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Mechanisms involved in enhancing human performance by changing the lighting in the industrial workplace

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Abstract

This paper addresses the question: "What is happening when we change the lighting at an industrial workplace?" and develops a new approach for looking at the effects of a change of lighting at the workplace on performance.

Installing new lighting in the workplace may influence the performance of people working there by way of several mechanisms. In this paper the mechanisms are described: visual performance, visual comfort, visual ambience, interpersonal relationships, biological clock, stimulation, job satisfaction, problem solving, the halo effect, and the change process. The importance of these mechanisms is discussed and the results of old field studies in industrial environments have been put together to illustrate the effect of lighting change in industry.

Relevance to industry: To be able to estimate the influence of lighting and lighting change in industrial environment it is essential to collect and separate the mechanisms which are involved to the lighting change process. This helps both practitioners and researchers for concentrating their efforts in the field of industrial lighting.

Keywords: Industrial lighting; Human productivity; Change mechanisms; Working environment

1. Introduction

Changing lighting conditions is a change process that influences performance via many routes. Wyon (1996) introduced a kind of step-by-step method to describe the relationship between an environmental change and performance in terms of specific mechanisms that explain the effects of the change. When these mechanisms are defined as chains of hypotheses, each of which must be true for the mechanism to be valid, then we can test each link in the chain separately.

A model of the influence of light and lighting change is presented in Fig. 1.

Light influences people via a visual and a non-image-forming (NIF, also called psycho-biological)

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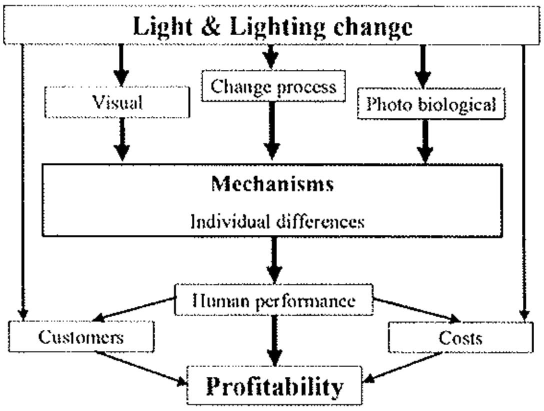

Fig. 1. Model of the effects of light and lighting change on profitability in the industrial environment.

path in the brain. The mechanisms that affect performance will be described with the chain approach. Human performance is directly linked to profitability in the industrial environment. Individual differences will influence the effect of the mechanisms. In this paper, the change process itself will also be handled as a mechanism. The costs of the lighting change and the effects via customers also affect profitability, but these are not discussed in detail in this paper.

The idea behind this simplified conceptual model and this paper is the effect on human performance and profitability when a lighting installation is replaced. The mechanisms that are described later in this paper are distinguished by their origin. This view is different from the view behind other models, like the one by Boyce (2003) in which three routes have been shown whereby lighting conditions can influence human performance, or the one by Veitch (2001) in which relationships between lighting conditions, individual processes and individual outcomes have been described.

2. The impact of changing the lighting in industrial workplaces

Improving the lighting at the workplace has several positive effects on the performance of the workers. Lighting influences productivity factors such as output, errors and accidents (van Bommel et al., 2002; Völker, 1999). A literature search yielded several field studies in which lighting change effects have been measured in an industrial environment. Unfortunately, only few of the studies are well documented. Some are just used as examples in general papers. Most of them are old but still useful.

In Figs. 2 and 3 the results of all studies found in literature have been put together. Fig. 2 gives the increase in work output and Fig. 3 the decrease in errors or rejects, as a function of task illuminance. The dotted lines connect the "before" and "after the change" situation for each individual study. The solid curves are drawn by calculating the average slope from the reported results as a function of the illuminance. All available studies or examples are included, although the reliability of some of them was impossible to estimate. There were not enough data available of the individual cases to perform a meta-analysis. The solid curves give the trend of the performance improvement (increase outputs—decrease rejects), as has been found in the studies mentioned above, and show that there is an effect of the illuminance on performance. The curves may not be used, however, to predict the performance improvement quantitatively when the illuminance is changed, because of the uncertainty of individual studies.

