean illuminances chosen by the subjects are shown in Figure 2. The values range from 270 lux to 3300 lux, covering the total range available. The subjects' means are spread quite uniformly between these values. There was no significant correlation between age and preferred illuminance. After setting the illuminance, the subjects only occasionally changed the lighting before the hourly automatic switch off.

3.5 Illuminances at the workstation

The differences in average illuminance between the different workstations were due to personal preferences. No significant relation between set illuminance and workstation illuminance could be found.

3.6 Rhythms

3.6.1 General rhythms

Rhythms were tested in such a way that all results were restricted to specific sets of test persons. The alternative would have been to assume that the test persons in the study are a sample of the wider group of potential test persons, but this would have given different results in the analysis.

Figure 3 shows the selected illuminances during the day for the dataset 'Main users'. Values between 05:00 and 06:00 hours and between 06:00 and 07:00 hours are not shown in the graph, because these values are not reliable owing to the warming up period of the (still-cold) lamps.

Factorial ANOVA (analysis of variance) was performed (dependent variable illuminance, factors person and time) and showed:

- a significant main effect for the factor time:

  $F(8, 19442) = 4.6$, $P < 0.0001$;
- a significant main effect for the factor person:

  $F(10, 19444) = 2272$, $P < 0.0001$;
- a significant interaction between person and time:

  $F(80, 19442) = 5.5$, $P < 0.0001$.

Tukey HSD (honestly significant difference) pairwise comparison was used to compare the mean illuminances for the different times of the day. The mean illuminance between 07:00 hours and 08:00 hours was significantly higher than the values at other times. Also the mean illuminance between 11:00 and 12:00 hours was significantly different from the illuminances at 12:00 and 13:00 hours ($P = 0.037$).

The average illuminances in the morning were higher than those in the afternoon. The subjects were asked in the questionnaires whether they used more light in the morning or in the afternoon, but there was no correlation between the measured values and the answers given in the questionnaire.

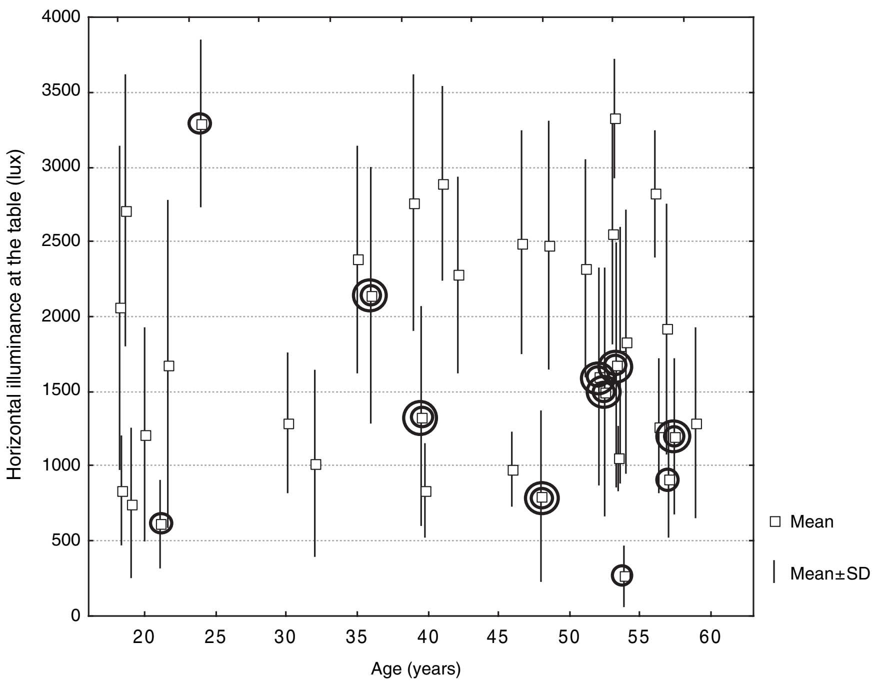

Figure 2 Relationship between selected horizontal illuminance and age of subject (dataset 'All users'). (Mean values and standard deviations are indicated.) (Small circles: dataset 'Main users'; large circles: 'Main users total period')

