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Appreciation of localised task lighting in shift work—A field study in the food industry

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Abstract

Localised task lighting was installed in addition to the general lighting installation in the food factory. Research has been carried out to test appreciation of this additional task lighting by workers working in fast-rotating shifts: viz. five shifts over the full year. There were between six and eight persons in one shift. Average age of workers was 42, most of whom were men. Employees' opinions and performance was measured in three ways: repeated working environment and lighting questionnaires, Karolinska Sleepiness Scale questionnaires (KSS), and measurements of the time that employees needed to solve small operating problems at packaging machines. Questionnaire results showed that employees liked the new lighting. They felt that higher lighting levels made them feel less sleepy and able to perform better. Direct performance measurements showed on average a statistically significant 3 per cent improvement with the higher illuminance. This difference and its direction was not clear for all error types. The KSS measurements showed no significant effect of higher or lower illuminances. However, there was a significant pattern revealed by the KSS, namely that employees felt sleepy during the first and third breaks and sleepier during the second break and at the end of the working day.

Keywords: Localised lighting; Industry; Human performance; Alertness; Well-being

1. Introduction

It has been shown in various studies that working in shifts has many negative effects, both psychological and physical.

Shift workers have:

- A higher incidence of psychological complaints (Rutenfranz et al., 1978).
- A higher rate of gastrointestinal problems (Angersbach et al., 1980).
- A higher level of stress (Kundi et al., 1981).
- Reduced immune function (Nakano et al., 1982; Knauth et al., 1980).
- Lower sleep quality (Åkerstedt, 1988).
- Disturbances in hormonal profiles during their sleep and work times (Weibel and Brandenberger, 1998).

Due to side effects, work productivity also tends to be lower (Bjerner and Swenssen, 1953; Mott et al., 1965; Folkard and Monk, 1985) and accident rates are higher (Weiner, 1984). Furthermore, shift workers are also generally less satisfied with the quality of their lives than are day workers (Rutenfranz et al., 1978).

Lighting could be one way to improve the productivity and well-being of shift workers. This idea is based on three main assumptions. First, that better lighting improves visual performance (Rea and Quellette, 1991; Eklund et al., 2001), and that improved visual performance helps the employee to work faster and more accurately. Second, that lighting (and darkness) can be used for delaying or advancing the circadian rhythms (Boivin and James, 2005). Third, that lighting can also create some direct stimulation effects (Rüger, 2005).

During past years, several studies have been carried out, especially concerning shift work and light. Bright light can reduce sleepiness during the night shift and lengthen the day sleep (Lowden et al., 2004), and reduce sleepiness after

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the night shift (Bjørvatn et al., 1999). Exposure to bright light at night time can be used to improve alertness and performance (Campbell and Dawson, 1990; Daurat et al., 2000) as well as to increase subjective alertness (Forêt et al., 1998). Adaptation to shift work is strongest if the total light exposure is under control and if, after the bright light at night, the exposure is limited during the morning (Eastman et al., 1994; Yoon et al., 2002; Boivin and James, 2002). There is also some evidence to suggest that bright light during the daytime can reduce the impact of sleep loss on sleepiness levels and performance after short (5 h) night sleep (Phipps-Nelson et al., 2003). The effect of the lighting on the performance and mood of shift workers has also been measured under real working conditions. For example, Iscr-Colec et al. (1996) measured the effects of bright light on performance and mood in morning and evening people and found no significant effects. Boyce et al. (1997), too, measured the effects of lighting on the task performance and mood of night-shift workers. They found effects in complex cognitive tasks but not in the performance of the cognitively simple, repetitive tasks used in this study.

The definition of bright light is not clear. Depending on the study considered, "bright light" creates illuminances between 1000 and 10 000 lux. Some study reports do not define very clearly where the illuminance has been measured. From the circadian-adaptation point of view, light that is relevant is the light that enters the eyes. There is some evidence that the alerting effect of light can also be achieved in relatively low ambient lighting. Cajochen et al. (2000) tested the Dose–Response relationship for light intensity and alertness and its ocular and EEG correlates. The results show how subjective alertness and slow eye movements (sleepiness) are affected by lighting. The effect was apparent at around 100 lux (ambient room light), where half of the maximum alerting response to bright light of 9100 lux was obtained. It was also observed by researchers that both measures of alertness rapidly deteriorated upon return to dim light (<3 lux). According to the recent research results (Brainard et al., 2001; Thapan et al., 2001), it would appear that the peak of the sensitivity of human "non-visual" photoreceptors is between 430 and 490 nm. This means that not only the amount of light but also its spectral sensitivity influences the biological effect such as circadian phase shift. Present lighting parameters, namely luminous flux and illuminances, are based on the photopic eye sensitivity curve, which peaks at 555 nm.

Several different kinds of work-shift patterns are used in industry. This creates difficulties in forecasting what would be the best light exposure for every shift. Permanent working "and living" in a night-shift environment would be the most simple but quite theoretical case, although it is not uncommon in the USA. During free periods, it would be difficult to maintain the same circadian phase due to many social and practical reasons. Because people's circadian free-run period is normally longer than 24 h, the phase-delay will be easier than phase-advance (Knauth, 1995). This means that clockwise-rotating shifts (morning–afternoon–night) are theoretically preferable. Depending on the time, bright light affects the human rhythms in different ways. In principle, strong light in the late evening will delay the circadian rhythm so that workers are better able to adapt for the night shift (Horowittz and Tanigava, 2002).