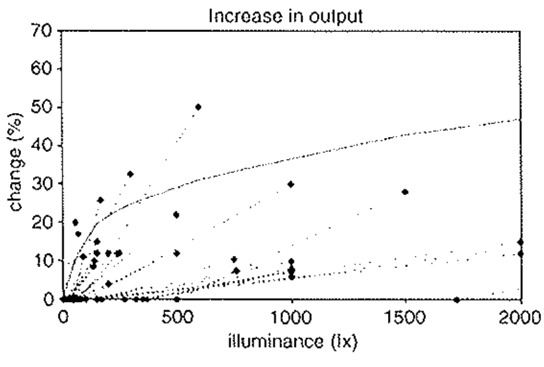

Fig. 2. Lighting change effect for work output. The dotted lines show the results of the individual tests and the solid curve shows the calculated average slopes. (29 cases) (Ruffer, 1925, 1927; Schneider, 1938; Goldstern and Putnoky, 1931; Bitterli, 1955; Stenzel, 1962a, b; Crouch, 1967; Lindner, 1975; Carlton, 1980).

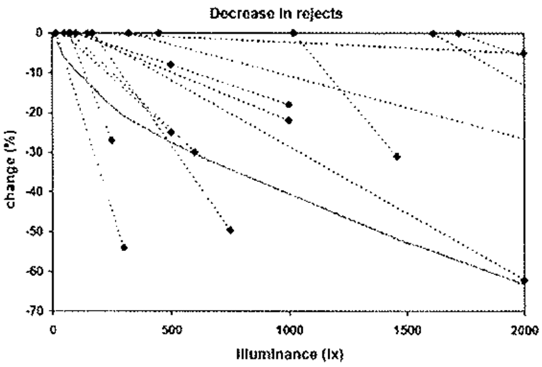

Fig. 3. Lighting change effect for rejects. The dotted lines show the results of the individual tests and the solid curve shows the calculated average slopes. (15 cases) (Goldstern and Putnoky, 1931; Schneider, 1938; Bitterli, 1955; Crouch, 1967; Lindner, 1975; Carlton, 1980; Buchanan et al., 1991).

One should keep in mind that in experiments on human performance an increase of productivity could be caused by 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 Hawthorne effect was first established in the studies in the relay-assembly test room in the Hawthorne plants starting on 25.4.1927 and ending on 18.6.1932 (Parsons, 1974). The duration of the work and rest pauses were manipulated. A group of five women was separated and observed intensively. Two of the women were replaced in the middle of the test because they had talked too much during the test. The Hawthorne effect might be stronger in laboratory tests where people are monitored intensively outside their normal environment. Case studies in the normal industrial environment might have a lower risk of the Hawthorne effect than, for example, field studies in an office environment. Industrial workers are more used to being controlled, and in many cases no extra control is needed for the test.

Many studies started with very low illuminances. This increases the uncertainty of the solid curves, which are averages. It is remarkable that even if the size and the reason for improving the performance is not clear, almost all individual studies indicate improvement of performance after the lighting change. In most cases the illuminance has been increased, but this does not mean that illuminance is the only, or even the most important, factor behind the success.

The solid curves differ in the sense that the decrease in rejects shows a steeper slope than does the increase in output for illuminances above 300 lux. Although the results depend on (unknown) boundary conditions, such as initial quality level and process robustness, it could indicate that outputs are more strongly influenced by visual performance (just how well, we are able to see). When the illuminance is sufficient for the visual performance, the increase in output decreases. It is also possible that other factors block the increase in output. Many factories are producing more or less quantified amounts of products per time frame, depending on orders and contracts, or speed is determined by the machines employed; and even if the working environment offers possibilities to increase the number of products, it is not always done or desired. The ongoing decrease of rejects can be caused by another mechanism, such as brain stimulation. According to the study of Cajochen et al. (1999), 500–1000 lux is needed on the eye to increase alertness during early biological night, which means that the horizontal illuminance should be in the range of 1000–2000 lux.

Another reason for the ongoing decrease of rejects could be that higher quality is never blocked by factory policies such as higher outputs, but rather is strongly supported.

To be able to estimate the effects of a change of lighting, more and better quantitatively described field studies are necessary. In principle, the more information we have from a field study the better.