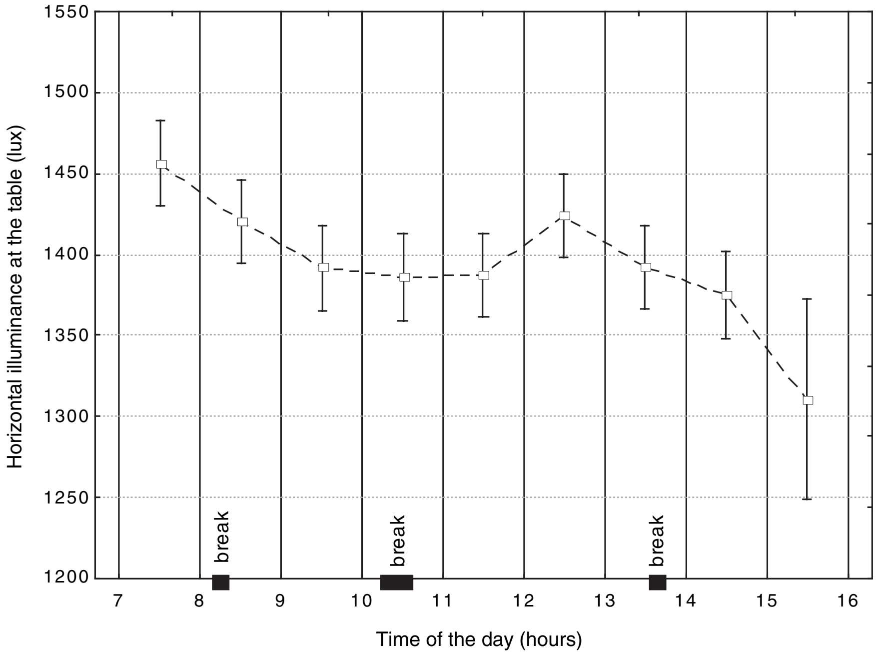

Figure 3 Average horizontal illuminance as a function of time of day (dataset 'Main users'). Illuminances are averaged between 07:00 hours and 08:00 hours, 08:00 hours and 09:00 hours, etc. The mean value is the mean of the personal mean values during the indicated hour. Blocks on the time-axis indicate workbreaks. (Vertical bars denote the 0.95 confidence intervals.)

Figure 4 shows the weekly rhythms of every subject in the group 'Main users total period'. Only those weeks where the user was in the test area every day were taken into account. The number of full weeks is limited because of the irregular presence of the subjects, holidays, and short-time data-logging problems. The total number of full weeks is 34 (two to nine full weeks per person). There were more full weeks during the summer than during the winter.

Factorial ANOVA was performed (dependent variable illuminance, factors person and weekday) and the results were analysed by a Tukey HSD) for different weekdays. Only one person did not show any significant difference ($P < 0.05$) between any pair of weekdays. The strongest effects observed ($P < 0.001$) are the increase in illuminance from Monday to Tuesday and from Tuesday to Wednesday for one person, the 'Wednesday drop' for one person and the 'Friday peak' for one person.

Figure 5 shows the mean horizontal illuminances as a function of the weekday. The curves in Figure 5 are for winter and summer (before and after 15 April). The subjects used a lower illuminance in the summer than in the winter. Except for the lighting level, the main difference between summer and winter was a different behaviour on a Thursday than on a Friday.

Factorial ANOVA (analysis of variance) has been performed (dependent variable illuminance and factors person, season and weekday) and showed:

- a significant main effect for the factor season:

  $F(1{,}13904) = 668$, $P < 0.0001$;
- a significant main effect for the factor person:

  $F(6{,}13904) = 452$, $P < 0.0001$;
- a significant main effect for the factor weekday:

  $F(4, 13904) = 34.8$, $P < 0.0001$.

