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EFFECTS OF INDOOR LIGHTING ON MOOD AND COGNITION

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Abstract

Two experiments investigated the effect of indoor lighting on cognitive performance via mood. Experiment 1 varied two lighting parameters in a factorial, between-subject design: two illuminance levels (dim; 300 lx vs bright; 1500 lx) by two colour temperatures ('warm' white; 3000K vs 'cool' white; 4000K) at high CRI (Colour Rendering Index; 95). In experiment 2 the parameters of lighting were identical to the first experiment, except for the low CRI (CRI; 55). In both experiments gender was introduced as an additional grouping factor. Results in experiment 1 showed that a colour temperature which induced the least negative mood enhanced the performance in the long-term memory and problem-solving tasks, in both genders. In experiment 2, the combination of colour temperature and illuminance that best preserved the positive mood in one gender enhanced this gender's performance in the problem-solving and free recall tasks. Thus, subjects' mood valences and their cognitive performances *varied* significantly with the genders' emotionally different reactions to the indoor lighting. This suggests, in practice, that the criteria for *good* indoor lighting may be revised, taking into account females' and males' emotional and cognitive responses as well.

Introduction

From birth, through the years of education and work settings to old people's homes/hospital we sojourn in artificial milieus. Hence, we perform mentally and react emotionally within settings that are artificial, in contrast to environments where we have evolved and developed our internal faculties. Of course, there are occasions in between when people do visit and enjoy real natural settings. The point is, however, that for most of our lives we spend our time in man-made settings that entail, and expose us to, different physical indoor variables—one such is artificial light.

Research concerning the effects of light on man has explored issues of light and human visual system to a significant degree (see e.g. Boyce, 1981; Megaw, 1992 for reviews). This framework has produced an extensive body of results which have been broadly applied as general requirements and practical recommendations for qualitative lighting (e.g. Galer, 1987). However, these results are restricted to perception and perceptual tasks.

Are there any effects of lighting on other psychological processes than the purely perceptual, e.g. on emotional, cognitive? 'Unfortunately, whilst this is all plausible and widely believed there is little reliable experimental evidence that such indirect effects of lighting occur' (Boyce, 1981, pp. 222–223). Recently, several papers have, however, tried to demonstrate the 'indirect', i.e. behavioral effects of lighting (e.g. Butler & Biner, 1987; Gifford, 1988; Veitch & Kaye, 1988; Biner *et al.*, 1989; Heerwagen, 1990; Veitch *et al.*, 1991). Taken together, these results are neither conclusive nor do they carry a framework for behavioral lighting research.

The present paper, however, outlines briefly and tentatively a heuristic aid for this kind of research: a model of artificial biotope and organism (see Fig. 1). This sketchy frame of reference focuses on a causation of affect from the luminous milieu on cognitive processes via moods.

According to a dictionary, a biotope defines a *milieu of living* (*bios*—mode of life; *topos*—place) and one of the definitions of an environment has to do with *influences* (see e.g. *Webster's Third New International Dictionary*, 1968). If we first combine these definitions into a generic concept of influencing milieus of living and, second, divide it into two categories of settings then we obtain: (i) a *natural* biotope and (ii) an *artificial* biotope—the present article is concerned with the latter. This permits, in addition, a parallel inquiry and a production of data that may reveal similar–dissimilar effects on

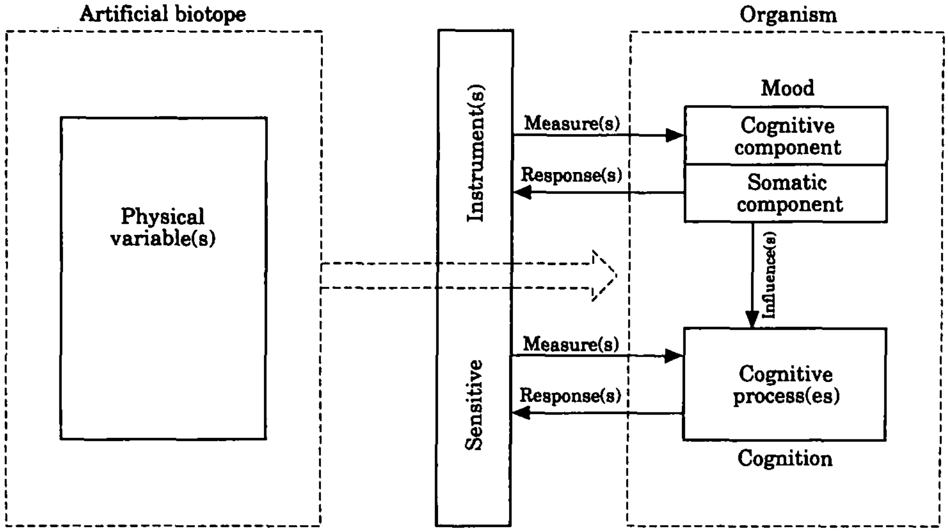

FIGURE 1. A tentative model of artificial biotope and organism.

organism, produced by these two categorically different types of biotope. The experimental interface between the artificial milieu of living and the psychological organism is our measuring instrument, i.e. tasks that should be sensitive to changes in this biotiope as well as the reliable, valid measures of the psychological processes involved. In sum, and following Fig. 1, it is hypothesized that: (i) the luminous milieu, a local artificial milieu of living, may act as a mood inducer that induces different mood valences in subjects; and (ii) that their cognitive processes at hand may, in turn, be affected via these moods.

Recently, Baron *et al.* (1992) tried to show a similar line of affect, however, no effects of luminous conditions on mood were shown. Still, results were interpreted *as if* a positive mood was, indeed, at hand and mediated the lighting effects seen in cognitive performance! According to these authors, performance on a dependent measure within a luminous exposure condition gives results similar to results obtained on the same dependent measure, but within another condition where we know that a positive mood is present. It is possible, therefore, to conclude that mood accounts indirectly for the effects on performance in a luminous exposure condition, but the effects are *not* directly found. 'Together, these facts suggest that lighting conditions did indeed influence performance through the intervening variable of positive affect' (Baron *et al.*, 1992, p. 26). However, compare this with: 'Thus, there was no evidence . . . that subjects experienced differential affective reactions to the various lighting conditions' (Baron *et al.*, 1992, p. 10). This kind of argument should really be questioned, because if this line of reasoning was generally applied by the scientific establishment then *everything* could be assumed to account for a result as long as the scientist shows a parallel example-condition where that kind of result is produced.

Why did Baron *et al.* (1992) not obtain *direct* mood reactions to various lighting conditions? This is probably due to two major flaws in their experimental design, namely: (1) The affective state measure was administered after and *not* before exposure; (2) What was the exposure time? Subjects should stay in a luminous setting for at least a couple of hours in order to assure that if this variable really generates any kind of effects, a prolonged time exposure would test this hypothesis. This research is in its early stages and what we must do is first investigate whether lighting conditions induce emotional states *at all* and second, establish the exposure time limits (all or none, or incremental) for this physical variable's effect to be produced. Baron *et al.* (1992) did not specify the time exposure in their experiments. However, looking at what subjects did, they were probably exposed for around 20–40 min which is perhaps *not* sufficient for an emotional response.