3. Mechanisms for the effects of a change of lighting

3.1. General introduction

A lighting change can be brought about by changing the artificial lighting or the daylight contribution. It has been indicated in the previous section that there is an effect lighting change on the performance of workers. Different mechanisms are responsible for this effect. A mechanism includes all the chains that can be created under one origin. The different origins are independent, and it is possible to find at least one chain that is specific only to this mechanism. When changing the lighting, it is possible to achieve increased performance via the following mechanisms.

1. Visual performance
   When people can see the task better, they can perform better.
2. Visual comfort
   Decreasing discomfort glare influences performance because of increased concentration.
3. Visual ambience
   Lighting influences visual ambience, which being part of the working environment, influences performance.
4. Interpersonal relationships
   How people see each other influences how they feel about each other, which influences co-operation and productivity.
5. Biological clock
   Light adjusts the biological clock, which controls the circadian rhythms and thus influences performance at certain times.
6. Stimulation
   Light stimulates psychological and physiological processes, which enhances performance.
7. Job satisfaction
   Improving lighting conditions might increase job satisfaction via task significance and autonomy, which influences performance.
8. Solving problems
   Solving existing lighting problems, which are complained about, increases well-being and motivation, which enhances performance.
9. The halo effect
   The effect of the belief in the superiority of a new technology or product itself might result in enhanced performance.
10. Change process
    Good change management increases the positive effects of the lighting change and diminishes negative effects.

These mechanisms are described in more detail in the following paragraphs. It is assumed that individual performance influences productivity. In those cases where individual performance does not influence workforce productivity, lighting change has no effect on profitability.

Links of the example chains have been marked by using letters A, B, C, D and E. The last two links of each chain, shown below, are always the same, and are assumed to be true. In the descriptions of the mechanisms, these last two links are not always repeated. In some chains, only 4 links are distinguished, and here the last links are C and D instead of D and E.

The last two links of the chains:

D (C) Individual performance and the success of the teamwork influences workforce productivity,
E (D) Workforce productivity influences business profitability.

3.2. *Mechanism 1, visual performance*

Chain 1

A. Lighting influences visual performance.
B. Visual performance influences task performance.
C. Task performance influences total individual performance.

The first statement is obvious—we need light to be able to see. Visual performance is a quite-well studied topic in lighting. The relative visual performance model (RVP) (Rea and Quellette, 1991) is a model that has been developed during the past 20 years and that can predict visual performance in some tasks (Bailey et al., 1993; Eklund et al., 2001). Also, the lighting standards, such as the new European norm (EN 12464-1—Lighting for indoor workplaces), are mainly based on visual performance.

The effect of visual performance on task performance is not always clear. Visual performance has a different importance in different tasks. Some tasks do not need much light in order to be performed well visually. And task illuminance is not the only factor that influences visual performance—glare, spatial distribution, spectral composition, individual differences, and the task itself also play an important role in the impact of this mechanism.

Since the task is supposed to be a significant part of the work to be performed, the total performance of the individual worker will be influenced by the task performance.

3.3. Mechanism 2, visual comfort

Chain 2

A. Discomfort glare creates the sensation of pain or annoyance.
B. Pain and annoyance affect our possibilities to concentrate on the task.
C. Concentration level influences individual performance.

Visual comfort might be compromised even if visual performance is still good. A typical example is discomfort glare that creates a sensation of annoyance without affecting visual performance. A lighting change that improves visual comfort, such as a decrease of discomfort glare, yields a higher performance by reducing a disturbing factor present in the environment.

3.4. Mechanism 3, visual ambience

Chain 3

A. Lighting influences the working environment via visual ambience.
B. The working environment influences well-being and feelings.
C. Positive effect increases individual performance.

Boyden (1971) distinguishes "survival needs" and "well-being needs" in humans. The survival needs are mostly fulfilled in a working environment, but failure to satisfy well-being needs produces psychosocial maladjustment and stress-related illnesses. One of the needs mentioned is: "A visual environment that is interesting, that has aesthetic integrity, and in which a certain amount of change meaningful to the observer is taking place". Lighting is directly linked to this need.

Many significant effects of positive, pleasant feelings have been reported in literature. Important work-related results of positive mood are, for example: the inclination to help others, positive effects on memory, more efficient decision making, increased innovation and creative problem solving tendencies. All these are direct links to better individual performance (Isen and Baron, 1991).

