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REVISITING THE PERFORMANCE AND MOOD EFFECTS OF INFORMATION ABOUT LIGHTING AND FLUORESCENT LAMP TYPE[1]

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Abstract
Popular articles and manufacturers' literature assert that full-spectrum fluorescent lighting improves cognitive performance, vision, and mood. Previous experimental investigations have failed to demonstrate these effects. This paper reports an attempt to replicate work by Veitch, Gifford, and Hine (1991) concerning the effects of information sets about lighting on performance and mood. In this 2 (lamp type) x 4 (information sets) x 2 (gender) factorial experiment, 104 male and 104 female participants were led to expect good, poor, or indifferent outcomes of working under full-spectrum or cool-white fluorescent lighting, or they were not given any information. There were no effects of lamp type or information set on performance or mood. The results are discussed in relation to other evidence that cognitive processes mediate lighting-behaviour relationships.

Introduction

One persistent report in advertising media and some trade journals is that fluorescent lighting that is similar to natural daylight (commonly called *full-spectrum* lighting[3]) is superior to other types of fluorescent lighting in terms of health and productivity effects. For example, advertising material obtained in 1994 from an exhibitor at a major psychological convention stated that their lamp "is the only patented ... general purpose fluorescent lamp that simulates natural daylight. This simulation is a major asset toward creating the perfect interior lighted environment" (Anonymous, 1988). The brochure continues by describing anecdotal and unreviewed evidence that people "feel better, are more alert, see better, and perform better" under this manufacturer's lamps.

Controlled experimental attempts to demonstrate the claims made by the proponents of full-spectrum lighting provide no support for such effects (e.g., Boray, Gifford, & Rosenblood, 1989; Boyce & Rea, 1994; Veitch, Gifford, & Hine, 1991). Reviews of the literature find no compelling support for any of the performance, mood, or health effects attributed to full-spectrum fluorescent lighting, with the exception of fine colour discriminations, which are more accurately performed under light sources with high colour rendering indices, including full-spectrum fluorescent lamps (Boyce, 1994; Veitch & McColl, 1994, 1997). One reason for the null results is the generally poor quality of much of the research in this field; as Gifford (1994) observed, "many full-spectrum lighting studies have Achilles' heels all over their bodies!" (p. 38).

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[3] There is no industry-wide definition of a full-spectrum fluorescent lamp; for this study, Boyce's (1994) definition is used: a full-spectrum lamp is a fluorescent lamp having a Colour Rendering Index (CRI) greater than 90 and a Correlated Colour Temperature (CCT) greater than 5000 Kelvin, emissions throughout the visible spectrum and some in the near-ultraviolet (UVA).

Veitch et al. (1991) tested the hypothesis that beliefs about full-spectrum lighting, rather than the lamp type itself, underlie the persistent anecdotal reports: Perhaps people report working and feeling better under full-spectrum lamps because they expect to, particularly if they have been exposed to manufacturers' literature such as that described above. The study showed that when existing lighting beliefs were statistically controlled, both favourable and unfavourable information about full-spectrum lighting led to improved reading performance and increased self-reported arousal. There was no effect of lamp type on any dependent measure.

Veitch et al. (1991) suggested that two separate mechanisms might have operated in such a way as to cause performance improvements following exposure to either positive or negative information about full-spectrum lighting. The positive information effect might reflect the operation of demand characteristics, in which the subjects responded as they were expected to respond. The negative information condition was, in fact, an "indifferent information" condition in that it attempted to discredit manufacturers' claims, rather than creating expectancies about undesirable outcomes. The negative information effect Veitch et al. observed could be an instance of reactance (Brehm, 1966), in that the subjects responded with more effort, rather than less, when presented with an attempt to discredit the advertising claims for full-spectrum lighting.

The experiment described in this paper is a systematic replication[4] of the investigation reported by Veitch et al. (1991). It was designed to overcome limitations of the earlier work. This experiment included four information sets: negative, indifferent, and positive sets, and a no-information condition. The negative set explicitly stated that the lighting type in use might cause poor performance and fatigue; the indifferent set stated that no behavioural effects of the fluorescent lamps should be expected. The separation of negative and indifferent information was intended to provide a clean test of the demand characteristics hypothesis. In addition, the present experiment used a true factorial design, combining two lamp types (full-spectrum (FS) and cool-white (CW) fluorescent lamps) with the four information sets. Veitch et al. were unable to test the hypothesis that information type might interact with lamp type.