Offering more light to shift workers also means higher use of energy if the light is provided in the same way as before. One option could be more localised lighting. If the lighting is provided in the form of more local task lighting rather than general lighting, increasing the light level can sometimes be achieved without increasing the use of energy (Juslén and Kremer, 2005).

The scope of the study described in this paper was to test if shift workers would prefer localised lighting. Furthermore, we examined whether the level of localised lighting, which is higher than the minimum prescribed in the present lighting standard (EN 12464-1, European standard, Light and lighting—Lighting of work places—Part 1: Indoor work places), would be favoured by employees and whether the level influences their performance or alertness.

2. Methods

2.1. Working and test environment

The industrial area where the test took place is part of a big chocolate factory. At the end of a long production line is a packaging room, see Fig. 1. Here a wide conveyor belt splits into eight smaller belts, transporting the products to the wrapping machines, where the chocolates are wrapped in paper. As is usual in the food industry, the floors are tiled with light-coloured ceramic tiles and parts of the walls consist of glass and the ceiling is painted white. The test

Fig. 1. Test area: packaging room. Note the general diffuse lighting at ceiling level supplying a general uniform illuminance of 400 lux at 1 m above floor level, and the additional task lighting installed parallel to the packaging lines.

area looks bright and clean. The air is temperature and humidity conditioned to maintain the quality of the chocolates. The packaging room housing the wrapping machines measures 20 m × 20 m with a free height of 7 m.

2.2. Work

The subjects were operators (section operators, machine minders and shift co-ordinators) who monitored the packaging machines. Their work did not change during the test period. If something goes wrong, it is their job to fix it as quickly as possible so as not to disturb the production process. Since the production process is continuous, a machine not working properly could result in chocolates arriving in the packaging hall having to be put in the reject containers. Depending on the state of the chocolate, it is then either classified as waste or as material that can be used again at the beginning of the process.

2.3. Lighting installation

The original lighting installation is mounted at ceiling level (+7 m) and consists of traditional water-protected luminaires (fluorescent lamps, 2 × 58 W T8, 4000 K, $R_a > 85$). This old installation, which provided a horizontal illuminance 1 m above the floor of ~400 lux in the open space, was left as it was. When needed during the test period, maintenance to the lighting installation was carried out to secure constant lighting conditions. Daylight is not available in the packaging room, only artificial light.

Additional to the old general lighting installation, a dimmable lighting system was installed above the chocolate-packaging lines. This new task lighting, installed in eight rows parallel to the packaging lines, consists of 72 closed luminaires (fluorescent lamps, 2 × 58 W T8, 4000 K, $R_a > 85$) at a mounting height of 2.8 m (to underside of luminaire). Each row is composed of a semi-continuous row of luminaires above the small conveyor belts (Fig. 1) and a continuous row of luminaires at the packaging machines (Fig. 2). The luminaires are louvred to prevent glare, and their wide-beam light distribution and the resulting lighting installation is in accordance with the recommendations of EN 12464-1. Fig. 1 shows the test area, the new task-lighting installation, and the old general lighting installation. In Fig. 2 the packaging machines are shown more closely. The additional task lighting installation has increased the illuminance to ~1150 lux in the front part of the hall, above the conveyor belts where the lines of task-lighting luminaires were not continuous. At the top of the packaging machines, where the additional lines of task lighting are continuous, the illuminance of 300 lux before the new installation has been increased to 2000 lux.

New lighting was installed at the end of 2003. From April 2004 onwards, during the even weeks, the task-lighting installation was set to a high illuminance, and during the uneven weeks to a low illuminance. The illuminance measured at the reference point above the machines (see Fig. 2) was 2000 lux during the even weeks and 350 lux during the uneven weeks. The lowest illuminance with dimmed task lighting is still higher than with just the general lighting. The illuminance was set each week at the start of the Monday-morning shift.

Fig. 2. Packaging machine. The dot at the top of the machine indicates a reference point for the illuminance (originally 300 lux, low-level task lighting 350 lux, high-level task lighting 2000 lux).

2.4. Subjects and shift schedule

The operators were mainly men. This is due to the fact that before 1995 it was not legally permitted to hire women for regular night work in industry in The Netherlands. Most of the present workers have been working in the factory for more than 15 years, and their average age is about 40 years. Six to eight employees were working in the area during each shift. The shift system was the so-called fast-rotating five-shift system. A shift group is working during the morning shift (07:00–15:00) on days 1 and 2; during the afternoon shift (15:00–23:00) on days 3 and 4; and during the night shift (23:00–07:00) on days 5 and 6. Each group has 4 days off: days 7, 8, 9 and 10. On day 11 the morning shift once again starts. In each shift a coffee break, a lunch break and a second coffee break are scheduled in such a way that operation continues all the time. Fig. 3 shows the shift pattern over 10 days. This shift schedule of 10 days does not interfere with the high/low illuminance schedule based on 7 days.