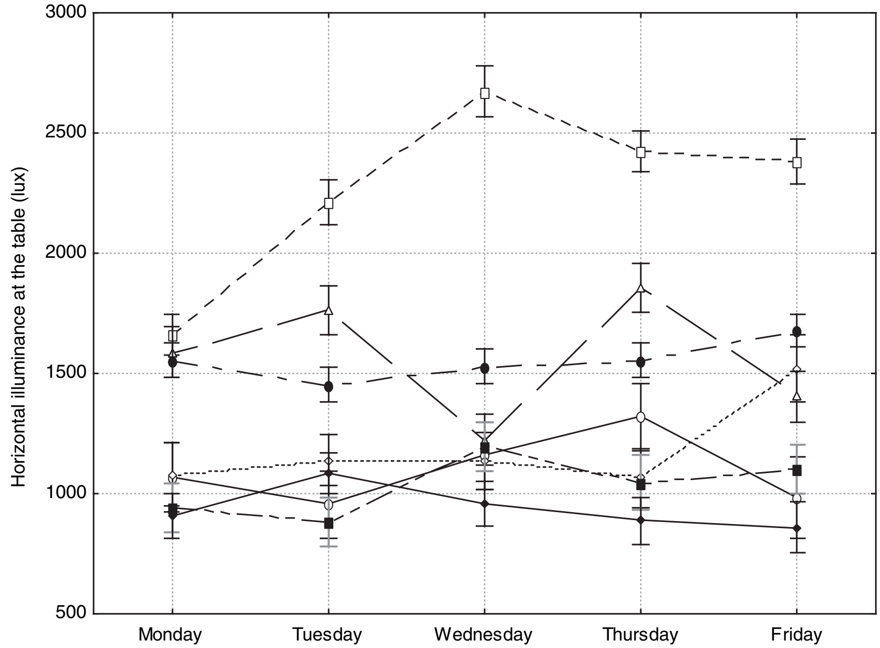

Figure 4 Average horizontal illuminances per person for each day of the week ('Main users total period') where only full weeks have been taken into account. (Vertical bars denote 0.95 confidence intervals.)

Tukey HSD pairwise comparison was used to compare the mean illuminances for each weekday for the different seasons. The mean illuminance on Mondays was significantly lower than on Tuesdays only for the winter season ($P < 0.0001$). The mean illuminance on Fridays was lower than on Thursdays during summer ($P < 0.0001$), but during winter the difference was not significant.

Figure 6 shows the seasonal differences. The solid line shows the mean illuminances for the group 'Main users total period' for a division into sub-seasons. Some subjects were only in the test area during either the winter or the summer period, and the mean values for these 'sub-groups' are also shown in Figure 6.

3.6.2 Strength of the behaviour patterns

The individual subjects did not all follow the general trends described in the previous section. Table 3 shows how the trends were followed on an individual level. The first number in the 'follow' column shows the number of subjects who followed the trend both at the $P < 0.30$ and $P < 0.05$ levels of significance. The column 'oppose' shows in the same way how many subjects showed a behaviour different from the general trend.

3.7 Weather and selected illuminance

For the dataset 'Main users total period' the relationship between the illuminances chosen and the outdoor temperature (daily average) was analysed. In Table 4 the average illuminances for different temperature intervals are shown. The correlation between illuminance and outdoor temperature is statistically significant ($r = -0.17$, $P = 0.01$).