According to this chain, the illuminated environment influences performance via positive mood and not only via better visual performance (mechanism 1). It is difficult to estimate the size of the effect of this mechanism in increased overall performance in real industrial environments. Anyway it has been shown that the physical environment affects performance by influencing the effectiveness of teamwork in industry (Sundström and Altman, 1989).

3.5. Mechanism 4, interpersonal relationships

Chain 4

A. Light influences a person's appearance.
B. A person's appearance influences interpersonal relationships.
C. Interpersonal relationships influence teamwork.

The characteristics of light influencing communication and interpersonal relationships are luminance, spatial distribution and spectral composition. The (vertical) illuminance (or luminance) determines how well the other person's face and expressions can be seen. The direction of the light has an influence on the shadows, which can change the expression observed, and the spectral composition is important for the colour rendering (e.g. of the skin colour). The colour of the skin is a signal of health and mood. Skin and clothes look different under different lighting; consequently, people with different skin tones prefer different lamps (Quellman and Boyce, 2002).

Visual performance plays a role here, but in this mechanism the emphasis lies on how the other person appears, not on how well he or she can be seen. Appearance influences interpersonal relationships, which in turn have several effects on performance. Body language and appearance provide an important part of the information for the interpersonal relationship. It has been shown that interpersonal relationships influence the effectiveness of teamwork (Sundström et al., 1990).

The light level also has an effect on conversational sound level (Veitch and Kaye, 1988), which then influences the interpersonal relationships. The change in conversational sound levels depending on light level is not connected directly to visual performance.

3.6. Mechanism 5, biological clock

Chain 5

A. Light exposure influences the biological clock.
B. The biological clock influences the circadian rhythms.
C. The circadian rhythms influence individual performance of shift workers.

Circadian rhythms are changing patterns that have a period of approximately 24 hours. Examples of circadian rhythms are body temperature, alertness, and hormonal rhythms such as melatonin and cortisol. Circannual (annual) rhythms also influence our body processes. Our biological clock is located in the suprachiasmatic nucleus, and ocular light synchronises it (Brainard and Bernecker, 1995). Without daily light exposure, the free-running period of our circadian system would be more than 24 hours. Recent studies, by 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. To achieve maximum effects one has to use either high photopic lighting levels or lamps that produce more light of wavelengths around 460 nm. According the Dawson et al. (1995), bright light has been shown to be "superior" to melatonin administration in controlling the biological clock.

The biological clock needs to be set if we want to perform well outside the normal daytime (e.g. after travelling across several time zones and during night shifts). Travellers are familiar with desynchronisation of their biological clock and the local time—so-called jetlag. Shift workers face the same problem when they are trying to work while their body clock says it is time to sleep. The effect of light on the circadian rhythm depends on the time of the day (Czeisler et al., 1988). Bright (or photo-biologically effective) light late in the evening, before the body temperature minimum, will delay our circadian rhythms, whereas light in the early morning, after the body temperature minimum, will advance the rhythms. Timing, intensity, spectral distribution, spatial distribution and duration of the light exposure together with individual factors define how large the phase shift is. Light influencing the circadian rhythms is supposed to be one element to improve the quality of life and the performance of shift workers. In case studies (Baker, 1995; Boyce et al., 1997), where bright light during the night shift has been used, increased performance has been observed.

It is assumed that daytime workers can also benefit by increased lighting levels, especially in the morning and during the so-called "post-lunch dip" (van den Beld, 2002). For example, light exposure in the morning affects cortisol levels in humans (Scheer and Buijs, 1999). The light/dark cycle sets the amplitude of the hormonal rhythms (Jewett et al.,1994), and when the hormonal rhythms are stronger, we sleep better and are more alert when we are awake. Being not so sleepy when we are awake then naturally also improves our performance (Dinges and Kribbs, 1991).

3.7. Mechanism 6, stimulation effects

For the direct stimulation effects, two chains are described.

Chain 6a

A. Lighting level and colour temperature influence mood.
B. Better mood increases individual performance (see mechanism 2).

Chain 6b

A. Increased lighting level decreases sleepiness measured as EEG delta waves.
B. Sleepiness influences individual performance.