Method

Participants

Participants were recruited from the general public by advertisement in the local newspapers. The advertisements were for an experiment on "office design and performance", and did not specifically identify any feature of office design as the topic. One hundred and four women and 104 men participated. Their ages ranged from 20-69 years (M=35.7; median=34), and they had participated in the paid work force from 0-45 years (M=10.5; median=8). Their educational backgrounds ranged from high school diplomas to doctoral degrees. All had normal or corrected-to-normal vision, normal hearing, and were fluent in English. The participants were paid an honorarium of $50 for their participation in this half-day session.

Setting

The experiment took place in a suite dedicated to human factors research at a government

[4] In systematic replication, one tests the same hypothesis or hypotheses again, using different participants and minor, or sometimes major, differences in methods. Obtaining similar results again provides evidence of the generality of the original findings, by the principle of converging evidence (Durso & Mellgren, 1989; Kerlinger, 1986).

laboratory. This facility consisted of four 4.5 m x 4.5 m windowless office mock-ups opening from a central corridor (two on each side). The offices were furnished identically, in a manner typical of middle-management enclosed offices. The carpet, wall covering, desk, credenza, guest chairs, and trim were in shades of grey to minimise any chromatic cues concerning the lighting. (The desk chairs were in a light lilac, but were of course not visible to the subject when seated.)

The offices were lit using standard 4-foot recessed fluorescent troffers with 40-watt lamps, core-coil magnetic ballasts, and K-12 prismatic lenses. Two of the offices had cool-white (CW) fluorescent lamps (General Electric F40T12CW, CCT = 4250K, CRI = 62), and two had full-spectrum (FS) fluorescent lamps (GE F40T12C50, CCT = 5000K, CRI = 91).[53] (The spectral power distributions (SPDs) for these lamps have been previously published [Boray et al., 1989]). These two lamp types were chosen because, at the time of the experiment, CW lamps with these characteristics were in widespread use; whereas, advertising and promotional claims promised performance and mood improvements if FS lamps were installed in their place. The comparison, therefore, was externally valid. Although the lamps differed in CRI relative to their respective CCTs, this difference was not expected to influence performance on these achromatic tasks.

Illuminance levels in all four offices were equated by wrapping black tape around certain lamps or on luminaires to achieve 680 lux mean horizontal illuminance measured on the desk surface. The black tape reduced the light output from the luminaires without altering the SPD, as electrical dimming would have. The illuminance was calculated from luminance measurements of a known reflectance standard, using a Pritchard spectroradiometer (Photo Research 703A), to control for photometric errors that occur when comparing the output of different lamp types using standard photometers calibrated to an incandescent standard lamp (Ouellette, 1993). The 680 lx illuminance level is consistent with currently accepted standards for office lighting when working with high-contrast paper-based tasks (Rea, 1993).

The corridor between the rooms was lit using warm-white fluorescent lamps (GEF40T12WW, CCT=3020, CRI=52). The consent forms and one questionnaire were completed in the office outside the facility. This room was lit in a random pattern of cool-white and warm-white lamps; the illuminance at the table used for the forms was approximately 800 lx.

Materials and Measures

Information sets. The information sets were presented using a 2-minute videotape presentation produced for this experiment. The speaker in the video was an actor hired to play the role of a spokesman for a fictitious company, "Geneva Lighting", that ostensibly had funded the experiment. The content information specific to the experimental condition was sandwiched between opening and closing sequences that were identical for all conditions. These sequences informed the viewer that

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[5] Colour temperatures describe the colour of a light source in terms of the colour of a blackbody radiator, which is a theoretical object that radiates energy perfectly (Helms & Belcher, 1991). *Correlated colour temperature* (CCT) is the colour temperature (in Kelvin) at which a blackbody radiator has the same colour appearance as the fluorescent lamp (which is not a radiator). CRI refers to the colour appearance of illuminated objects under a given light source, rather than the colour appearance of the light itself. It is a comparison of the colour appearance of objects under the test light source with the colour appearance of the same objects when illuminated by a reference (standard) light source of the same colour temperature. If the match between the colour appearances under the two lamps is perfect, CRI=100. CRI values for lamps with different CCT cannot be directly compared because each is relative to a different standard.