Consecutive days which had a temperature difference of more than 5°C (in winter, before 15 April) and more than 3°C (in summer, after 15 April) were used to determine whether the outside temperature had an effect on the preferred illuminance. In Finland the temperature differences are greater during winter than during summer. The decision to use 5°C

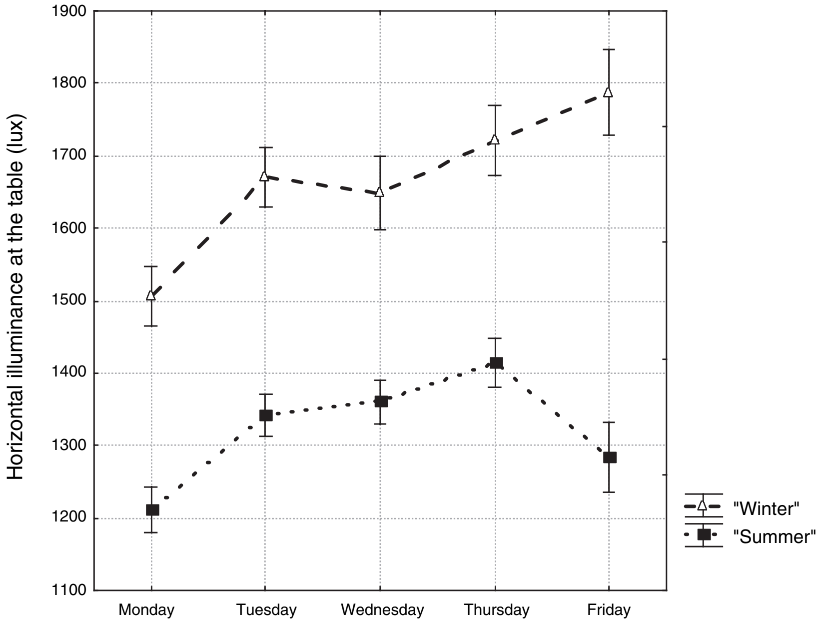

Figure 5 Mean horizontal illuminances as a function of the day of the week for the group 'Main users total period'. The dashed curve shows mean values during the winter and the dotted curve the mean values during the summer. Data from all weekdays were taken into account to calculate the personal means. (Vertical bars denote 0.95 confidence intervals.)

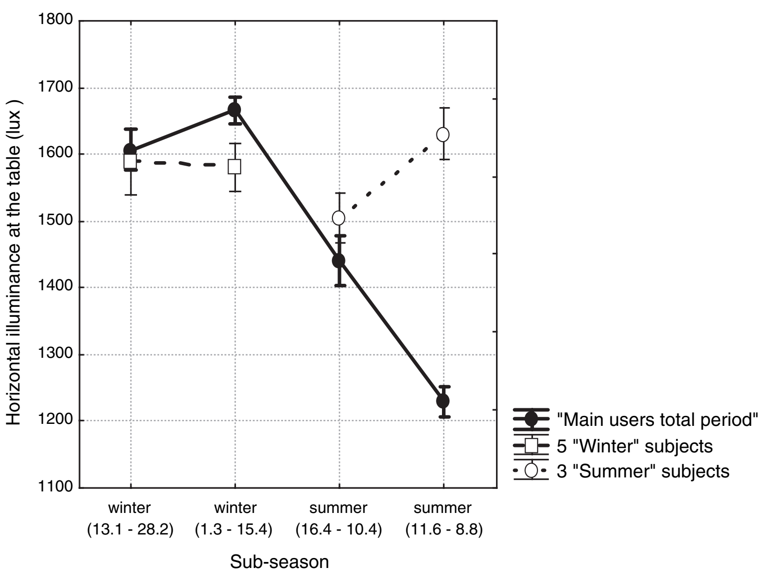

Figure 6 Mean horizontal illuminances for three groups per sub-season. ('Main users total period', five persons who were present only during both winter periods, three persons who were present only during the summer.) Sub-seasons: winter 1, 13 January–28 February, winter 2, 1 March–15 April, summer 1, 16 April–10 June, summer 2, 11 June–8 August) (Vertical bars denote 0.95 confidence intervals.)