Light has several direct and indirect stimulation effects on our psychological (example chain 6a) and physiological (example chain 6b) processes. The increase of daylight in springtime, for example, creates well-known positive mood effects. Studies (Knez, 1995, 1997; McCloughan et al., 1999) have shown that the lighting level and colour temperature also influence our mood indoors. The problem with mood and colour temperature is that personal differences are so big that finding general rules is difficult. Higher lighting levels also influence the electroencephalogram (EEG), keeping us more alert and less sleepy (Daurat et al., 1993; Küller and Wetterberg, 1993).

The Yerkes–Dodson law (Yerkes and Dodson, 1908), which is also called the arousal theory, suggests that the relationship between arousal (sensory stimulation) and human performance varies systematically following the so-called "inverted U" function. Higher arousal means higher performance, until a certain level is reached above which increased arousal starts to influence performance negatively. Lighting is supposed to be a rather mild arousal agent. Lighting is supposed to increase human performance, especially when arousal moves from low to medium levels and the task is not very difficult (Gifford, 1988). Many industrial jobs have repetitive tasks where this mechanism might cause effects. To be able to maximise benefits out of this mechanism we should install an adjustable lighting installation, because after adaptation to the changed circumstances the effect is probably not so strong (Gifford et al., 1997).

A study by Tops et al. (1998) shows a relationship between the illuminance at the working plane and the length of continuous presence in an office. This was explained by an arousing capacity of light, which increases with increasing lighting levels. A number of researchers have supported the hypothesis that lighting directly and positively influences the arousal state (Biner, 1991). An improvement in attention and concentration between 15:00 h and 17:00 h in a 2500 lux condition as compared with a 500 lux condition has been reported by Grünberger et al. (1993). An alternative explanation is that high light levels slow the rate of tiring among subjects, as has been found with visual tasks (see Boyce et al., 1989 for a review). Assuming that with higher lighting levels people tire more slowly, it follows that they are able to stay longer in the office before having to leave for a break.

3.8. *Mechanism 7, job satisfaction*

Two chains are described.
Chain 7a

A. Improved lighting gives the employee a signal that his work is significant.
B. Perceived task significance influences job satisfaction.
C. Job satisfaction influences individual job performance.

Chain 7b

A. Opportunity to control lighting conditions increases the feeling of autonomy.
B. Autonomy influences job satisfaction.
C. Job satisfaction influences individual job performance.

This mechanism (both chains) has an influence only for cases where task significance or autonomy influence job satisfaction. In those industrial jobs where this is not the case, improved lighting will have no effect via this mechanism.

In an often-used job satisfaction model presented by Hackman and Oldham (1976), the focus lies on five core job characteristics, which are: task identity, feedback, skill variety, task significance and autonomy. Lighting change has an effect on task significance and autonomy. The fact of having a new lighting installation itself gives the employee the message that he and his job are important. The lighting installation might also have features that increase the feeling of autonomy, such as individual control options for level and/or colour temperature. Studies that have been done in the office environment have shown that the possibility to control the lighting is preferred by people (Moore et al., 2002; Escuyer and Fontoynont, 2001; Maniccia et al., 1999). In industry, people have fewer possibilities to control their environment, which might mean that lighting controls are even more important for them than for office workers.

According to a meta-analysis made by Tait et al. (1989), job satisfaction correlates moderately well with life satisfaction ($r = 0.44$). There is also a moderate correlation between job satisfaction and job performance ($r = 0.30$) (Judge et al., 2001b). In any case, the strength and even direction of the correlation between job satisfaction and job performance in the individual cases is not totally clear. For example, an older meta-analysis gave a much weaker correlation ($r = 0.17$) (Iaffaldano and Muchinsky, 1985). 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).

3.9. *Mechanism 8, problem solving*

Two chains are described.

Chain 8a

A. Solving problems that employees complain about increases well-being and motivation.
B. Well-being and motivation influence individual performance (see mechanism 2).

Chain 8b

A. Employing high-frequency ballasts instead of magnetic ones limits flicker.
B. Flicker causes fatigue and eyestrain and results in lower sustained performance.
C. Decreasing fatigue and eyestrain increases individual performance.