Geneva Lighting, whose business is to create quality working environments, has an interest in establishing good office design, but wished to take an opportunity to present some information about lighting before the session began. The information sets were inserted at this point in the video using graphs with a voice-over by the spokesman. After the information set, the spokesman returned to thank the participants for their participation in the experiment.

There were seven permutations of the information: FS positive; CW positive; FS indifferent; CW indifferent; FS negative; CW negative; and, No information. The same No information condition was used for both lamp types. It consisted of a brief explanation that light is a mixture of different wavelengths and is measured in lumens per metre squared (lux). The negative conditions informed the participants what light source was in use in the office they occupied and that it might leave them feeling tired, and cause them to have difficulty with the tasks. The indifferent conditions informed the participants what light source was in use in the office they occupied, and that there is no evidence that it would have any effect on their performance or mood. The positive conditions informed the participants what light source was in use in the office they occupied and told them to expect to feel better at the end of the session and to enjoy the work more. The negative, indifferent, and positive information conditions each featured a bar graph of data ostensibly illustrating the outcome using existing data (all these graphs used imaginary data). The FS and CW conditions differed only in that the FS conditions stated that FS light "mimics natural daylight, and is popular these days", whereas the CW conditions stated that "it's the most common type of office lighting in the world today". Both lamps were said to be under test for energy efficiency.

Pre-existing beliefs. A new scale to measure lighting beliefs was developed for use in this study and independently validated (Veitch & Gifford, 1996). The 32-item Lighting Beliefs Questionnaire consists of statements about lighting effects on performance, mood, and health, with which respondents indicate their agreement or disagreement on 5-point Likert scales. For example, "I do my best work in places that are lit using natural daylight." "Fluorescent light seldom gives me a headache." Ten additional true-false items assessed technical knowledge about lighting. In the validation study, with 302 respondents, alpha was .79 for the Lighting Beliefs Questionnaire and .83 for the Lighting Knowledge test.

Participants also completed a 22-item questionnaire, the Person-Surroundings Scale, concerning their beliefs about the behavioural and mood effects of the physical environment in general (Gifford, 1992). This questionnaire has demonstrated low-acceptable internal consistency, with alpha = .63 (Veitch & Gifford, 1996). Demographic information about age, years of work experience, education, and vision was also collected as part of this questionnaire.

Performance and mood measures. Intellectual task performance was assessed using brain-teaser puzzles of the type used to test potential members of Mensa (e.g., Fixx, 1972). A collection of 15 such puzzles was pilot tested on university undergraduates in a previous study (Veitch, 1993) and displayed adequate internal consistency (alpha=.75) and variability. Reading comprehension was included in this study to replicate the measures used by Veitch et al. (1991). It was assessed using the Reading Comprehension subtest of the Canadian Adult Achievement Test (Level D) (The Psychological Corporation, 1991), a standardised achievement test for adults with the equivalent of at least 11-12 years of schooling. The mood measure used in this study was the Russell and Mehrabian Three-Factor Mood Scale, a set of 18 bipolar adjective pairs in which the participant indicates the degree of feeling on a semantic differential scale. Previous research has established that these items reliably form three factors: Arousal, Pleasure, and Dominance (Russell & Mehrabian, 1977).

Post-experimental questionnaire. At the end of the experimental session, all participants completed a questionnaire with three open-ended questions to probe their expectations about the purpose and anticipated results of the experiment. These were a test for expectancy biases. The questionnaire also included four Likert-scaled questions about the difficulty of the tasks and four Likert-scaled questions addressing the credibility and interest of the video presentation, the participants' opinions of the session as being boring, and how tiring they found the reading test and brain-teaser puzzles to be.

Procedure

Two experimenters shared the duties for data collection. Experimenter A (who was male) was responsible for participant recruitment and scheduling, and for administering all dependent measures except the post-experimental questionnaire. Experimenter B (who was female) assigned the participants to experimental conditions (both lamp type and information set), ran the videotape presentation, administered the post-experimental questionnaire, and debriefed the participants at the end of the session. Every effort was taken to maintain a double-blind experiment to avoid creating biases in experimenter or participant: Experimenter A was not informed of the hypotheses under test until the data had been collected and scored; Experimenter B had no responsibility for instructing, administering, or scoring the dependent measures except the post-experimental questionnaire.