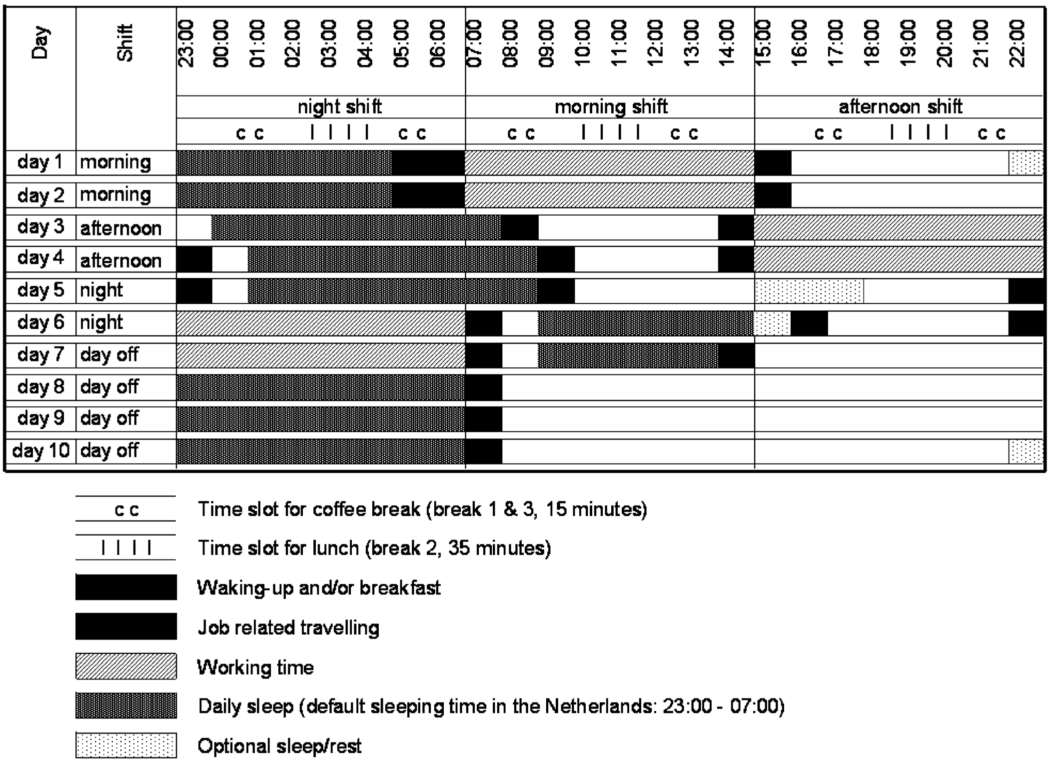

Fig. 3. Shift organisation including breaks and theoretical sleeping patterns.

2.5. Measurements

2.5.1. General

Measurements have been carried out on three aspects, namely productivity of the process and employees, alertness of the employees, and opinions of employees by means of questionnaires. Table 1 gives an overview of the activities during the full test period.

Reference groups were used only in the absenteeism comparison. Since the packaging line under study was different to others in the factory, there were no comparative measurements for productivity. Changing the illuminance of the additional localised lighting every week gave us an opportunity to eliminate the influence of other possible changes happening in the factory environment. This gave us a reliable way of measuring the real effect of illuminance on productivity by measuring machine repair times and alertness (via KSS questionnaires) under both lighting conditions.

2.5.2. Questionnaires

As can be seen from Table 1, lighting and working environment related questionnaires were delivered to the employees three times. They are called here "Before", "After" and "Final" questionnaires. They were not fully identical. Factory management facilitated filling in all questionnaires during working time.

Before installing the new lighting, employees were informed that the lighting would be changed. They completed "Before" questionnaires in the late autumn of 2003, so before any change to their working environment was made. "Morningness/Eveningness" questionnaires (Horne et al., 1976, questionnaire according Kerkhof, 1984) were also delivered to the employees to obtain information with respect to the subjects. By means of the latter questionnaires we obtained information regarding the "type" to which employees belong so that if there had been strong differences, "type" could have been used as an independent variable. As the employees indicated in the information sessions they were interested in the results of the "Morningness/Eveningness" questionnaires, every individual received his score and "type" on the morning/evening type questionnaire in a sealed envelope.

The additional task lighting was installed during the maintenance break of the production at the end of 2003. The illuminance was set to maximum. Approximately 5 weeks later, employees filled in the "After" questionnaires. A "Final" questionnaire was supplied to the employees at the end of September 2005.

In the first part of the "Before" and "Final" questionnaire, operators were questioned concerning the factory environment: "How important do you consider following characteristics of the factory environment?" Things to rate were: Comfortable temperature, Much light, Uniform lighting, Good ventilation, Windows, Factory decor, Low noise level, Much space, View, Possibility to control for yourselves the settings of installations, and Presence of colleagues. The scale was from 1 to 5 (1: Not important, 5: Very important). As the "After" questionnaire was filled in just a few months after the "Before"

Table 1
Time schedule of the test period

Start activity	End activity	Activity description
June 2003		First contacts with factory, design of test, ordering of materials
Nov. 2003		Information session employees
Dec. 2003		"Before" questionnaires on working environment, "Before" questionnaires on lighting, "Morningness/ Eveningness" questionnaires
Dec. 2003 (end)	Jan. 2004	New task lighting installation installed during annual maintenance break
Jan. 2004	April 2004	Task lighting switched on to full level
Feb. 2004		"After" questionnaire on working environment, "After" questionnaire on lighting
April 2004	Sep. 2005	Alternating lighting level: even weeks high level, uneven weeks low level
May 2004	Aug. 2004	Measuring of machine productivity
Sep. 2004	Oct. 2004	First try recording repair times of machines
April 2005	Aug. 2005	Recording repair times of machines
April 2005	July 2005	Karolinksa Sleepiness Scale forms
Sep. 2005		"Final" questionnaire on working environment, "Final" questionnaire on lighting
2003	2005	Absenteeism figures via human resource management
Oct. 2005		End of study

questionnaire, we decided not to repeat the general factory environment questions this time.