Taken together: does a luminous setting act as a mood inducer and, if so, will these mood valences impair or enhance ongoing cognitive processes? Two experiments are designed in sufficient detail to investigate this issue. The first experiment varied three independent variables in a factorial, between-subject design: two illuminance levels (dim; 300 lx vs bright; 1500 lx) by two colour temperatures ('warm' white; 3000K-Kelvin vs 'cool' white; 4000K) by gender. Illuminance and colour temperature levels were chosen in order to investigate the results of preference studies (*cf.* Flynn, 1977) which indicated that subjects prefer dim vs bright and 'warm' vs 'cool' light. That is, dim illuminance and a 'warm' white light source may induce a positive mood more than bright illuminance and a 'cool' white light source if we translate preference measure as some kind of affective verbal report. The colour rendering parameter (Colour Rendering Index; CRI) which has been neglected, or not controlled in previous studies (*cf.* Baron *et al.*, 1992) is also included for investigation and applied across experiments. High CRI is employed across illuminance and colour temperature in experiment 1 compared to low CRI in experiment 2.

It must be noted that the 'warm' and 'cool' light sources refer to an chromatic scale diagram, where the colour temperature of white light sources range from 2700K to 6500K. At one end of this dimension-spectrum the light source is more *reddish* and, on the opposite side the light source is more *bluish*. Consequently, the reddish and bluish light sources' appearances are attributed as 'warm' and 'cool'.

Experiment 1

Method

Subjects. Ninety-six subjects, aged from 18 to 55 (recruited through the local press and radio advertisements) were paid 200 Swedish crowns (*c.* 30 U.S. dollars) to participate. They were randomly assigned to eight groups with 12 subjects in each.

Environmental setting. The experiment was conducted in a chamber-room (3·9 m × 3·8 m × 2·5 m) where physical variables such as heat and humidity were controlled by a computerised climate system. The chamber was furnished as an office, but without any exaggerated decor (see Fig. 1). In addition, a *neutral* room-coloration was applied. More precisely, the experimental room comprised (i) a big green flower placed in front of the subjects in a corner, (ii) two false windows with green curtains, (iii) green writing pads on the tables, and (iv) placed in front of the subjects, a personal computer (PC) on which the free recall task was run. Walls and ceiling were off-white, and the floor was off-white with grey, trailing patterns on its surface.

Apparatus. Six ceiling-mounted fluorescent luminaires containing four lamps each (Osram, 36W, L36/32, 3000K: 'warm' white vs L36/22, 4000K: 'cool' white; CRI = 95 for both colour temperatures) were installed. The illuminance levels were measured on subjects' tables (horizontal surface, by a Hagner Luxmeter (Model E2). These levels were varied by

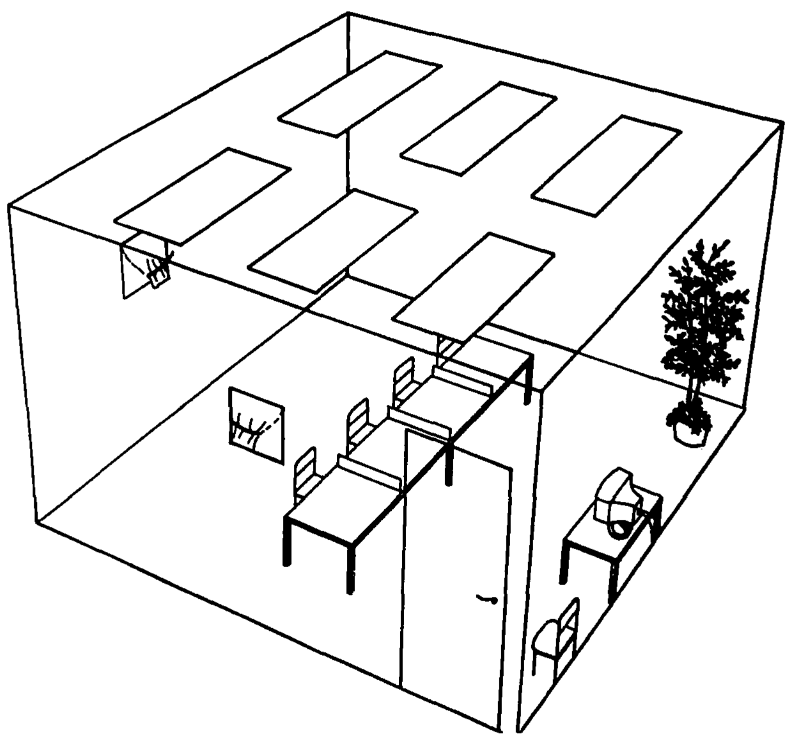

FIGURE 2. The experimental room, a chamber where the luminous milieu parameters were manipulated and other physical variables controlled.

muting the number of tubes from four to two in each luminary and the colour temperature was varied by changing lamps. They were all new and were on for 2 weeks before the experiments started. Before each experimental session the lamps were operated for 20–30 min in order to stabilize the illuminance. In addition, the following luminances (cd/m^2: surface light incident measured by a Hagner Universal Photometer—Model S2) were measured in the experimental room, across type of lamps and CRIs in 300 lx condition: table (*c.* 49 cd/m^2), writing pad (*c.* 34 cd/m^2), answer sheet paper (*c.* 85 cd/m^2), floor (*c.* 15 cd/m^2), PC-screen (*c.* 45 cd/m^2) and wall in front of subjects (*c.* 47 cd/m^2). For the 1500 lx condition the following luminances were measured: table (*c.* 245 cd/m^2), writing pad (*c.* 175 cd/m^2), answer sheet paper (*c.* 423 cd/m^2), floor (*c.* 66 cd/m^2), PC-screen (*c.* 65 cd/m^2) and wall in front of subjects (*c.* 225 cd/m^2). In sum, in going from 300 lx to 1500 lx all the luminance measure-points increased with approximately a factor of 5, except for the PC-screen luminance which increased with factor of 1·4. Hence, the PC-screen visibility should not account for the performance differences in free recall between the illuminance conditions.

Basic design and independent variables. The experiment followed a factorial, between-subject design with three independent variables: 2 (illuminance levels; 300 lx vs 1500 lx) × 2 (colour temperatures; 3000K vs 4000) × 2 (gender). Thus, there were four lighting conditions by gender.

Dependent variables. The study comprised four cognitive tasks, plus mood and room light evaluation measures: (1) Long-term recall and recognition tasks; seven pages of compressed text (Carter, 1982) about an ancient culture was used as an encoding–retrieval task. In the beginning of the experiment subjects read the text (encoding) and at the end (retrieval) they were asked to accomplish (i) six general knowledge questions (recall) and (ii) 18 multiple choice (recognition) questions about this text (Hygge, 1993).