Sessions were approximately three hours long. Four participants were tested per session, one in each of the enclosed offices. All participants in one session were of the same gender; the schedule was counterbalanced so that equal numbers of men and women were tested in morning and afternoon sessions and across days of the week. The participants were randomly assigned to lamp type and information sets conditions prior to their arrival for the session. The lamps were warmed-up for at least one hour prior to the session and the desktop illuminance verified using a Minolta TM-1 illuminance meter. At this time, Experimenter B also set up the videocassette recorder in each office with the appropriate tape for the session.

When the participants arrived at the building, Experimenter A greeted them, escorted them to the laboratory, and settled them around a table in the outer room. He read a prepared statement about the study, identifying it as a study about office design effects on performance and explaining the rights and responsibilities of participation. The subjects then signed a consent form. While still seated around the table, they completed a questionnaire including the Lighting Beliefs Questionnaire, Lighting Knowledge test, the Person-Surroundings Scale, and demographic information. These data were collected for use as possible covariates, in view of the results of the previous experiment (Veitch et al., 1991).

Experimenter B then entered, introduced herself, and directed each of the four participants to one of the four enclosed offices. Once all four were settled at their desks, she visited each office in turn to play the videotape (this was the information set manipulation), returning at the end to shut off the machine.

Experimenter A returned at this point to administer the brain-teaser puzzles (45 minutes), reading comprehension test (45 minutes), and mood questionnaire (5 minutes). Newsmagazines were provided in each office to occupy the participants if they completed the tasks early (few did so). Following the mood questionnaire, experimenter A left the laboratory; experimenter B administered the post-experimental questionnaire and then asked the participants to return to the outer room for the debriefing.

The debriefing was carefully worded to address any lingering effects of the videotape presentation: both the positive and negative information sets conditions (for both lamp types) included information that is not supported by the scientific literature. The debriefing specifically explained the reason for the use of deception in this experiment, and participants were invited to ask any questions or to contact the principal investigator. No participant indicated any adverse reaction to any aspect of the session.

Results

Manipulation Check

The post-experimental manipulation checks were included to protect against the possibility of bias in the data attributable to beliefs about lighting or the experiment itself. There were three open-ended questions in which participants were asked to report their understanding of the purpose of the experiment; the environmental influences on them during the session; and, their belief about the researchers' expected outcome. The responses to these questions were scored on a categorical basis to indicate whether the individual had formed expectations related to the lamp type or information set hypotheses.

The coding was difficult because most respondents gave very brief, point-form responses. A large number of participants (146) had determined that lighting was a focus of the experiment, but only two had identified the video presentation as an experimental manipulation. Only four respondents indicated that they had responded consistently with the prediction of the video they saw, although 35 indicated that we expected people to respond consistently with the information in the video.

Comparison of all participants who had scored affirmatively on any one of the three manipulation check items (N=155) to those who had not (N=53) revealed no relationship to experimental condition, or to pre-existing lighting beliefs or knowledge. All participants were therefore retained for the analyses, as there was no compelling reason to believe that the opinions they had expressed were likely to have biased their mood or performance responses.

Examining the ratings of the credibility and interest of the video presentation, it was evident that the video spokesman was somewhat credible (median = 3 on a scale of 0-4) and slightly less interesting (median = 2). Between-groups comparisons for these variables are discussed below.

Descriptive Statistics

Reliability and distribution checks were run on all variables prior to inferential analyses. The reading comprehension test had an internal consistency of .80. For the brain-teaser puzzles, alpha was .69. Both variables had negatively skewed distributions. The reading test, with a maximum score of 54, had a median score of 46 and M=43.85 (SD=6.66). The puzzle scores (maximum 15) had a median of 10 and M=9.24 (SD=2.55). For the mood measures, arousal, pleasure, and dominance, alpha values were .71, .88, and .75 respectively. These dimensions were measured on a scale from 0-8. Arousal and dominance scores approximated a normal distribution (arousal median=4.33, M=4.23, SD=1.04; dominance median=3.83, M=3.77, SD=0.99); pleasure scores were positively skewed (median=2.83, M=2.97, SD=1.34).