Table 3 Strength of the behaviour patterns

Trend	Dataset	Follow	Oppose	No trend
More light 7–8 than 9–10	Main users	7(4)	2(2)	2
More light 11–12 than 12–13	Main users	3(3)	2(1)	6
Less light during last working hour than before	Main users	6(5)	–	5
More light on Winter Friday than Thursday	Main users total period	4(2)	2(2)	1
Less light on Summer Friday than Thursday	Main users total period	4(4)	1(1)	2
More light on the Winter than on the Summer	Main users total period	4(4)	2(2)	1
More light on the Wnter than on the Summer	All users[a]	9(7)	3(3)	2

The values show how many subjects followed or opposed the trends mentioned. The last column gives the number of subjects who did not follow any trend. (Follow $P<0.30$ ($P<0.05$); Oppose $P<0.30$ ($P<0.05$); No trend $P>0.30$ (one-way ANOVA))
[a]*Note*: In the group 'All users', 14 of the 37 subjects were present during both seasons

in winter and 3°C in summer was made to get a comparable amount of data for both seasons. There was no statistically significant effect of the temperature difference between consecutive days for the selected illuminances.

There was a very small significant difference between rainy and dry days (two-way ANOVA, 'Main users total period') in winter (rainy days average 1561 lux versus dry days 1602 lux). In summer the difference was even smaller, and not significant. Furthermore, the differences between the last day of a longer dry or rainy period and the following day were not significant.

4. Discussion

4.1 Methodology

The possible errors in the values that are presented in this paper were caused mainly by the temperature behaviour of the lamps. T5 lamps are very temperature sensitive. When the subject switches on the cold lamps and chooses a lighting level, the lamps will warm up (slowly) and after some time the light output will increase. This occurs especially at low dimming levels. For dimming values near the maximum light output, the temperature of the lamps might rise above the optimum after a certain period and the light level decrease. So the recorded illuminances may differ from the values initially chosen. This was also the reason for omitting the early-morning values (05:00–07:00 hours) in the investigation of the day rhythms (Figure 3).

Table 4 Mean horizontal illuminance at each outdoor temperature (T) range

T (°C)	Mean E (lux)
< −5	1620
−5...0	1530
0...5	1510
5...10	1400
10...15	1300
>15	1180

The most important 'error' factor was most probably the user himself. Size, way of working, hairstyle, colours of the clothing etc., influence the light level on the task area. Because of shadowing by the user, the illuminance values attained at the task area were probably lower than the values measured on the empty and unoccupied table, as used in this paper. Because all the values have been measured and calculated in the same way, these errors have no effect on the rhythms.

The measurement period limited the possibility for generalizing the results. Even though the measurement period was quite long in this study, it was still less than a year. So we were not able to see if the trends continued during the remainder of the year. The limited number of subjects and their irregular presence at the workstations (datasets 'Main users' and 'Main users total period') was also a problem. This, together with the huge differences in preferred lighting levels makes it impossible to analyse trends over shorter periods.

4.2 Illuminances and people's opinions

That personal differences in preferences between people are large was the dominating result of this study. The selected illuminances are very high compared with the present-day lighting standards. The European norm (EN 12464-1—Lighting for indoor workplaces) prescribes 500 lux for the maintained illuminance for this type of work. Among all the subjects, only one used a lower illuminance than this. Higher preferred levels than in the standards have been reported previously in an office study by Begemann *et al*.[7] Some other control behaviour studies (such as Escuyer and Fontoynont[2] and Moore *et al*.[3]) in office environments have shown the opposite, indicating the possibility that controlling the lighting could lead to lower levels. Even though this study lacks the daylight contribution, two similarities between the methodology used here and in the study of Begemann *et al*. distinguish them from most other studies. First, the illuminance range is much higher than is normally available in practice. The subjects thus had the opportunity of selecting very high levels. Second, the task-lighting luminaires were switched off automatically several times during the day. This forced the subjects to use the lighting control system; but whether the lighting control would have been used more often than once a day without this interruption remains unknown. The general lighting in the area was so low that it forced subjects to switch on the lights again immediately after they had been switched off.