The original lighting installation might have "quality" problems such as glare, bad colour rendering, stroboscopic effects, noise from ballasts, wrongly located luminaires, difficult control of luminaires, etc., which are causing complaints and difficult working conditions. "Repairing" these kinds of problems has direct positive results via two routes. Firstly, repairing conditions gives a signal to employees that they are being listened to by the employers and that they have influence, which increases their motivation (chain 8a). Secondly, that getting rid of the problems improves the physical working environment and gives the employees the opportunity to work effectively (chain 8b).

Chain 8a influences performance in the same way as the chains described under mechanism 7 (viz. changing environmental conditions shows the employee that his job is significant and that it is worthwhile to improve conditions). In this mechanism, the reason for the change comes from the employee, and a reaction to his demands will give him feelings of autonomy and importance.

Lighting might also cause other problems. A typical, but not visual-performance-related example is flicker from magnetic ballasts causing problems such as headaches (Wilkins et al., 1998). When the magnetic ballasts are replaced by electronic ballasts, the problems disappear. And as in chain 8b, getting rid of those problems influences performance; for example, in the form of reduced absenteeism. Health-related things are not the only beneficial outcomes of using electronic (high-frequency) ballasts. A study by Veitch and Newsham (1998) shows that task performance is also better when electronic ballasts are employed.

3.10. *Mechanism 9, the halo effect*

Chain 9

A. People have positive presumptions about good lighting.
B. Their presumptions influence individual performance.

The term "the halo effect" was first used by Thorndike (1920). It describes how a person's first impression influences the total judgement of that person. The halo effect can be applied to people as well as to things. Sometimes the subjects of technological intervention believe that a new technology is wonderful, and that belief is the real cause of improved performance (Bloggs and

Draper, 1996). The beliefs can be like those tested by Veitch et al. (1993): "Brighter light leads to greater productivity" or "People feel happier when working under light that is similar to natural daylight." It is not important whether or not these beliefs are well founded. The origin of these beliefs might be anything. In many cases the halo effect increases the positive effect of the lighting change on individual and organisational performance.

3.11. Mechanism 10. change process

Chain 10

A. Lighting change is a change process.
B. Change management influences the results of the change process.
C. Results of the change process influence individual performance.

A change of lighting is a management intervention, which can be done in different ways. The way the change process is managed influences the results (Pascale et al., 1997). Changing the working environment can lead to a change in work output. The most common basic advice to managers since the early studies of participative change management (Coch and French, 1948) has been to involve and/or inform people about the change. Even though a better environment is most probably well accepted, there is always the possibility of the negative mechanism called "resistance to change" if the change process is not well handled. Involving people in the lighting change could be accomplished by giving them the possibility to influence the lighting installation. Those involved could be kept informed simply by telling them the reason for the change in advance (lower energy consumption, flicker-free installation, better lighting for performing tasks, etc.).

4. Discussion

The tasks in industry are many and varied. The impact of the mechanisms described varies from task to task. When visually demanding tasks are performed under very low lighting levels, the most powerful mechanism, when lighting is improved, will be visual performance. When improving the performance of shift workers by means of the lighting, the main mechanism will be the effects of changing the biological clock and direct brain stimulation. And when changing the lighting conditions of electrical assembly workers, who already have good lighting, job satisfaction and change management might produce the strongest effects.

Fig. 4 gives an overview of the estimated importance of change mechanisms for different kinds of tasks. The tasks have been divided into shift work, visually demanding individual work performed during the daytime, and visually non-demanding teamwork during the daytime. For all groups, managing the change is important as well as the stimulating effect of light. The difference in importance of the halo effect for different tasks is hard to estimate. This difference is merely between different persons. The importance of visual performance and the biological clock is different for the different types of task for obvious reasons. The importance of the visual ambience is assumed to be different between the daytime groups because a person with an individual task is supposed to be focused on his visually demanding task while a team worker is assumed to pay more attention to his environment. Interpersonal relationships are