(2) Problem-solving task; the embedded figure task (*cf.* Smith & Broadbent, 1980) measured the problem-solving performance (Hartley, 1989). Two answer sheets, each comprising five solution figures at the top and 16 target-figures (tasks) below constituted this task. The following instruction was given: 'Your task is to find one of five simple figures (A, B, C, D, E) in a more complex figure. Indicate your answer by marking the corresponding letter of a simple figure below the complex one. There is only one of these simpler figures in each complex figure. They will always be right side up and exactly the same size as one of the five lettered figures.'

(3) Free recall task; this task was evolved in order to employ a test of the mood-congruence phenomenon, i.e. a test of subjects' memory performance in relation to the valence of their mood and material to be learned (see Blaney, 1986 for a review). On a PC-screen subjects were shown three word-lists (containing 16 words each) with positive, negative and neutral affective tones. Words in all three lists were equally frequent in the Swedish language (Allen, 1970) and they were composed of 5–8 letters. The order of list presentation was randomized across subjects. After each list presentation the subjects' task was to write down directly after the last word (which was always followed by an instruction-word 'stop') all the words on an answer sheet (in no particular order), which they had just seen on the PC-screen.

(4) Performance appraisal task; the present performance appraisal task contained only neutral information about a fictitious employee (Baron *et al.*, 1992), in order to investigate a mood-congruence effect: if a rater feels good or bad does he/she ascribe this mood valence to neutral task information by evaluating a fictitious ratee in accordance with that mood? Subjects were instructed that they should imagine they are working in a company where their job is to evaluate employees occasionally for the company management (an 'independent-evaluator'). The task comprises two pages: (i) a female secretary's personnel folder containing neutral characteristics, i.e. balanced positive and negative information, (ii) an evaluation sheet, where judgements are made on a 7-point scale including the following dimensions: qualifications for current job, work-related skills, motivation, attitude to the job, work-related achievement, intelligence, concern with the work-related instructions, ability to get along with others, deserves a promotion, overall evaluation.

(5) Mood measure; in the beginning of the experiment and after *c.* 85 min of luminous exposure, subjects completed a current affective state questionnaire (Watson *et al.* 1988); PANAS (Positive Affect Negative Effect Scales). This mood measure comprises 10 items (adjectives) per emotional dimension that are orthogonal, i.e. adjectives constituting positive and negative dimensions of mood have, according to Watson *et al.* (1988), considerable loadings on a related emotional dimension but near zero on the opposite one. Moreover: '(PA) reflects the extent to which a person feels enthusiastic, active and alert . . . (NA) is a general dimension of subjective distress and unpleasurable engagement that subsumes a variety of aversive mood states' (Watson

et al., 1988, p. 1063). Ratings are made on a 5-point scale (related to the question: 'How do you feel now?') ranging from 1: 'little, or not at all' to 5: 'very much'.

(6) Room light evaluation measure; after the completion of tasks and mood scales, subjects were asked to evaluate the room light. This questionnaire was evolved in order to obtain a complementary measure to the experimental manipulations. Hence, to relate subjective–objective assessments of the luminous milieu (see Rea, 1982; Tiller, 1990 for this discussion) and to investigate the between-gender discrimination ability of the room light conditions. The task comprised seven 5-point, unipolar items. Bipolar items were not used in order to avoid range effects (Poulton, 1975), i.e. an observer bias which lead to middle-range evaluations. The items (adjectives) were selected in order to permit subjects to attribute their assessments to the experimentally manipulated lighting parameters. The following adjectives constituted the questionnaire: glaring, dim, soft, bright, warm, intense and cool. The question was: 'How would you evaluate the room light?'

Procedure. The subjects were informed that their general task was to work with several cognitive tasks namely, memory, problem-solving and judgement tasks. Furthermore, they were told that there was enough time for each subtask and that they would be given a subinstruction and time limit for the very next task. According to a pilot study, the following time limits were given: text reading (35 min), PANAS (5 min), room light evaluation (5 min), embedded figure task (35 min), free recall task (5 min) performance appraisal task (10 min), text answers (20 min). All together (including the instructions) the experiment lasted for *c.* 120 min. Two to four subjects were run at each session (see Fig. 2). Due to some tasks' characteristics, the following chronological order of tasks and questionnaires was administered across all groups and subjects: (1) PANAS (an initial affective state test, i.e. before exposure); (2) Text-reading (first task, because it measures a long-term recall and recognition, i.e. there has to be as long a time interval as possible between encoding and retrieval); (3) Problem-solving task (it comes in third position so as to prolong the light exposure time); (4) Free recall task (relates to PANAS); (5) PANAS (after *c.* 85 min exposure test); (6) Performance appraisal task (relates also to PANAS); (7) Long-term recall and recognition task (115 min after the process of encoding started and *c.* 75 min after its completion); (8) Room light evaluation (logically the last task after subjects' completion of cognitive and mood measures).

TABLE 1

Mean room light evaluations and cell standard deviations (in parentheses) on seven dimensions as a function of illuminance level (300 lx vs 1500 lx)

Estimation dimensions	Illuminance		p
	300 lx	1500 lx	
Glaring	1·69 (1·07)	2·19 (1·24)	0·038
Dim	2·27 (1·21)	1·60 (0·92)	0·003
Soft	2·02 (0·95)	1·40 (0·82)	0·001
Bright	2·69 (1·09)	3·38 (1·05)	0·002
Warm	2·06 (1·15)	1·71 (1·01)	N.S.
Intense	2·35 (1·19)	3·21 (1·31)	0·001
Cool	2·73 (1·31)	2·79 (1·28)	N.S.

Results

Room light estimation

For each evaluation-dimension, the subjects' scores were analysed by an analysis of variance including the basic design independent variables.

Glaring. There were main effects of illuminance $F(1, 88) = 4{\cdot}57$, $p < 0{\cdot}05$ and gender $F(1, 88) = 4{\cdot}57$, $p < 0{\cdot}05$. These results showed that low illuminance was estimated as less glaring (see Table 1) than high illuminance, and females estimated the room light as significantly more glaring than males regardless of illuminances and colour temperatures (see Table 2).

Dim. There were main effects of illuminance $F(1, 88) = 10{\cdot}33$, $p < 0{\cdot}01$ and gender $F(1, 88) = 14{\cdot}57$, $p < 0{\cdot}01$ (see Tables 1 and 2). Subjects estimated the low compared to the high illuminance conditions as significantly more dim, and females estimated the room light across all conditions as significantly less dim than males.