That people like to have the possibility of controlling the lighting was reported earlier for an office environment (for example see Maniccia *et al*.[1] and Escuyer and Fontoynont[2]). It is not surprising that people like to be able to control the lighting in an industrial environment, where the possibilities for any kind of control are very limited. Also, the fact that people felt that good lighting has a positive influence on their work was expected. The questionnaire did not define what was meant by 'good lighting'. Therefore no conclusions can be drawn about what 'good lighting' is from the subjects' point of view.

Some subjects made remarks in the questionnaires about the hourly switch-off of the lighting, which they disliked. After the test period, the lights were only switched off at the beginning of the breaks, and the users were happy with this.

The difference between the 'Main users' and the other users indicate that people who are more familiar with the task use less light than those who are less familiar with it. The 'Main users' were mainly working in the test area assembling the same kind of product, whereas the other subjects were mainly working somewhere else assembling other kinds of product.

4.3 Rhythms

The day rhythm (morning—afternoon, Figure 3) can be divided into three parts, with possible explanations.

Morning 07:00–09:00 hours. According other studies, subjective alertness[8] and speed scores of visual search tasks[9] are lower in the early morning than later during the hours when the subjects are working. Since those papers were written, it has been suggested that light exposure in the morning affects the cortisol level in humans[10,11] and higher lighting levels also influence the electroencephalogram (EEG), keeping people more alert and less sleepy,[12,13] the higher levels in the morning could indicate that people use light to avoid sleepiness. More studies are needed to show if this really is the case.

Midday 10:00–13:00 hours. The small, but significant peak around 12:30 hours might be related to arousal or hormonal rhythms of the subjects. One assumption is that they are connected to so-called 'post-lunch-dip'. The subjects might have compensated for a feeling of decreased alertness in the afternoon by using more light. The peak was small, and alertness rhythms were not measured. Also, per person, this trend was the weakest one

(Table 3) and substantive conclusions cannot be drawn from these data.

Afternoon 14:00–16:00 hours. The subjects were allowed to leave their workplace without tidying up—there was no specific tidying up or cleaning period. The feeling that the workday is soon to end could explain the lower light level during the last hour. The procedure forced the user to push the button for several seconds to get high levels. When the time to go home was approaching, the subjects might not always have been in the mood to adjust the light level—they just switched the light on.

Even though the changes per hour (Figure 3) were relatively small and the trends quite weak, the subjects preferred different lighting levels at different times of the day. The reasons remain unclear and dominating results are still huge differences between people.

The weekly rhythms of the subjects are quite different (Figure 4). Some had much stronger rhythms than others. Possible explanations for the weekly rhythms at the preferred illuminances could be sleep rhythm or mood changes caused by weekly activities, which were not monitored in this study.

The trend for using more and more light later and later during the week (Figure 5) changed on summer Fridays. There was no difference in the work the subjects had to do on different days. There is no clear explanation for the different behaviour, although the approaching weekend might influence the light level chosen. There might be a large mood difference between Fridays in summer and winter. However, this assumption should be studied further taking into account the social activeness of summer weekends and their effects on mood in Finland, before drawing conclusions. Also the size of the group was too small for drawing substantive conclusions.

The trend for using less light during the summer than during the winter was clear for this group, although not all subjects followed this general trend. Because of the time frame of the study, the question as to whether the difference is caused by the seasons or by the subjects getting more used to the system, cannot be fully answered. If becoming accustomed to the lighting control system had been the reason for using lower illuminances, this should have resulted in a downward trend in the first two sub-seasons for all subject groups (Figure 6). This was not the case. Subjects who were present only during summer or winter did not use significantly lower illuminances during the second sub-season of work. Also, the group 'Main users total period' did not show this tendency between first and second sub-seasons they were in. This indicated that getting used to the system did not have a significant effect on the preferred lighting conditions. The seasonal effect is much stronger.