Existing beliefs and knowledge about lighting and the physical environment had been included in the present study because of their importance to the analyses in the earlier work, in which these beliefs were used as a covariate in order to detect effects of an information set manipulation (Veitch et al., 1991). In this study, the Lighting Beliefs Questionnaire data had a mean value of 2.41 (on a scale of 0-4, with 0 indicating no agreement with statements about lighting effects on people), standard deviation 0.33, alpha = .80. These are comparable to the validation sample statistics (*M*=2.26; *SD*=0.33, alpha=.79) (Veitch & Gifford, 1996). For the Lighting Knowledge test (possible scores 0-10 items correct), *M*=5.78; *SD*=0.97, alpha=.65 (this is less variable and less internally consistent than in the Veitch & Gifford [1996] data). For the Person-Surroundings Scale (values can range from 0-6 with higher means indicating stronger beliefs), *M*=4.07; *SD*=0.61, alpha=.58. There were no differences between the groups on any of these variables; therefore, no covariates were used in the subsequent analyses.

Table 1: *Cell and Marginal Means (Standard Deviations) for Performance and Mood Data*

Lamp		Information Set				Lamp Type
Type	Variable	Negative	Indifferent	Positive	None	Marginal
CW	Reading	44.54 (6.92)	44.66 (5.27)	45.77 (3.64)	42.38 (8.05)	44.34 (6.23)
	Puzzles	9.57 (2.91)	9.00 (2.51)	9.62 (2.39)	9.35 (2.83)	9.39 (2.64)
	Arousal	4.37 (1.07)	4.51 (0.81)	4.16 (0.94)	4.10 (1.08)	4.29 (0.98)
	Pleasure	3.24 (1.53)	3.03 (1/29)	2.81 (1.30)	2.87 (1.41)	2.99 (1.38)
	Dominance	3.86 (0.98)	3.61 (1.16)	3.59 (0.92)	3.81 (0.76)	3.72 (0.96)
FS	Reading	43.31 (7.76)	43.08 (6.22)	44.58 (6.77)	42.46 (7.61)	43.36 (7.05)
	Puzzles	8.77 (2.36)	9.39 (2.19)	8.96 (2.49)	9.27 (2.88)	9.10 (2.47)
	Arousal	4.08 (0.89)	4.20 (1.13)	3.96 (1.12)	4.48 (1.23)	4.18 (1.10)
	Pleasure	2.86 (1.57)	2.97 (1.21)	2.92 (0.91)	3.06 (1.50)	2.95 (1.30)
	Dominance	4.05 (0.95)	3.76 (0.88)	3.62 (1.08)	3.99 (1.15)	3.86 (1.02)
Info Sets	Reading	43.92 (7.31)	43.87 (5.76)	45.17(5.42)	42.42 (7.75)	<u>43.85 (6.66)</u>
Marginals	Puzzles	9.17 (2.66)	9.19 (2.34)	9.29 (2.44)	9.31 (2.83)	<u>9.24 (2.55)</u>
	Arousal	4.23 (0.99)	4.36 (0.99)	4.06 (1.03)	4.29 (1.16)	<u>4.23 (1.04)</u>
	Pleasure	3.05 (1.55)	3.00 (1.24)	2.86 (1.11)	2.97 (1.44)	<u>2.97 (1.34)</u>
	Dominance	3.96 (0.96)	3.68 (1.02)	3.61 90.99)	3.90 (0.97)	<u>3.79 (0.99)</u>

Note. Reading test maximum score, 54. Puzzle score maximum, 15. Arousal, pleasure, and dominance scales range 0 - 8, higher values reflecting more intense mood. Underlined values are grand means.

Multivariate Analysis of Variance

The data from the 208 participants was examined using a 2 x 4 x 2 (Lamp Type x Information Set x Gender) factorial between-subjects multivariate analysis of variance (MANOVA). The principal dependent variables, consistent with the analyses of Veitch et al. (1991) included all the performance (brain-teaser puzzles and reading comprehension) and mood (pleasure, arousal, and dominance) scores. Table 1 shows the cell and marginal means and standard deviations for the performance data for the lamp type and information set conditions, collapsed across gender. Gender was included as a blocking variable in the MANOVA model because Knez (1995) reported interaction effects between lamp type (cool-white and warm-white fluorescent lamps) and gender on mood and cognitive performance scores. However, the claims made for FS fluorescent lighting are not gender-specific, and no gender effects were expected.