TABLE 2

Mean room light evaluations and cell standard deviations (in parentheses) on seven dimensions as a function of gender

Estimation dimensions	Genders		p
	females	males	
Glaring	2·19 (1·25)	1·69 (1·01)	0·035
Dim	1·54 (0·80)	2·33 (1·17)	0·000
Soft	1·52 (0·75)	1·90 (0·98)	0·041
Bright	3·17 (1·06)	2·90 (1·02)	N.S.
Warm	1·94 (1·16)	1·83 (0·99)	N.S.
Intense	3·19 (1·18)	2·38 (1·17)	0·001
Cool	2·92 (1·16)	2·60 (1·20)	N.S.

Soft. Also in this dimension the results illustrated the same kinds of effects, i.e. main effects of illuminance $F(1, 88) = 11{\cdot}90$, $p < 0{\cdot}01$ and gender $F(1, 88) = 4{\cdot}28$, $p < 0{\cdot}05$. Hence a 300 lx condition was estimated as signficantly softer than a 1500 lx condition. Compared to males, females evaluated the room light, across all conditions, as less soft.

Intense. There were main effects of illuminance $F(1, 88) = 12{\cdot}27$, $p < 0{\cdot}01$ and gender $F(1, 88) = 11{\cdot}10$, $p < 0{\cdot}01$. Also on this dimension subjects reacted consistently in regards to their discrimination ability and gender. Consequently, low illuminance conditions were estimated as less intense than high illuminance conditions and females evaluated the room light regardless of illuminances and colour temperatures, as more intense than males.

Bright. A main effect of illuminance $F(1, 88) = 10{\cdot}28$, $p < 0{\cdot}01$ showed that subjects estimated a 1500 lx condition as significantly more bright than a 300 lx condition.

Cool. An interaction between colour temperature and gender $F(1, 88) = 8{\cdot}74$, $p < 0{\cdot}01$ showed that females estimated the 'warm' white light source as significantly cooler than the 'cool' one, regardless of the illuminance levels. The opposite results were obtained for males. It must be noted, however, that no significant effects whatsoever regarding the *warm* dimension was obtained.

Mood

According to Ericsson and Simon (1980) subjects do provide accurate verbal data if retrospective reports are not required, i.e. if the information that subjects are asked to introspect is in focal attention. This article employs just such a verbal report instrument for mood states which, in addition, means that mood is measured at a mood-cognitive-component level, in contrast to a somatic one (see Figure 1). The PANAS instrument was handed out in the beginning of the experiment and after *c*. 90 min of light exposure. This was done in order to permit a basic design analysis computed with block 2 minus block 1 scores as a dependent measure.

Positive mood. There were no significant results.

Negative mood. A significant interaction between colour temperature and gender was obtained, $F(1, 88) = 7{\cdot}13$, $p < 0{\cdot}01$. As can be seen in Fig. 3, females' negative mood decreased in the 'warm' and increased in the 'cool' white light source. Males' negative mood, on the contrary, increased dramatically in the 'warm' compared to the 'cool' condition.

Problem-solving

Subjects' scores were subjected to an analysis of variance, which comprised the basic design independent variables.

An interaction between colour temperature and gender $F(1, 88) = 4{\cdot}28$, $p < 0{\cdot}05$ showed that females performed significantly better in the 'warm' than in the 'cool' white light source, and the opposite result was yielded for males (see Fig. 4).

Long-term recall and recognition

The range of points per question in recall was 0 to 3 and in recognition 0 to 1. In the recall, two indepen-

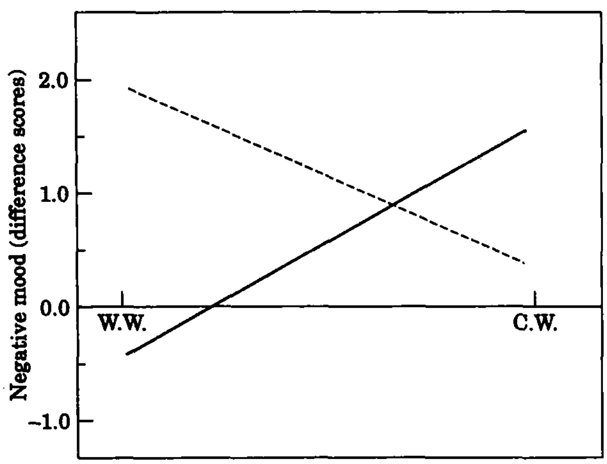

FIGURE 3. Mean negative mood in respective gender, as a function of 'warm' (w.w.) and 'cool' (c.w.) white light source (⊢—⊣ = ♀; ⊢ – ⊣ = ♂.)

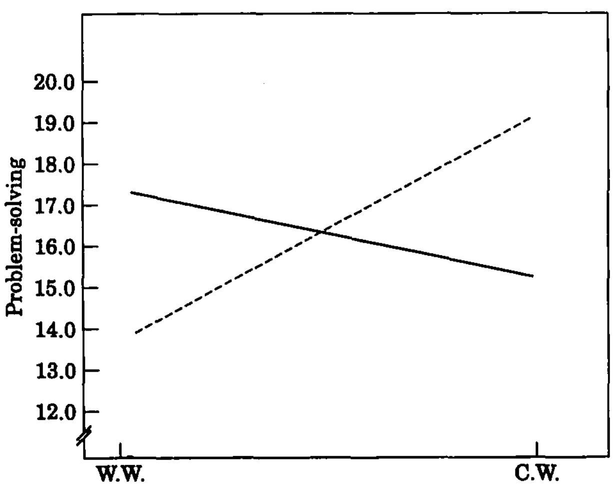

FIGURE 4. Mean problem-solving performance in respective gender, as a function of 'warm' (w.w.) and 'cool' white (c.w.) light source. (⊢—⊣ = ♀; ⊢ – ⊣ = ♂.)

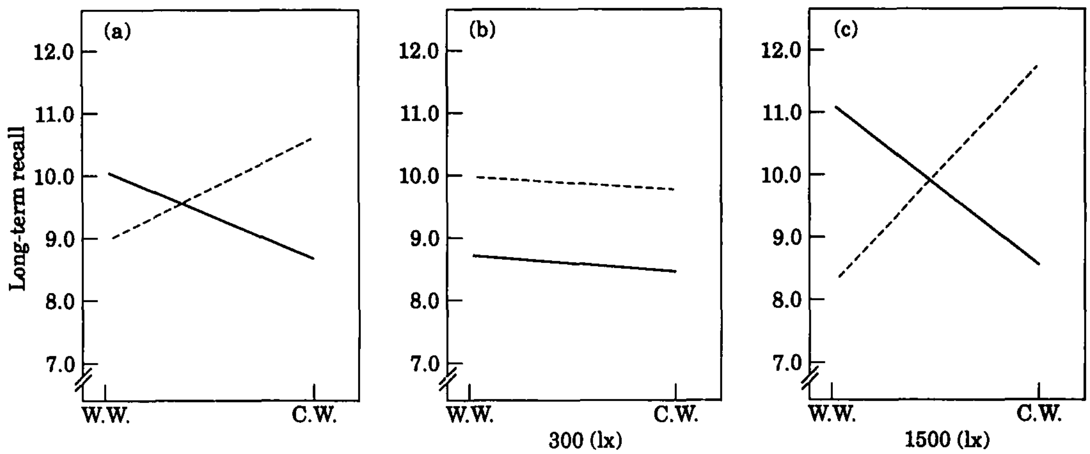

FIGURE 5. Mean long-term recall performance in respective gender, as a function of 'warm' (w.w.) and 'cool' (c.w.) white light source (a), in low (b) and high (c) illuminance conditions. (⊢—⊣ = ♀; ⊢--⊣ = ♂.)

dent judges arrived at 18 conflicting cases out of 576 (6 × 96) possible recall questions. Every conflicting case was later randomly classified as one of the conflicting answer-points (e.g. 2 or 3 points for a given answer). This gives an inter-judge reliability of 0·97 (576 minus 18 by 576). Subjects' long-term recall and recognition scores were subjected to an analysis of variance, involving the basic design independent variables.