It could be that being aware of good weather and the sunlight outside made some subjects prefer lower illuminances. There were no fast changes between consecutive days with different weather conditions. The correlation between outdoor temperature and preferred illuminance might be influenced by the fact that in Finland there is a strong correlation between season and temperature and the illuminance from sunlight. In this case, there was no daylight. The interview results indicate that subjects did not consciously use different levels for different seasons. Why then was there such a significant change? There is some evidence that higher illuminances improve vitality and alleviate distress in healthy people during winter.[14] The possibility of being exposed to daylight before (or after) work might have influenced the illuminance chosen. In the summer, the subjects had already received their dose of bright light on the way to work or during the previous evening.

The selected illuminances also follow seasonal mood trends reported elsewhere.[15] During May, June, July and August, people are generally in a better mood than during November, December, January, February and March, an effect which might be connected to the amount of sunlight available. This could mean that the trend of using lower illuminances during the summer is connected to the general seasonal mood. There is also some evidence that higher illuminances reduce a female's negative mood.[16] Even though connections between lighting and mood are far from clear, and the results of many studies are contradictory, there might be an unconscious tendency to use light as a mood-improvement tool. The difference between summer and winter Fridays points in the same direction. The Friday differences also indicate that the sunlight illuminance in the morning is not the only factor. The times when people could be assumed to have been affected most by mood are also the times they are assumed to feel most tired. So both mood and fatigue could be now used to explain trends. Present evidence that higher illuminances increases alertness and decreases sleepiness is better established than the evidence about the effect of illuminance on mood. Evidence in this paper suggests that the subjects were probably using higher illuminances during certain periods because they felt more tired.

5. Conclusions

From this study it can concluded that industrial assembly workers, under the circumstances described in this paper, without daylight at their workplace:

- show large personal differences in preferred illuminances (for the same task);
- might have individual weekly rhythms for preferred illuminances;
- use lower illuminances if they are familiar with the task;
- prefer to have significantly higher illuminances than the minimum required by norms and standards;
- feel that the range from approximately 300 lux to 3000 lux is wide enough;
- like to have personal lighting control possibilities;
- have a general belief that good lighting has a positive influence on their work.

As a group, they used in this study:

- higher illuminances in the morning than during the rest of the day;
- higher illuminances on Fridays than on Thursdays during the winter, and the opposite during the summer;
- higher illuminances during the winter than during the summer.

There was no single trend significantly followed by all users. Personal differences are so strong that trends are valid only on group level, and they cannot be used to predict the behaviour of a certain individual. The productivity part of this study will be published elsewhere.

Further studies should be carried out to confirm these findings for other and larger populations.

Acknowledgements

We are grateful to all IDMAN personnel, and especially to all the subjects who participated in this study. Our special thanks go to Martti Koskikallio for collecting the presence data for all the subjects and for helping out in many practical issues during the research. We also thank Markus Kajander, Jaana Haapamäki, Juha Ylönen, Rauli Palmroos, Jussi Korvenranta, Kaija Nurmi and Rauno Mäenpää for their assistance during the measurements, and Pentti Jokinen and his group for the installation of the test luminaires. The assistance of Philips' Lighting Controls department has been essential in being able to datalog the illuminances used. Our thanks to Henk Verstegen, Chris Martens, Noël Bonné, and their colleagues.

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Discussion

Comment on 'Preferred task-lighting levels in an industrial work area without daylight' by H Juslén, MCHM Wouters and AD Tenner

PR Boyce (Canterbury, Kent, UK)

Observations of how people use lighting controls have been almost entirely confined to offices, so it is good to see a study looking at industrial work. Unfortunately, this paper is deficient in a number of areas. For a start, few details are given of the nature of the industrial work illuminated. It is said to be the assembly of luminaire components but how the visual difficulty of the tasks varied with the components being assembled is not discussed, nor is how the type of component being assembled relates to the people forming the three different groups discussed. Given that the illuminances chosen are almost all greater than those recommended by lighting authorities, it is important to know the details of the work being done.