The second part of all three questionnaires was the same. Subjects were asked: "What is your impression of your own working area?" The scale was from 1 (very negative) to 5 (very positive). Things to rate were: Pleasant, Interesting, Bright, Warm (temperature), Spacious, Quiet (with little or no movement or sound), Cosy, Orderly, Tidy, Clean, Nice, and Clarity of arrangement.

The third part of the "Before" and "Final" questionnaires contained questions relating to employee alertness and shift preferences. Employees were asked to state when they felt most active and most tired and which shift they preferred.

Questions relating to lighting were present in all three questionnaires. In the "Before" questionnaire employees were asked to evaluate the present lighting in different ways. In the "After" questionnaire the same questions were repeated and some new ones added. In this questionnaire employees were also asked to compare the previous (no longer existing) lighting conditions and the new lighting situation. The "Final" questionnaire was supplied to the employees after the long period during which the lighting level was changed every week. Most of the questions relating to the lighting in the "Final" questionnaire concerned the comparison of these "low" and "high" lighting levels. The lighting-condition comparison questions in the "After" and "Final" questionnaires were answered in a situation where the old lighting reference they "compared" was no longer visible.

Operators were free to select the place where they stayed when there were no problems with the machines. During these times they could also stay outside the test area, so an area without additional task lighting was installed. For this reason, in the "Final" questionnaire they were also asked how big a part of their working time did they estimate was spent in the area with additional task lighting.

2.5.3. Productivity

At the beginning of the test, productivity was measured using standard available factory data by monitoring scrap and rework and their relation to lighting. However, after a few months of monitoring, discussions with shift management showed that this data measured the productivity of the process, but not human performance in the test hall. The system of monitoring the repair times of the machines was introduced in the autumn of 2004. Dependant variable was repair time, and independent variables were illuminance, error type, shift and machine. Recording of the repair times for the machines started in September 2004, but did not continue very long due to technical shortcomings. The data-recording system was improved and it started again in April 2005 and continued until the end of August 2005. The data presented in this paper are from this period. Four typical machine interruptions were selected, based on the estimation that solving these interruptions was influenced by the human performance. The four errors, whose repair times were monitored, were:

Wrapping paper input is blocked: The machine stops and the operator has to take action. The operator opens the door of the cabinet on the machine and visually inspects the situation. A small tool is used to remove the blockage. The paper is then cut once and the machine prepared. After closing the door of the cabinet, the machine is started again.

Photocell does not see a spot: This failure, in which the machine has missed some registration spots, occurs frequently when the paper roll is replaced. The operator reads the error at the control panel, presses some knobs, and the machine starts again. In general it is not necessary to open the cabinet.

Streamer blocks: This error occurs in the chocolate delivery line quite near to the packaging area. As this is the most frequently occurring error, the operator first examines the streamer before looking at the control panel. A bar of chocolate blocks the streamer (two on top of each other or a misshaped chocolate). After opening the cabinet, the offending chocolate is removed manually, the cabinet is closed, and the machine can be re-started.

Wrapping roll open: This error is the continuation of some other errors (cabinet door open, meaning someone would like to adjust the machine). Solving the problem can take less than a minute or up to 20 min.

2.5.4. Subjective alertness

Between April 2005 and the end of July, Dutch Karolinska Sleepiness Scale (KSS) (Akerstedt, 1996) forms were also available in the test area, and employees were asked to fill in these forms four times a day, before every break (1st coffee break, lunch break and 2nd coffee break) and at the end of the working day. KSS is a tool to measure levels of sleepiness and consists of a nine-point scale that ranges from 1 = very alert to 9 = very sleepy (viz. great effort to stay awake or fighting sleep). Dependent variable was KSS rating and independent variables were illuminance, break and shift.

2.5.5. Absenteeism

Absenteeism data were taken from human resource management data, available for the total factory. Due to the detailed registration, absenteeism data were available for the workers in the packaging room under test, for workers in other, not identical packaging rooms, and for the full industrial worker population of the factory.

3. Results

3.1. Questionnaires

Forty-six ‘‘Before’’, 39 ‘‘After’’ and 26 ‘‘Final’’ questionnaires were returned. The lower number of ‘‘Final’’ questionnaires was due in part to it being delivered only to permanent workers and in part because of the fewer number of workers in the area.

Opinions about factory environment in general: Opinions with respect to the factory environment in general were solicited in the ‘‘Before’’ and ‘‘Final’’ questionnaires. In the ‘‘Before’’ questionnaire, only ‘‘windows’’ and ‘‘possibility to control for yourself the setting of installations’’ were rated a little bit lower than 4 (important), the rest were above. Differences are not statistically significant (*t*-test for independent samples). In the ‘‘Final’’ questionnaire, things were also rated around 4 (important). The main difference was that having a ‘‘low noise level’’, which in the ‘‘Before’’ questionnaire was in the middle, was now rated to be the most important thing in the factory environment. However, these differences are not statistically significant (*t*-test for independent samples).