With one exception, there were no significant multivariate main effects or interactions on the performance and mood scores. The multivariate test for the gender main effect was statistically significant, Wilks' lambda = .933 ($F(5,188)=2.70$, $p<.05$). It was associated with a significant univariate contrast for the brain-teaser puzzle scores ($F(1,192)=8.99$, $p<.05$). Men achieved a mean score of 9.76 (*SD*=2.32) puzzles correct, whereas women achieved a mean score of 8.72 (*SD*=2.68).

The same MANOVA model was also applied to the eight Likert-scaled items in the post-experimental questionnaire. There were no significant multivariate main effects or interactions. Table 2 shows the cell and marginal means and standard deviations for the post-experimental questionnaire data for the lamp type and information set conditions, collapsed across gender.

Table 2: *Cell and Marginal Means (Standard Deviations) for Post-Experimental Questionnaire Data*

Lamp		Information Set				Lamp Type
Type	Variable	Negative	Indifferent	Positive	None	Marginal
CW	Difficulty: Puzzle	2.31 (1.09)	2.28 (1.14)	2.33 (0.92)	2.36 (1.04)	2.32 (1.03)
	Difficulty: Reading	1.39 (1.02)	0.84 (0.85)	1.13 (0.85)	1.20 (0.96)	1.14 (0.93)
	Difficulty: Questionnaires	1.39 (1.02)	0.88 (0.93)	0.67 (0.70)	1.08 (1.07)	1.01 (0.96)
	Difficulty: All tasks	1.736 (0.87)	1.56 (1.04)	1.71 (0.75)	1.67 (0.87)	1.67 (0.88)
	Credible spokesman	2.35 (0.94)	2.40 (0.71)	2.25 (1.03)	2.40 (0.76)	2.35 (0.86)
	Interesting video	2.04 (1.00)	1.88 (0.88)	1.67 (0.64)	1.64 (0.91)	1.81 (0.87)
	Boring session	1.46 (0.91)	1.52 (0.92)	1.25 (0.53)	1.40 (0.87)	1.41 (0.82)
	Tiring tasks	2.08 (1.06)	1.36 (1.14)	1.08 (0.88)	1.52 (1.16)	1.52 (1.11)
FS	Difficulty: Puzzle	2.65 (0.75)	2.41 (1.01)	2.42 (1.03)	2.25 (1.03)	2.44 (0.95)
	Difficulty: Reading	1.50 (1.21)	1.09 (0.97)	1.12 (0.77)	1.08 (0.93)	1.20 (0.98)
	Difficulty: Questionnaires	1.27 (0.87)	1.05 (0.95)	1.27 (0.92)	0.71 (0.75)	1.08 (0.89)
	Difficulty: All tasks	1.85 (0.73)	1.59 (0.96)	1.65 (0.85)	1.63 (0.77)	1.68 (0.82)
FS	Credible spokesman	2.85 (0.61)	2.55 (0.91)	2.62 (0.64)	1.96 (0.96)	2.50 (0.84)
	Interesting video	2.12 (0.95)	2.18 (1.10)	2.04 (0.82)	1.42 (0.97)	1.94 (0.99)
	Boring session	1.50 (1.07)	1.14 (0.64)	1.15 (0.73)	1.58 (0.93)	1.35 (0.88)
	Tiring tasks	1.77 (1.03)	1.50 (1.06)	1.69 (1.26)	1.63 (1.06)	1.65 (1.10)
Info. Set	Difficulty: Puzzle	2.48 (0.94)	2.34 (1.07)	2.38 (0.97)	2.31 (1.03)	<u>2.38 (0.99)</u>
Marginals	Difficulty: Reading	1.44 (1.11)	0.96 (0.91)	1.12 (0.80)	1.14 (0.94)	<u>1.17 (0.96)</u>
	Difficulty: Questionnaires	1.33 (0.94)	0.96 (0.93)	0.98 (0.87)	0.90 (0.94)	<u>1.05 (0.93)</u>
	Difficulty: All tasks	1.79 (0.80)	1.57 (0.99)	1.68 (0.79)	1.65 (0.81)	<u>1.68 (0.85)</u>
	Credible spokesman	2.60 (0.82)	2.47 (0.80)	2.44 (0.86)	2.18 (0.88)	<u>2.42 (0.85)</u>
	Interesting video	2.08 (0.97)	2.02 (0.99)	1.86 (0.76)	1.53 (0.94)	<u>1.87 (0.93)</u>
	Boring session	1.48 (0.98)	1.34 (0.82)	1.20 (0.64)	1.49 (0.89)	<u>1.38 (0.85)</u>
	Tiring tasks	1.92 (1.05)	1.43 (1.08)	1.40 (1.13)	1.57 (1.10)	<u>1.59 (1.10)</u>