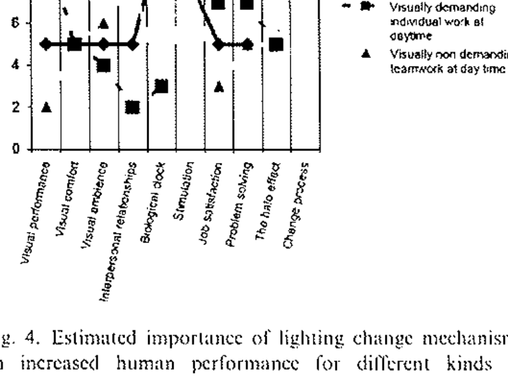

Fig. 4. Estimated importance of lighting change mechanisms on increased human performance for different kinds of industrial work.

supposed to be more important for the performance of team workers than for individual workers, which explains the difference in estimated importance of this change mechanism between daytime workers. Teamwork is often arranged in such a way that the workers have more influence on their work than does an individual assembly worker. This explains why the importance of increasing job satisfaction is assumed to be higher for persons who work individually. The same holds true for the difference involving the problem-solving mechanism. Team workers are already more used to being heard. The importance of the individual mechanism naturally depends on the starting level. So, for example, if visual comfort is a problem for night-shift workers in a given workplace, it could be rated in that place on a scale of ten. Although the tasks in Fig. 4 are simplified, the approach helps to evaluate the areas on which to focus when changing the lighting.

It is important to note that human beings will react differently to changes due to their individual differences in gender, cultural background, life style, family situation, genetics, personality, etc. This also means that the individually-preferred ambience is different. And lighting is part of that ambience. Different genders experience different "feelings" under the same lighting conditions (Knez, 1995; McCloughan et al., 1999). Differences are not only between people—the same person might be in a different mood at different times. These differences form a big challenge for the lighting designer. Personal lighting controls are one way to maximise performance by fulfilling these individual lighting needs. Individual differences also cause problems to the chain approach, which is described in this paper. Though it is clear that changing the lighting has effects via several chains under one mechanism, the change might influence different persons in different ways. For example, the differences in sleepiness among shift workers are high (Härmä, 1995). Some people gain more benefit from a circadian phase shift made by the dark/light cycle than do others. And it has also been shown that there are differences in preferred room illuminance and colour temperature (Begemann et al., 1997). Not everyone prefers a change of the illuminance in the same direction. And the same lighting change might cause a positive effect via one mechanism and a negative effect via another.

When studying these mechanisms the Hawthorne effect should be taken into account. Among the studies related to the ten mechanisms described in this paper, visual performance related studies will probably suffer the least from the Hawthorne effect. The Halo effect is difficult to separate from the Hawthorne effect. The knowledge of being under the study might effect the results of all the studies. Lighting is a difficult area to study since lighting conditions are hard, even not impossible, to change without the subject realising it. The chain approach used in this paper can help to limit the effects of the study protocol.

Among the ten mechanisms described in this paper, "stimulation" seems to be the least clear. The stimulation effects of light were discussed under one mechanism, but future research might give us tools to divide this mechanism over several mechanisms. With our present knowledge, the connections between physical and psychological effects of light stimulation appear so complicated that they had to be simplified here under one mechanism. We have not considered any stimulation or health effects of light via the skin in any of these mechanisms, because there is no evidence that this effect plays a role for the lighting levels that are used in indoor working places.

5. Conclusions

We are able to say that there are at least ten mechanisms that contribute to the increase of human performance after improving the lighting. The mechanisms that have been described in the previous sections are: visual performance, visual comfort, visual ambience, interpersonal relationships, biological clock, stimulation, job satisfaction, problem solving, the halo effect, and the change process.

Seeing lighting change as a change process can give us a more realistic picture than just comparing different lighting conditions. We recommend that this viewpoint be used more often when lighting in general is discussed. It also provides non-lighting professionals with some possibilities for estimating the meaning of lighting and lighting change (e.g. investors). Seeing lighting change as a process with several mechanisms, which are partly "light related mechanisms" and partly general change mechanisms, will help them to estimate whether a lighting change is worth the investment. Where the costs of lighting are normally around 0.1 per cent of the total costs of work in offices (Fontoynont, 2002), and even less in industry, where capital-intensive machines are also present, it is obvious that even a small positive effect may justify a change of lighting. In the old field studies, the changes have been quite big, and more field studies are needed to estimate the importance of lighting change and its individual mechanisms. For that reason, several field studies have been planned and started already in different European countries.

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