Recall. Results showed two significant interactions, namely colour temperature by gender $F(1, 88) = 3{\cdot}92$, $p < 0{\cdot}05$ (see Fig. 5a) and colour temperature by illuminance by gender $F(1, 88) = 3{\cdot}70$, $p < 0{\cdot}05$ (see Fig. 5b, c). As can be seen in Fig. 5a, the genders performed significantly better in a room light condition that induced the least negative mood in each respective gender (compare Figs 3 and 5a).

In the 1500 lx condition (see Fig. 5c), the three-way interaction was consistent with the previously shown interactions between colour temperature and gender on problem-solving (see Fig. 4). However, in the low illuminance condition (see Fig. 5b) males produced higher recall scores than females in both colour temperature conditions. This means that the high illuminance condition accounted for the two-way interaction results between colour temperature and gender on long-term recall.

Recognition. There was only one significant result, a three-way interaction between colour temperature, illuminance and gender $F(1, 88) = 4{\cdot}45$,

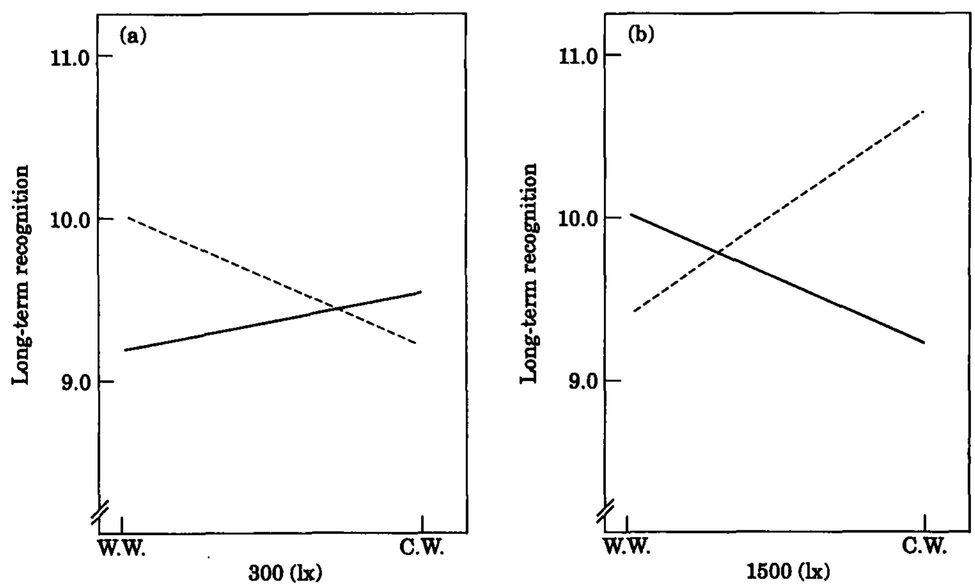

FIGURE 6. Mean long-term recognition performance in respective gender, as a function of 'warm' (w.w.) and 'cool' (c.w.) white light source, in low (a) and high (b) illuminance conditions. (⊢—⊣ = ♀; ⊢--⊣ = ♂.)

$p < 0{\cdot}05$. In the low illuminance condition (see Fig. 6a) males performed better in 'warm' than in 'cool' light source. The result in the high illuminance condition was similar to the results in the previous cognitive tasks (compare Figs 4, 5a, 5c and 6b).

Free recall

The subject's retrieval scores were subjected to an analysis of variance involving the following four independent variables; 2 (colour temperatures) 2 (illuminance levels) 2 (gender) 3 (lists: positive word-list, negative word-list, neutral word-list) with the last variable as a within-subject factor.

The results revealed two main effects, namely a main effect of type of list $F(2, 176) = 7{\cdot}01$, $p < 0{\cdot}01$ and a main effect of gender $F(1, 88) = 3{\cdot}95$, $p < 0{\cdot}05$. The subjects recalled more words from a positive than a negative word-list. On the other hand, there was practically no difference in free recall performance from the positive and neutral word-lists. Females were better in free recall than males (see Fig. 7).

Performance appraisal

For each estimation-dimension, the subjects' scores were subjected to an analysis of variance which included the basic design independent variables.

Ability to get along with others. Results showed two main effects, that of illuminance $F(1, 88) = 4{\cdot}66$, $p < 0{\cdot}05$ and gender $F(1, 88) = 3{\cdot}97$, $p < 0{\cdot}05$. Hence,

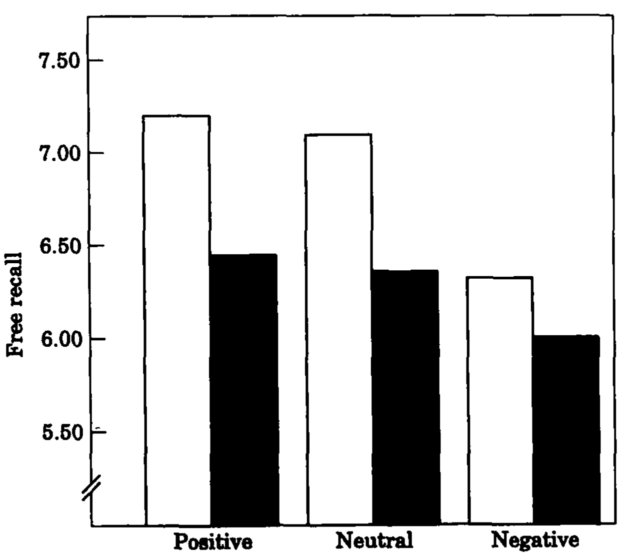

FIGURE 7. Mean free recall performance in respective gender, as a function of to-be-remembered list comprising words of positive, neutral and negative valences. (■ = ♂; □ = ♀.)

raters judged the fictitious employee as having more of the ability in 1500 lx ($M = 4{\cdot}17$) than in 300 lx ($M = 3{\cdot}63$) condition. Furthermore, male ($M = 4{\cdot}15$) compared to female raters ($M = 3{\cdot}65$) ascribed significantly higher scores in this quality to the fictitious female secretary.