Note. All scales have possible range 0-4, with higher values indicating stronger ratings. Underlined values are grand means.

Discussion

This experiment found no evidence that information provided about lighting, nor the fluorescent lamp type itself, affects mood or performance. The effects observed by Veitch et al. (1991), which were medium-sized (Cohen's f=0.25 [Cohen, 1988]), did not replicate. This is striking because this experiment was powerful enough to detect such effects, if they were present: Power was .94 for the lamp type comparison and .85 for the information sets comparison, taking $p<.05$ as the significance level. Biases were carefully controlled by using a double-blind between-groups experimental design, and by assessing pre-existing lighting beliefs.

Differences in experimental details might account for the failure to replicate. These differences suggest, however, that findings of Veitch et al. (1991) might not generalise to offices and office workers. Although it was a laboratory experiment, the setting was designed to be a realistic office environment, and the participants were recruited from the general public. The participants received an honorarium consisted with the rate of pay for office work. In contrast, Veitch et al. (1991) obtained volunteers from the population of university undergraduates in social science courses. Although all participants in the present experiment were guaranteed to receive the honorarium regardless of their performance or other responses (indeed, they were assured of receiving the honorarium even if they chose to leave the session before its end), it is possible that this incentive ensured that all participants would maintain maximum effort, regardless of the experimental manipulation. One might expect that similar incentives to work exist in offices and other workplaces.

Veitch et al. (1991) were able to assess existing lighting beliefs long in advance of experimental sessions; in the present experiment, lighting beliefs were assessed shortly before the video presentation of the information sets. Although it is possible that the questionnaires about lighting heightened sensitivity to lighting and lighting information, thereby reducing the strength of the information sets manipulation, this seems unlikely. Participants rated the video as credible, and generally did not identify the video presentation as an experimental manipulation. A substantial number identified lighting as a target of investigation, but this number did not vary across information sets.

Another difference between this experiment and the original was a longer exposure time (total session length was 3 hours, rather than 50 minutes). This change was made in order to overcome the criticism that too-short exposure times provide too small a light dose for an observable effect. The present experiment cannot rule out this possibility; only investigations with longer exposures can do so. However, the failure to replicate the Veitch et al. (1991) information sets effects on arousal and reading performance with the longer exposure time might indicate a moderating effect of adaptation. Perhaps the effect of information sets does not persist over time.

The absence of lamp type main effects is consistent with many field and experimental studies (Veitch & McColl, 1994, 1997). Proponents of full-spectrum fluorescent lighting have claimed that the effects of the spectral composition of illumination are strong. This statistically powerful and carefully-controlled experiment found no support for the claim that complex, cognitive tasks and mood are affected, in the short term, by the spectral composition of fluorescent lamps.

Because the setting was largely achromatic, the effects of lamp type on the appearance of surface colours was minimised. This aspect of the procedure clarified the lamp type comparison by removing aesthetic differences between the rooms (and also helped to minimise the cues for Experimenter A, who was blind to the experimental conditions). It is possible that in settings with more varied finishes, the combination of lamp type and surface colours could lead to a difference in aesthetic appeal that might result in differences in mood or performance. These would not, however, be direct effects of lamp type on behaviour, but mediated effects through cognitive processes.

As has been known for decades, the effects of lighting are subtle and easily obscured by social and cognitive conditions (cf. Roethlisberger & Dickson, 1939). More recently, several investigators have suggested that cognitive processes mediate behavioural responses to lighting (e.g. Baron, Rea, & Daniels, 1992; Knez, 1995; Veitch et al. 1991). However, the overall pattern of their results is far from robust and fails to identify clearly which processes are operative.