Employees’ perception of their own working environment: Employees evaluated their own environment at around 3.5 (slightly positive) in all questionnaires. Some differences occurred in the answers, but these were not significant (*t*-test for independent samples). ‘‘Quiet’’ (with little or no movement or sound) was reported negatively (not enough quiet/too noisy) in the ‘‘Before’’ questionnaire, more negative in the ‘‘After’’ questionnaire, and even more negative in the ‘‘Final’’ questionnaire. Compared to the ‘‘Before’’ questionnaire, Bright, Nice and Clarity of arrangement went up, while others went down a little in the ‘‘After’’ questionnaire.

Alertness and shift preference: In the ‘‘Before’’ and ‘‘Final’’ questionnaires the general opinions concerning alertness and shift preferences were also asked for. Fig. 4 shows the results for the ‘‘Final’’ questionnaire. The distribution of the answers was almost the same as in the ‘‘Before’’ questionnaire. The only significant difference was that in the ‘‘Before’’ questionnaire there were more ‘‘neutral’’ opinions than in the ‘‘Final’’ questionnaire (*t*-test for independent samples). Operators were most tired during the night and morning shifts. They felt most tired at the beginning of the morning shift and at the end of the night shift. They felt most active at the beginning of the evening shift.

Lighting: Lighting-related questions were asked in every questionnaire. The results are shown in Fig. 5. Even before the change (‘‘Before’’ questionnaire), operators felt that the lighting level was sufficient for their work. However, after the installation of the task lighting, they strongly believed that the lighting was better than before, and that it helped them to do their work better (‘‘After’’ questionnaire). Glare or colour differentiation were not presumed to be a problem, either before or after. All questionnaires (‘‘Before’’, ‘‘After’’ and ‘‘Final’’) indicated that the subjects were of the general belief that ‘‘Good lighting has an influence on my work’’. The results of the ‘‘Final’’ questionnaire show that they were very much in favour of a higher lighting level. They felt that a higher lighting level made them less sleepy, feel better, and that it helped them to work better (‘‘Final’’ questionnaire). They also wanted to keep the installation, and even to have new installations in other parts of the factory (‘‘Final’’ questionnaire).

Presence in test area: In the ‘‘Final’’ questionnaire operators were asked to evaluate during which part of their working time they were present in the test area. The questionnaire showed that operators estimated that they spent on average 62% (min 10%, max 100%) of their working time in the test area.

Morningness–Eveningness: Thirty-eight employees filled in the Dutch Morningness–Eveningness questionnaire before the new lighting installation was installed (Horne and Östberg, 1976; Kerkhof, 1984). One of the employees was ‘‘Definitely Morning Type’’, four were ‘‘Moderately Morning Type’’ and seven were ‘‘Moderately Evening Type’’. The remaining 26 persons belong to ‘‘Neither Type’’ and were uniformly spread over the neither-type area.

3.2. Alertness

The alertness of the subjects was measured by the KSS questionnaires. Answers were received from around 15%

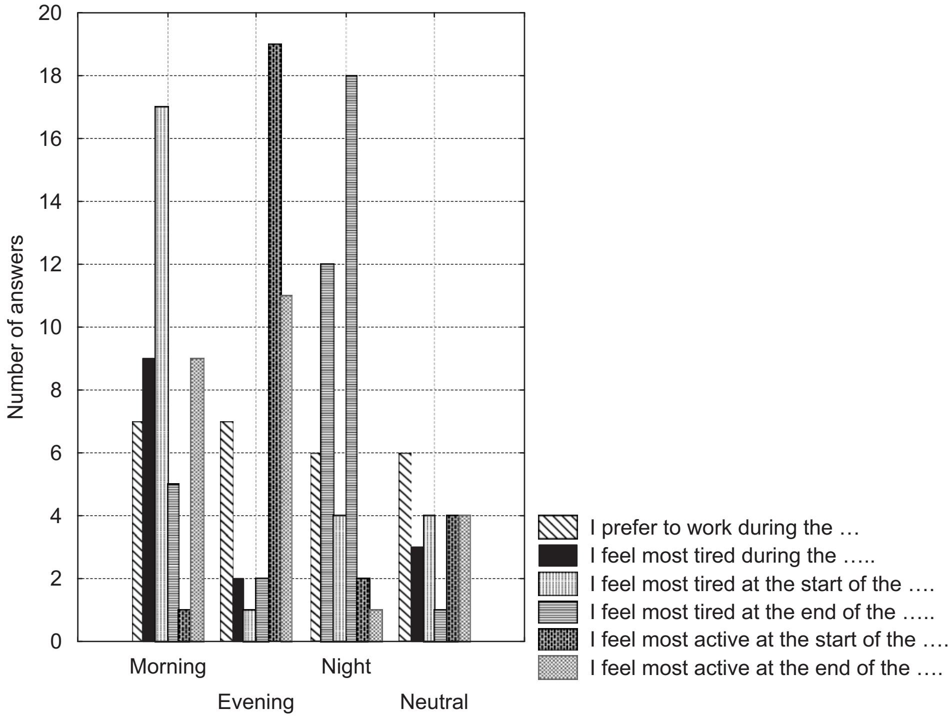

Fig. 4. Answers to the different shift-related questions in the "Final" questionnaire.

of the employees. The average of every break (data available) has been calculated and these values have been used to detect possible differences. The results per shift, break and lighting conditions are shown in Fig. 6. Three-factor analysis of variance (dependent variable KSS averages per break; factors: illuminance (high, low); break (1, 2, 3, end of the shift); and shift (Morning, Evening, Night) was performed to test the difference.