Deserves a promotion. The analysis indicated a main effect of illuminance $F(1, 88) = 5{\cdot}44$, $p < 0{\cdot}05$ and a tendency to a main effect of gender $F(1, 88) = 3{\cdot}44$, $p < 0{\cdot}06$. Subjects rated the female secretary significantly higher in 1500 lx ($M = 3{\cdot}71$) compared to 300 lx ($M = 3{\cdot}13$) and males judged her as deserving a promotion to a higher degree than did females ($M = 3{\cdot}65$ vs $M = 3{\cdot}19$). In the two following evaluation dimensions the results illustrated the same tendency (i.e. slightly below 5% level of significance) towards a main effect of gender.

Overall sum rating. There was a tendency to a significant main effect of gender $F(1, 88) = 3{\cdot}05$, $p < 0{\cdot}08$ which means that male raters, generally, across all estimation dimensions rated the female fictitious employee higher than female raters did, ($\Sigma = 45{\cdot}50$ vs $\Sigma = 42{\cdot}44$).

Work-related achievement. A main effect of gender $F(1, 88) = 3{\cdot}09$, $p < 0{\cdot}08$ showed that males, once again, in comparison with females, rated the ratee higher ($M = 4{\cdot}25$ vs $M = 3{\cdot}90$).

Attitude to the job. A significant interaction between colour temperature and illuminance was found $F(1, 88) = 5{\cdot}19$, $p < 0{\cdot}05$. In the 'warm' white light source subjects estimated the appraisee as having a better attitude to her job in the 1500 lx ($M = 3{\cdot}79$) than in the 300 lx condition ($M = 3{\cdot}21$). In the 'cool' white light source the opposite result was obtained (1500 lx; $M = 3{\cdot}54$ vs 300 lx; $M = 3{\cdot}79$).

Discussion

The subjects proved to be good and consistent in evaluating illuminance levels, i.e. their discriminating ability was well calibrated on the following five dimensions: glaring, dim, soft, bright and intense (Table 1). The room light in general was consistently evaluated differently by females and males (Table 2).

As hypothesized, the luminous milieu acted as a mood inducer. Thus, it changed mood in subjects. More precisely, an interaction between colour temperature and gender showed that the 'cool' room light induced least negative mood in males, and that the 'warm' room light accounted for the same effect in females.

The problem-solving, long-term recall and recognition results revealed a similar two-way interaction between colour temperature and gender. That is, females' problem-solving (Fig. 4) and long-term memory performances were significantly enhanced in the 'warm' white light source compared to 'cool' conditions where these processes were impaired, but enhanced for males. As regards the long-term memory performance, this was particularly present in the high illuminance condition (Figs 5c and 6b). In sum, the results revealed a two-way interaction between colour temperature and gender on (ii) negative mood and (iii) problem-solving and long-term recall and recognition.

The results concerning free recall were not in line with the above results (Fig. 7). A main effect of word-list showed that subjects recalled most words from the positive word-list and least from the negative one. This supports the mood-congruence hypothesis if we take into account that subjects were, indeed, mostly induced in a positive mood (block 2: positive mood, 26·93 vs negative mood, 12·64). The main effect of gender on free recall is more problematic to interpret because, females and males were equally induced in each respective mood, as regard the block 2 scores, and the data did not reveal any interaction between gender and word-list. A speculative interpretation, however, is that an equal state of affect can be differently assessed—measured as a mediation effect on a cognitive process (in this case free recall).

As mentioned, subjects were in a positive mood and their performance appraisal task contained only neutral information about a fictitious ratee. Hence, we would expected an *overestimation* bias. That is, in accordance with the subjects' positive mood they should have ascribed higher scores to a *neutral* ratee. Yet, compared with male raters, female raters ascribed less favorable abilities to the female appraisee which may be interpreted tentatively as a *halo* effect (see Cooper, 1981 for a review).

Experiment 2

In experiment 1, colour temperature and illuminance were manipulated at high CRI. In experiment 2, these manipulations were applied at low CRI. This parameter has previously been investigated, for example in relation to room-coloration and visual clarity (e.g. Bellchambers & Godby, 1972; Boyce, 1977), however, it has not been clearly addressed in the more stringent light exposure experiments (cf. Baron *et al.*, 1992). The objective of experiment 2 was to investigate whether the hypothesized line of affect from luminous milieu on cognition via mood, and obtained in experiment 1, is also present when colour temperature and illuminance are manipulated at low CRI.

Method

Subjects. Ninety-six subjects, aged 18–55, participated in the experiment. They were randomly divided into light source and illuminance groups. Hence, eight between-subject groups containing 12 subjects each took part in the experiment.

Environmental setting. The setting was identical to that of experiment 1 (see Fig. 3 for details).

Apparatus. Six ceiling-mounted fluorescent luminaires containing four fluorescent tubes each were installed (General Electric, 36W, F36/29, 2950K, CRI = 51: 'warm' vs F36/33, 4200K, CRI = 58: 'cool' white light source). All luminances, measures and procedures were identical to that of experiment 1.

Basic design and independent variables. As in experiment 1, three independent (between-subject factors) variables constituted the basic design, namely: 2 (colour temperatures; 2950K vs 4200K) × 2 (illuminances; 300 lx vs 1500 lx) × 2 (females vs males).

Dependent variables. Identical tasks to that of experiment 1 were used.

Procedure. This section was identical to that of experiment 1.

Results

Room light estimation

Dim. There was only one significant result, that of a main effect of illuminance $F(1, 88) = 16{\cdot}77$, $p < 0{\cdot}01$. Subjects evaluated, independently of colour temperatures, the low illuminance condition as more dim than the high one (see Table 3).

Soft. A main effect of illuminance $F(1, 88) = 12{\cdot}37$, $p < 0{\cdot}01$ showed that subjects estimated the low

TABLE 3
Mean room light evaluations and cell standard deviations (in parentheses) on seven dimensions as a function of illuminance level (300 lx vs 1500 lx)

Estimation dimensions	Illuminance		p
	300 lx	1500 lx	
Glare	1·79 (1·14)	1·98 (1·23)	N.S.
Dim	2·35 (1·26)	1·46 (0·80)	0·000
Soft	1·83 (1·04)	1·21 (0·57)	0·001
Bright	2·77 (1·21)	3·75 (1·06)	0·000
Warm	1·67 (1·04)	1·67 (0·95)	N.S.
Intense	2·46 (1·33)	3·10 (1·16)	0·014
Cool	3·04 (1·52)	2·75 (0·58)	N.S.