As for the results, these can be divided into two types; the average illuminances selected over the measurement period, and the trends in illuminances chosen over the day, over the week and over the seasons. The mean illuminances selected over the measurement period are given for all subject groups and show wide individual differences, a result that has been consistently found in offices. However, the rhythms in chosen illuminance over the day, the week and the season that have been identified are much less certain, for a number of reasons. First, the data presented is limited to specific groups of subjects. The justification for this limitation is given at the beginning of section 3.6.1 as follows '... all results were restricted to specific sets of test persons. The alternative would have been to assume the test persons in the study are a sample of a wider group of potential test persons but this would have given different results in the analysis' What does this mean? Are the specific groups not representative of some populations? If they are not, what value are their results? How different would the results of the analyses have been? Until answers are provided to these questions it is difficult to know how to evaluate the rhythm data.

Even if the limitation of the analyses to specific groups of subjects is accepted, there are some unusual features of the analyses. For example, the analysis of variance for the selected illuminances over the day has a statistically significant interaction between people and time. This is ignored, only the main effect of time being shown in Figure 3. This procedure is incorrect because a statistically significant interaction between person and time implies that different people show different patterns of selected illuminances over time. The mean illuminances selected by each individual in the group over time should have been given. Further, the section examining the strength of the behaviour patterns uses a significance level of $P<0.30$. This is completely unconventional in statistical analysis, because it allows a 30% chance of a type 1 error i.e., a difference that is declared to be statistically significant will occur by chance 30% of the time. If the conventional $P<0.05$ significance level is used, then the evidence for stable trends in illuminance selection over time, day, and season in Table 3 is much weaker. In fact, simple binomial tests applied to the numbers who follow the trend and oppose the trend, in each row of Table 3, fail to show any statistically significant differences for a two-tailed test, indicating that there is no clear trend in the data. This means that the only reliable conclusion that can be drawn from the data is that there are large inter-individual differences in preferred illuminances for this industrial task. Would the authors agree?

Authors' response to PR Boyce

HT Juslén, MCHM Wouters and AD Tenner

The authors would like to thank Dr Boyce for his comments and questions. We fully agree that a detailed description of the visual tasks is important. The study was a long-term field study in a real production environment with real workers, performing their work in their usual way. Assembly and packaging of different kinds of luminaire involve multiple tasks, each of which has typical visual demands.

Furthermore, the workers in this factory had a lot of freedom to organize their work and perform the tasks the way they felt best. Monitoring the exact detailed activity of individual workers was not possible. The work performed was not extremely visually demanding and could be performed adequately under 500 lux, which accords with the generally accepted norm EN12464-1. All workers were performing the same type of work and the three different groups discussed only differed in the amount of time they were present during the test period.

Dr Boyce comments that the identification of the rhythms in the chosen illuminance over the day, the week and the season are not strong.

The type of statistical analysis has an influence on the results. In this paper the authors have chosen to restrict the ANOVA conclusions rigorously to the persons in the experiment. In this case the factor person is what is called a fixed factor in ANOVA. This means that differences found in time of the day, the week and the season are only true for the persons in the experiment. If we were to expand the ANOVA conclusions beyond the persons in the experiment, we would have to treat the factor person as a random factor in ANOVA. The value of the conclusions would then become broader, but as a consequence the conclusions would become weaker with disappearing significance.

Dr Boyce suggests that the statistical significance between persons and time has been ignored, this, however, is clearly not the case. The Tukey HSD is used to identify the trends mentioned in Table 3. Based on the trends the number of persons following or opposing these trends are determined (person * time) for the conventional $P<0.05$ and the unusual value of $P<0.30$. This offers the reader the possibility of estimating the strength or weakness of the behaviour patterns. We agree that the only general conclusion that can be drawn is that there are large individual differences in preferred illuminances for this industrial task, as has also been formulated in the conclusions of the article.