Lighting did not have any statistically significant influence on the KSS answers. There were significant differences between breaks. KSS results showed that self-estimated sleepiness was higher at the beginning of the lunch break (KSS 3.9) than at the beginning of the first (KSS 3.0) and second (KSS 3.4) coffee breaks. It was the same at the end of the shift (KSS 4.2). Sleepiness was significantly higher than at the beginning of the second coffee break (KSS 3.4) ($F(3, 680) = 19.244$, $p<0.01$; Tukey HSD, $p<0.05$). Also sleepiness during the Night shift (KSS 4.1) was significantly higher than during the Morning shift (KSS 3.5) or during the Evening shift (KSS 3.4) ($F(2, 680) = 12.599$, $p<0.01$; Tukey HSD $p<0.01$).

3.3. Performance measured by machine-repair times

The performance was measured by recording the reaction/repair times of four error types. Only reaction/repair times longer than 10 s and shorter than 150 s have been taken into consideration. Four-factor analysis of variance (dependent variable repair time; factors: illuminance (high, low), error type (1–4); shift (Morning, Evening, Night); and machine (1–8)) was performed to test the difference. There was a significant main effect for the illuminance factor, showing that repair time was on average 3.0% shorter when the lighting level was higher ($F(1, 37{,}182) = 4.9961$, $p<0.05$). In Fig. 7, data per shift, error type and lighting conditions are shown. There we can see that the results per individual error during different shifts are not so clear. Only for error type "Photocell does not see spot" during the morning shift is the difference clear.

3.4. Absenteeism

Table 2 shows absenteeism percentages for the test area compared with the total factory and all packaging lines. The figures for years 2003 and 2004 are for a whole year, while for 2005 they are for up until 5 November. The absenteeism figures for 16 subjects who were working in the test area repairing machines in the years 2003, 2004 and 2005 are shown in the first column. The test-area group is the sub-group of all packaging rooms, which is the sub-group of total production. The number of production personnel is not the same for years 2003–2005, since the number of employees is decreasing.

It can be seen in the columns labelled "less than 6 weeks absenteeism" that this dropped in 2004 for all groups and increased again in 2005. However, absenteeism in the test hall in 2005 was lower than in 2003. Looking at the short-term absenteeism, we see that this decreased in the test area in 2004, when generally absenteeism was higher than in 2003. The trend is: short-term absenteeism is going down for the test group and up in the packaging rooms generally,