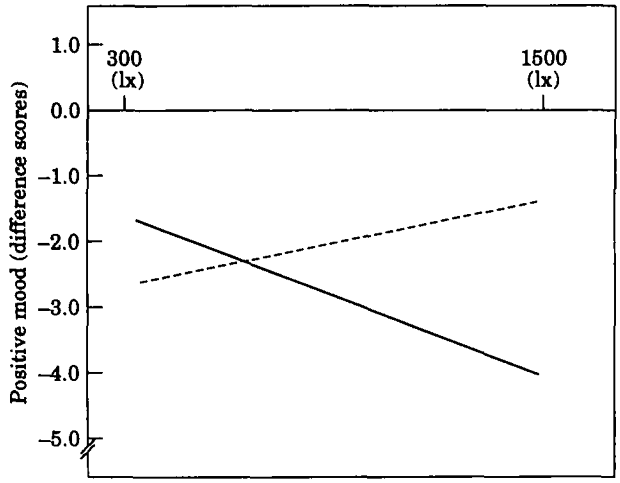

FIGURE 8. Mean positive mood in respective light source, as a function of low and high illuminance. (⊢—⊣ = c.w.; ⊢ – ⊣ = w.w.)

illuminance condition as significantly softer than the high one (see Table 3).

Intense. Also in this condition the result revealed the same effect, that of a main effect of illuminance $F(1, 88) = 6{\cdot}30$, $p < 0{\cdot}01$ (see Table 3). The high illuminance condition was estimated as significantly more intense than the low one.

Bright. The results showed two main effects, that of illuminance $F(1, 88) = 17{\cdot}22$, $p < 0{\cdot}01$ and colour temperature $F(1, 88) = 6{\cdot}56$, $p < 0{\cdot}01$. Subjects estimated the high illuminance condition as brighter than the low one (see Table 3) and the 'cool' white light source as brighter than the 'warm' one.

Mood

Positive mood. A two-way interaction between colour temperature and gender $F(1, 88) = 4{\cdot}20$, $p < 0{\cdot}05$ was obtained (see Fig. 8). As can be seen in Fig. 8, the 'cool' white colour temperature at low illuminance and the 'warm' white colour temperature at high illuminance preserved best the positive mood in subjects.

Negative mood. No significant results were obtained.

Problem-solving

A two-way interaction between colour temperature and illuminance $F(1, 88) = 3{\cdot}66$, $p < 0{\cdot}06$ showed that subjects' problem-solving performance varied with light source conditions that preserved best the positive mood (compare Figs 8 and 9).

Hence, the 'warm' white light source at 300 lx illuminance and the 'cool' white light source at 1500 lx illuminance showed to be optimal for subjects' problem-solving.

Long-term recall and recognition

The inter-judge reliability in long-term recall (two independent judges) was 0·99 (576 answers *minus* 5 conflicting cases *by* 576; see experiment 1 for details concerning this kind of reasoning).

Recall. No significant results were obtained.

Recognition. Consistent with experiment 1 (see Fig. 6b), an interaction between colour temperature and gender $F(1, 88) = 5{\cdot}12$, $p < 0{\cdot}05$ showed that females performed better in the 'warm' white light source than the 'cool' one, and the opposite result was true for males.

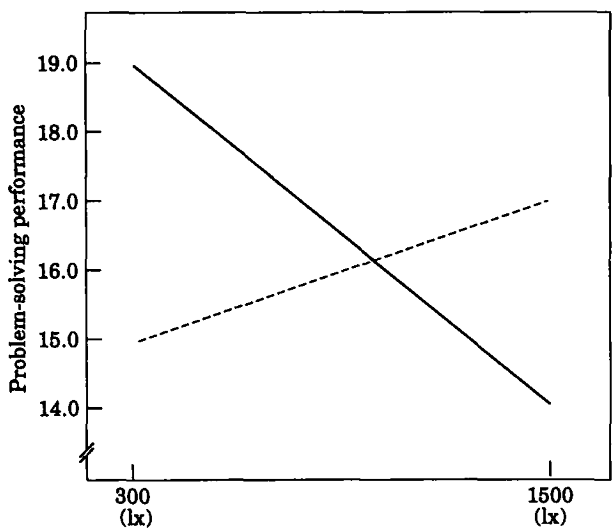

FIGURE 9. Mean problem-solving performance in respective light source, as a function of illuminance. (⊢—⊣ = c.w.; ⊢ – ⊣ = w.w.)

Free recall

Consistent with experiment 1, results showed the main effects of word-list $F(2, 176) = 3{\cdot}94$, $p < 0{\cdot}05$ and gender $F(1, 88) = 5{\cdot}96$, $p < 0{\cdot}05$. Thus, subjects recalled more positive than negative words from the respective word-list, as they should according to the mood-congruence hypothesis, and again females performed better than males. In addition, there was an interaction between colour temperature and illuminance $F(1, 88) = 5{\cdot}58$, $p < 0{\cdot}05$. This result followed a similar line of affect as illustrated in the positive mood and problem-solving sections; namely, the room light conditions (colour temperature crossed with illuminance) that produced best preservation of the positive mood in subjects, enhanced their problem-solving and free recall performances.

Performance appraisal

Work-related skills. There was a main effect of gender $F(1, 88) = 4{\cdot}19$, $p < 0{\cdot}05$. In comparison with male raters, female raters evaluated the ratee as having shown significantly more work-related skills.

Motivation. A significant interaction between illuminance and gender $F(1, 88) = 5{\cdot}30$, $p < 0{\cdot}05$ showed that more female than male raters evaluated the appraisee as more motivated, in the 300 lx condition.

Attitude to the job. A two-way interaction between illuminance and gender $F(1, 88) = 4{\cdot}82$, $p < 0{\cdot}05$ showed that more female than male raters judged the ratee more favourably in the low than in the high illuminance condition, where almost no difference between the genders occurred.

Intelligence. A main effect of gender $F(1, 88) = 5{\cdot}48$, $p < 0{\cdot}05$ showed that, female in comparison to male raters evaluated the appraisee as more intelligent.

Discussion

Concerning the illuminance levels, subjects' discrimination ability was shown to be consistent with the results of experiment 1 (compare Tables 1 and 3). However, no gender effect was obtained. This means that the room light conditions ('warm' and 'cool' white light sources combined with 300 lx and 1500 lx illuminances) at low CRI were not *distinct* enough (or another *unknown* characteristic of a low CRI) to produce a gender difference on room light evaluations.

Mood was, indeed, induced in subjects, but results differed from those in the former experiment. Positive mood was best preserved in the 'warm' white light source at 300 lx and in the 'cool' white light source at 1500 lx.

An interaction between colour temperature and illuminance showed that the problem-solving performance was enhanced in the room light condition that accounted for best preservation of the positive mood (compare Figs 8 and 9).

There was no significant result involved in long-term recall. Only long-term recognition results proved consistent in some respect with those obtained in the former experiment. Following Tulving's (1976) reasoning, this may imply that the room light at low CRI did not produce appropriate context cues to enhance the processes of long-term recall and recognition.