Biner (1991) found that lighting-induced arousal can be misattributed to an avoidance goal.

Aversive noise was rated as more unpleasant under bright than dim illumination. Moreover, this attribution was attenuated when participants were given an explicit attribution for the ambiguous arousal. When the participants were told that bright light can be stimulating, the effect of illuminance on noise unpleasantness ratings disappeared. Biner's evidence supported the contention that arousal induced by lighting can create a state of negative affect in which a negative stimulus is judged to be more unpleasant.

Baron et al. (1992), in contrast, reported a series of experiments that suggested a role for positive affect as a mediator of lighting-behaviour relationships. Certain light source and illuminance combinations were associated with improvements in performance and prosocial behaviours in a manner similar to the effects of increasing positive affect. However, there were no direct effects of lighting conditions on affect scores or on several other dependent measures. Baron et al. (1992) concluded that a precise determination of the mediating processes awaited future research.

Knez (1995) reported two experiments in which he compared the effects of warm-white and cool-white fluorescent lamps, two illuminance levels, and gender on a battery of cognitive tasks, mood scales, and ratings of the appearance of the lighting. In one experiment, lamps with good colour rendering properties were used; in the other, lamps with poor colour-rendering properties. He found no main effects of lamp type on any outcome. Overall, the experiments produced weak evidence that lighting conditions (lamp type and illuminance combinations) that induced negative affect reduced performance; those that induced positive affect improved performance. However, the interaction effects of Lamp Type X Gender and Lamp Type X Illuminance X Gender on cognitive tasks and mood scales in the first experiment did not replicate in the second experiment. Most surprisingly, changing the lamp type had no effect in either experiment on ratings of the appearance of the lighting.

Both Biner (1991) and Baron et al. (1992) noted that familiarity with a given lighting source and its association with a given setting could provide an additional mediating process to affect or arousal mechanisms. People exhibit consistent preferences for illuminance levels in a given setting (Butler & Biner, 1987), and these preferences are consistent with the notion that individuals attempt to optimise arousal differently for social situations and task demands (Biner, Butler, Fischer, & Westergren, 1989).

Findings to date provide partial support at best for the hypothesis that cognitive processes mediate lighting-behaviour relationships. The same dependent measures have been used in several studies and have produced inconsistent results despite the use of careful experimental controls and sound research design. The possibility exists that these comparatively short-term laboratory investigations offer inadequate time for such effects to develop; if such cognitive processes build over days, weeks, or months, then the existing literature is inadequate to evaluate the hypothesis. The challenge for future research is to design and conduct experiments that can distinguish between the rival hypotheses of arousal, affect, and beliefs, thereby providing clarity to the scholarly debate.

Although our understanding of mediating processes remains primitive, informed lighting choices can draw on other lighting research, which has detected short-term effects of lighting conditions on important behavioural outcomes. Light sources with good colour rendition are preferred over those with poor colour rendering properties, and elicit judgements that scenes appear more clear and sharp (Veitch & McColl, 1994, 1997). Low-frequency flicker, a property of fluorescent lamps run on magnetic ballasts, can adversely affect visual performance and reading (Veitch & McColl, 1995; Wilkins, 1986). Katzev (1992) found an effect of lighting system design on reading performance: Performance was best under a suspended direct/indirect system, and worst under recessed luminaires with acrylic lenses.

These findings, taken together, have implications for lighting practice and future research. Although the popular media continue to promote the notion that full-spectrum fluorescent lighting is beneficial to people (e.g., Blumenthal, 1992; Cook, 1994), the experimental evidence does not support these claims. Facilities managers, when faced with complaints about office lighting, should resist the temptation to look reflexively to the lamp as the source of lighting problems. The evidence does not support changing fluorescent lamp type as a solution to occupants' problems with fluorescent lighting. Field and laboratory studies have more consistently identified other aspects of the lighting system, such as the flicker rate (Veitch & McColl, 1995; Wilkins, Nimmo-Smith, Slater, & Bedocs, 1989) and luminaire design (Hedge, Sims, & Becker, 1995; Katzev, 1992) as levers for solutions to problems with interior lighting. Future research should focus on understanding these effects to characterise high-quality lit environments that meet human needs.

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