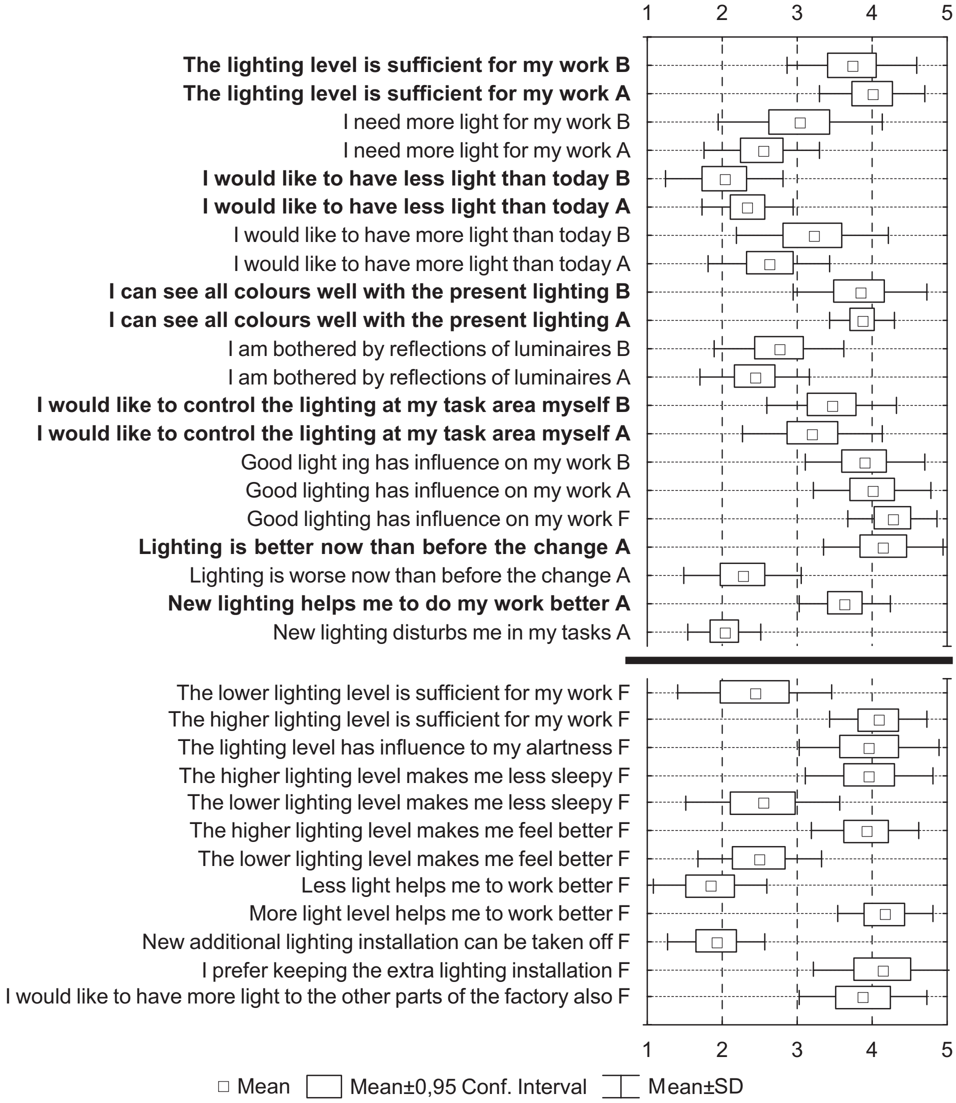

Fig. 5. Answers to the lighting-related statements. "B" indicates answers to the "Before" questionnaire filled in before the change; "A" indicates answers to the "After" questionnaire filled in after the change; "F" indicates answers to the "Final" questionnaire filled in at the end of the test. (1—Totally disagree, 2—Disagree, 3—No opinion, 4—Agree, 5—Totally agree.)

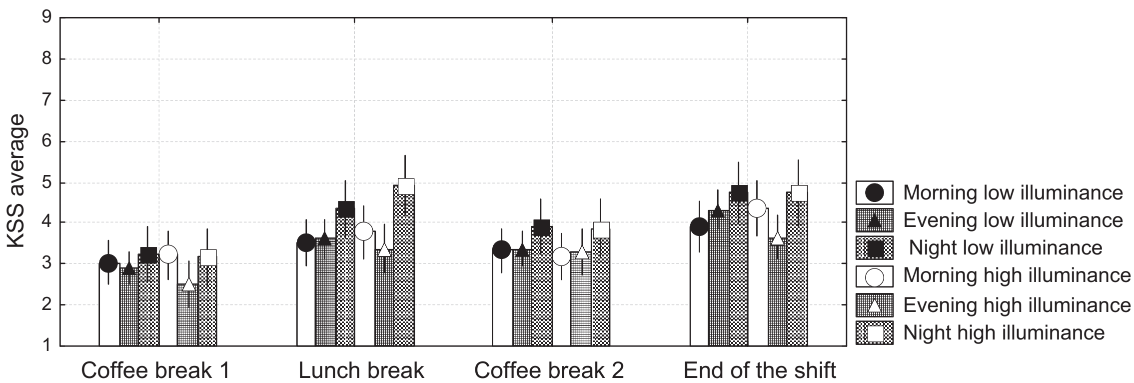

Fig. 6. Results of the three-factor analysis of variance (ANOVA). (Dependent variable KSS average per break; factors: Illuminance (high, low), break (1, 2, 3, end of the shift) and shift (Morning, Evening, Night). The higher the value, the sleepier the operator felt. (Vertical lines denote 95% confidence intervals.)

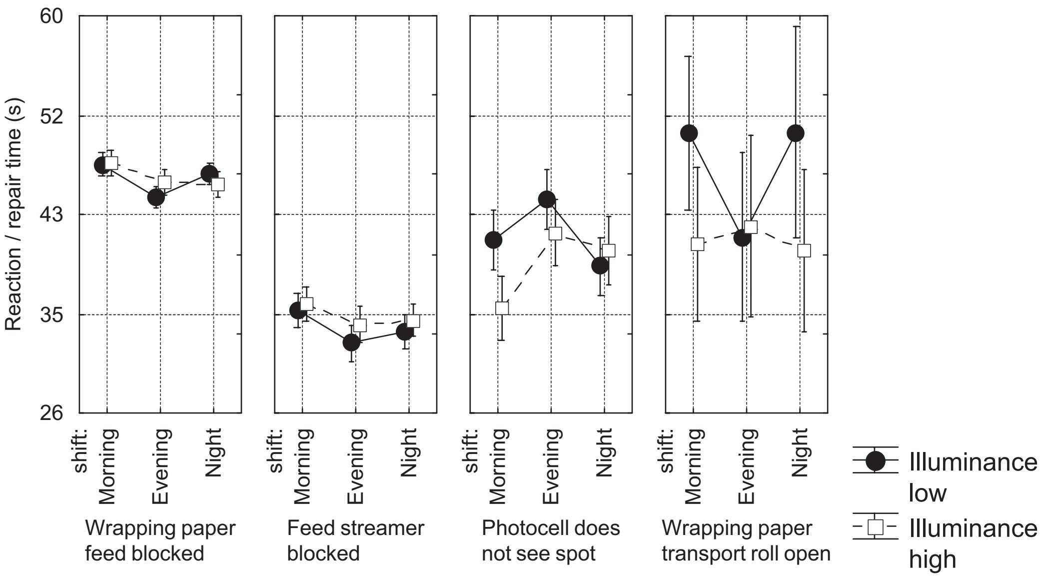

Fig. 7. Repair times per error type, shift, and lighting conditions. (Vertical bars denote 95% confidence intervals.)

Table 2
Absenteeism percentages in the test area, all packaging lines and total factory

Area	Number of subjects	Absenteeism					
		<1 week 2003	<1 week 2004	<1 week 2005	<6 weeks 2003	<6 weeks 2004	<6 weeks 2005
Test area	16	1.03 (100%)	1.01 (98%)	0.99 (96%)	4.66 (100%)	2.80 (60%)	3.85 (83%)
All packaging lines	320	0.95 (100%)	0.97 (102%)	1.14 (120%)	3.04 (100%)	2.44 (80%)	3.17 (104%)
Total factory	540	0.95 (100%)	1.00 (105%)	1.13 (119%)	2.99 (100%)	2.61 (87%)	3.01 (101%)

Between brackets, the relative change compared to 2003 for each area.

as well as on all packaging lines. These changes however, have not been tested statistically for two reasons. Firstly, since with absenteeism we are only looking at before and after results, many other variables might have had their effect, and significance testing would not make results any stronger. Secondly, individual absenteeism data were not available for researchers for confidence-related reasons.