Free recall results revealed a consistency with results from experiment 1 and an extension of those results. A main effect of word-list supported the mood-congruence hypothesis and an interaction between colour temperature and illuminance showed that the room light conditions, that produced best preservation of the positive mood accounted for an optimal free recall performance—as they did for problem-solving.

Results in the performance appraisal task differed radically from those in the previous experiment. However, they proved consistent in some respect with a halo-gender effect interpretation.

General Conclusions

The general aim was to investigate the hypothesized line of affect from luminous milieu on cognitive performance via mood, by two stringent light exposure experiments.

Results in experiment 1 showed that a luminous milieu which induced the least negative mood enhanced performance in the long-term recall, recognition and problem-solving tasks, in each gender respectively. In experiment 2, on the other hand, the luminous milieu which accounted for best preservation of the positive mood yielded the same effects in problem-solving and free recall tasks.

Free recall results, in both experiments, revealed a mood-congruence effect. The results obtained in experiment 1 in long-term recall and recognition tasks showed that both retrieval processes were affected in accordance with a congruent incongruent mood valence (Isen, 1984). This suggests, in addition, that highly structured material to-be-learned was, indeed, sensitive to memory–mood effects (see Ellis & Ashbrook, 1991 for an opposite prediction).

Concerning the performance appraisal task, results indicate a halo effect. That is, a rater bias which leads to an overall impression of an appraisee derived from, e.g. some trait or salient characteristic of that appraisee. One obvious such information cue available in this context is the ratee's gender. It must be noted, however, that in the present experiments we had only one gender represented on the ratee side and consequently a future study should investigate this in more detail by varying both genders and mood valences on the rater side and both genders on the ratee side in order to attain more conclusive data about this effect.

Taken together, the results obtained question the conclusion of previous studies that subjects prefer 'warm' and dim versus 'cool' and bright light (e.g. Flynn, 1977; Baron *et al.*, 1992). Instead, the subjects' mood valences and their cognitive performance *varied* significantly with the genders' emotionally different reactions to the colour temperature (experiment 1) and combinations of colour temperature and illuminance (experiment 2) at different CRIs. In practice, this implies that the criteria for *good* indoor lighting may be revised, taking into account females' and males' emotional and cognitive responses as well.

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References

Allen, S. (1970). *Frequency Dictionary of Present-day Swedish*. Stockholm: Almqvist & Wiksell.

Baron, R. A., Rea, M. S. & Daniels, S. G. (1992). Effects of indoor lighting (illuminance and spectral distribution) on the performance of cognitive tasks and interpersonal behaviors: the potential mediating role of positive affect. *Motivation and Emotion*, **1**, 1–33.

Bellchambers, H. E. & Godby, A. C. (1972). Illumination, colour rendering and visual clarity. *Lighting Research and Technology*, **4**, 104.

Biner, P. M., Butler, D. L., Fischer, A. R. & Westergren, A. J. (1989). An arousal optimization model of lighting level preferences: an interaction of social situation and task demands. *Environment and Behavior*, **1**, 3–16.

Blaney, P. H. (1986). Affect and memory: a review. *Psychological Bulletin*, **99**, 229–246.

Boyce, P. R. (1977). Investigations of the subjective balance between illuminance and lamp colour properties. *Lighting Research and Technology*, **9**, 7.

Boyce, P. R. (1981). *Human Factors in Lighting*. London: Applied Science Publishers.

Butler, D. L. & Biner, P. M. (1987). Preferred lighting levels: variability among settings, behaviors, and individuals. *Environment and Behavior*, **6**, 695–721.

Carter, R. (1982). *Äldre Kulturer*. Stockholm: Natur och Kultur.

Cooper, W. H. (1981). Ubiquitous halo: sources, solutions, and a paradox. *Psychological Bulletin*, **90**, 218–244.

Ellis, H. C. & Ashbrook, P. W. (1991). The 'state' of mood and memory research: A selective review. In D. Kuiken, Ed., *Mood and Memory, Theory, Research and Applications*. London: Sage Publications, pp. 1–21.

Ericsson, K. A. & Simon, H. A. (1980). Verbal reports as data. *Psychological Review*, **87**, 215–251.

Flynn, J. E. (1977). A study of subjective responses to low energy and nonuniform lighting systems. *Lighting Design and Application*, **7**, 6–15.

Galer, I. A. R., Ed. (1987). *Applied Ergonomics Handbook*. London: Butterworths.

Gifford, R. (1988). Light, decor, arousal, comfort and communication. *Journal of Environmental Psychology*, **8**, 177–189.

Hartley, A. A. (1989). The cognitive ecology of problem solving. In L. W. Poon, D. C. Rubin & B. A. Wilson, Eds, *Everyday Cognition in Adulthood and Late Life*. Cambridge: Cambridge University Press, pp. 300–329.

Heerwagen, J. H. (1990). Affective functioning, 'light hunger', and room brightness preferences. *Environment and Behavior*, **5**, 608–635.

Hygge, S. (1993). A comparison between noise from aircraft, road traffic and trains on long-term recall and recognition of a text in children aged 12–14 years. In H. Ising & B. Kruppa, Eds, *Noise and Disease*. Stuttgard: Gustav Fischer Verlag, pp. 422–427.

Isen, A. M. (1984). Toward understanding the role of affect in cognition. In R. Wyer & T. Srull, Eds, *Handbook of Social Cognition*. Hillsdale, NJ: Erlbaum, pp. 179–236.

Megaw, E. (1992). The visual environment. In A. P. Smith & D. M. Jones, Eds, *Handbook of Human Performance, Volume 1: The Physical Environment*. London: Academic Press, pp. 261–296.

Poulton, E. C. (1975). Observer bias. *Applied Ergonomics*, **1**, 3–8.

Rea, M. S. (1982). Calibration of subjective scaling responses. *Lighting Research & Technology*, **14**, 121–129.

Smith, A. P. & Broadbent, D. E. (1980). Effect of noise on performance on embedded figure tasks. *Journal of Applied Psychology*, **2**, 246–248.

Tiller, D. K. (1990). Toward a deeper understanding of psychological aspects of lighting. *Journal of the Illuminating Engineering Society*, **2**, 59–65.

Tulving, E. (1976). Ecphoric processes in recall and recognition. In J. Brown, Ed., *Recall and Recognition*. London: Wiley, pp. 37–73.

Veitch, J. A. & Kaye, S. M. (1988). Illumination effects on conversational sound levels and job candidate evaluation. *Journal of Environmental Psychology*, **8**, 223–233.

Veitch, J. A., Gifford, R. & Hine, D. W. (1991). Demand characteristics and full spectrum lighting effects on performance and mood. *Journal of Environmental Psychology*, **11**, 87–95.

Watson, D., Clark, L. A. & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: the PANAS scales. *Journal of Personality and Social Psychology*, **54**, 1063–1070.

Webster, N. (1968). *Webster's Third New International Diction-ary*. Springfield, Massachusetts: G & C Merriam Company, Publishers.

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