4. Discussion

The working environment part of the questionnaire did not show strong changes. Lighting was not rated as being either a more or a less important factor than other aspects in the working environment. At the end of the study, a "low noise level" was rated as the most important factor of the factory environment in general, and "quiet" as the most negative aspect (environment was too noisy) of the operators' personal environment. Since the noise level did not change during the test, it can be assumed that the improvement in the lighting conditions made the subjects concentrate more on the noise factor. The aspect you feel to be the problem (not quiet, high noise level), in our own working environment could be the factor you feel to be the most important in the working environment generally ("low noise level").

The lighting part of the questionnaire showed very clear results. Operators wanted to keep the new lighting, and preferred the high rather than the low illuminance. And they had a strong belief that the good lighting positively influenced their work. These are similar results to those reported in other long-term field studies in industry (Juslén and Kremer, 2005; Juslén et al., 2005). Glare was not a problem for employees, and they did not insist on being able to control the lighting themselves. Operators indicated that a higher lighting level helped them work better and made them feel better and more alert. Forêt et al. (1998) have reported a similar increase in subjective alertness.

However, KSS answers did not confirm the operators' general feeling that a higher illuminance made them less sleepy. Results did not differ significantly under different lighting levels. The low return rate of the questionnaires naturally affects the chances of obtaining significant results. Also the fact that, according to their own estimation, the operators spend only 62% of their working time in the newly lighted area reduces the possible effects. KSS showed an expected difference in sleepiness between the shifts, showing that the most tiredness occurred during the night shift. More interesting was the trend in sleepiness between the breaks. As expected, the operators were most alert at the beginning of the first break and most sleepy at the end of the shift. The peak in the sleepiness before the lunch was also interesting, since it happened during all three shifts. The reason for this remains unclear.

The clockwise shift-rotation system is good and allows employees to adapt and sleep quite well during their free time (Sallinen et al., 2003). The result revealed by the "Before" and "Final" questionnaires that operators felt most tired at the beginning of the morning shift can be explained by the shift-rotation system employed. After four free days, the operators have to wake up before 06:00 to be on time for the morning shift. The KSS and the "Before" and "Final" questionnaires all indicated that operators were most active during the evening shift. However, their shift preferences were quite uniformly spread. Unexpectedly, the Morningness/Eveningness questionnaire showed that operators were not more evening-type of persons. The evening-type of person, who has late body temperature minimum, adapts better to clockwise shift rotation (Crowley et al., 2003), and bright light might help him more to adapt than is the case with the morning type of person (Mitchell et al., 1997). The management is not using this kind of test for selecting employees, which can partly explain the results. It is also possible that continuous working in shifts flattens the questionnaire results.

Even although a comparison of repair times generally showed that repair was three per cent faster under the higher lighting level, this was not true for all error types during the different shifts. Actually, only for error "Photocell does not see a spot" on the morning shift was the difference really clear. The result of this study shows some—but not very strong—evidence that an increased lighting level improves performance as reported elsewhere (Campbell and Dawson, 1990; Daurat et al., 2000; Juslén et al., 2007).

One reason for the relatively modest performance results and the absence of significant alertness results might be the limited difference between the dim-light and bright-light situations in this study. The "Low" horizontal illuminance (350 lux) was already at the level where alertness is influenced (Cajochen et al., 2000). Finally, it should be remarked that the method employed in this field study does not permit of an opportunity to evaluate which effect leads to a slight improvement in performance. It can be visual, biological or psychological. One possibility in future research would be to use lighting systems where the colour temperature can also be changed: it would then be easier to separate possible visual and biological effects.

Finally, the absenteeism data showed an interesting trend, indicating that users benefited from the new lighting installation. Since the number of employees has been steadily decreasing over a number of years, the workload might be steadily increasing. This provides one possible reason for the increase in short-term absenteeism in the factory. It is interesting that the test group showed the opposite trend. However, since this test group consisted of only 16 persons, no firm conclusions can be drawn.

5. Conclusions

Additional localised lighting is highly appreciated by employees. The machine operators felt that much higher lighting levels than those previously in use made them feel less sleepy and improved their performance. This is partly confirmed by measurements of machine repair times. On average, repair times per error type, machine and shift were statistically significantly three per cent shorter under the higher lighting level. However, studying repair times per error type and shift, only one out of four characteristic machine failures during one shift (morning) showed a clear (14%) decrease in repair time when higher lighting levels were in use. The results of the KSS measurements did not confirm the self-assessment of alertness related to illuminance. The KSS study showed interesting statistically significant rhythms, namely that at the 2nd and 4th breaks employees felt sleepier than just before the 1st and 3rd breaks, irrespective of the shift. Employees felt most tired at the start of the morning shift (after having a 4-day holiday) and at the end of the night shift, and declared that they were most active at the start of the evening shift. The short-term absenteeism of the test group decreased (not tested statistically) by four per cent (2003–2005); the short-term absenteeism in the total production area of the factory generally increased by 19%.

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