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Exercised Control, Lighting Choices, and Energy Use: An Office Simulation Experiment

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Abstract

The belief that individual control leads to beneficial behavioural outcomes underlies many recommendations to install individual controls for workplace lighting, temperature, and ventilation in workplaces. The present experiment compared the work performance and satisfaction of 47 office workers who were given choices concerning workplace lighting (CS) with age- and sex-matched partners (PP) who were given no choices but worked under identical lighting. Preferred luminous conditions were recorded for both groups. Satisfaction with lighting and the work environment were high for both groups, and the majority of participants chose lighting conditions consistent with current codes and standards for lighting, including energy use. CS participants had greater perceived control than PP participants, but there were no differences in satisfaction, mood, performance or health. PP participants' lighting choices, recorded at the end of the day-long session, created less VDT glare than CS choices. Although there was no short-term benefit of perceived control over lighting, it appears that experience with workplace conditions could lead to the ability to reduce unpleasant conditions if choices were available.

Introduction

Among the classic observations in modern psychology is the finding that perceived control can moderate stress reactions (Glass & Singer , 1972). Glass and Singer used noise as a stressor, finding that exposure to unpredictable noise bursts during a session of simple cognitive tasks produced lower post-exposure frustration tolerance and lower proofreading performance as compared to no noise, although performance during the session was unaffected. When the noise was predictable, or when participants were told that to end the noise they need only flip a switch, the post-exposure deficits disappeared even though the noise exposure was unchanged. Sherrod (1974) reported similar findings for perceived control using crowding as a stressor, and the option to leave as the control manipulation.

When control over aversive stimuli is not available, *learned helplessness* can result, in which individuals suffer emotional, cognitive, and behavioural deficits (Seligman, 1974). Seligman's original work led to a theory of depression in which individuals attribute aversive events to internal causes that are global and stable (Abramson, Seligman, & Teasdale, 1978), attributions that develop from experience with repeated uncontrollable aversive events.

Beyond psychopathology, there exists a widespread belief that the absence of control, even in situations that are not themselves stressful, leads to feelings of unhappiness and powerlessness (Averill, 1973; Burger, 1989). Langer and Rodin (1976) demonstrated that the induction of a greater sense of personal responsibility, and placing emphasis on individual decision-making about such issues as furniture arrangement, plant care, and social activities, increased the activity level and happiness of elderly nursing home residents in a high-quality facility. The beneficial effects continued through an 18-month follow-up (Rodin & Langer, 1977).

The idea that a high degree of individual control enhances quality of life is often used to justify the adoption of individual controls for features such as lighting, temperature, and ventilation. Barnes (1981) argued that stress-free built environments require a clearly articulated choice structure, in which individuals use the options available to them both to construct satisfactory conditions and to develop the perception that they control their environments. Increases in perceived freedom (the availability of choices) and perceived control (the belief that one can predict the consequences of environmental choices and can cause desired changes to conditions) increase satisfaction with the built environment, according to Barnes. Becker (1986) also advocated furniture, lighting, and workspace adjustability as part of the *Quality Work Environment* that supports employee morale, performance, and well-being, in an analogous manner to the contribution of job autonomy to the *Quality of Work Life* movement.

Becker (1991) observed that employees are becoming more demanding of their employers, having higher expectations for the physical environment at work than in previous generations. Among their desires is the desire for control over workplace features (Brill, Margulis, Konar, & BOSTI, 1984; Harris & Associates, 1987; Veitch & Gifford, 1996a). This control, whether in the form of individual switching for lighting or thermostats, or operationalised as employee participation in workplace design decisions, is expensive. Empirical evidence is lacking to demonstrate which of these forms of control is desirable, and how substantive are their contributions to desirable outcomes such as improved satisfaction and work performance (Becker, 1991). Although Becker (1991) and other researchers have acknowledged limitations to the benefits of control over the physical environment -- for example, the possibility that one could overwhelm people by providing too much control (Barnes, 1981) -- discussions in trade magazines have tended to sound less discriminating, and more enthusiastic

(e.g., Standley, 1989; Wotton, 1989)

Examination of the general psychology literature reveals that control does not always lead to desirable outcomes; in effect, control can become a stressor rather than providing a means of escape from a stressor. Burger (1989) observed that people will decline control when it carries the risk of not achieving a desired goal or if it creates uncomfortable concern with self-presentation. If an expert seems more likely to make the correct choice, or if one risks looking foolish by making the wrong choice, the need to choose can be aversive. Wineman (1982) came to a similar conclusion for work environments; control can lead to undesired effects if it requires choices one did not wish to make. She speculated that in a high-demand job, additional choices concerning the physical environment could contribute to overload.

There are few empirical investigations concerning the effects of control over commonplace elements of workplace environments. Veitch and Gifford (1996b) varied the degree of control available for workplace lighting and examined its effects on task performance. In order to ensure that all participants completed the tasks under the same visual conditions, the control manipulation involved a choice, in which Choice participants had the option of rejecting or accepting the experimenter-assigned lighting condition. No Choice participants had no option. Only those who accepted the assigned place (having had the choice) were included in the data analysis. Choice was crossed with Preference, with half of the participants being assigned to their most-preferred condition, and half to their least-preferred condition. Participants given a choice about the lighting under which they worked performed more poorly and more slowly on a creativity task than participants who had no choice. Both having had a choice and having worked under lighting that one preferred led to the perception of having controlled the workplace lighting. Thus, the perception of control did not influence performance; however, the having a choice led to a small performance decrement. This form of control, however, required one to make a decision before the experimenter and another witness, conditions that likely increased self-consciousness. Veitch and Gifford (1996b) suggested that the experimental manipulation had activated one of Burger's (1989) processes by which control causes adverse effects.

These results contrast with field surveys that consistently report that a sizeable percentage of office employees prefer to have some degree of control over their office lighting. Fifty-four per cent reported this in a large North American survey (“Office lighting”, 1980), and 67% in one Midwestern US building (Ne’eman, Sweitzer, & Vine, 1984). Marans and Yan (1989) reported moderate to large correlations between workspace satisfaction and the ability to control lighting in enclosed offices (.24 to .36) and slightly smaller correlations for open offices (.18 to .20). In these studies, control over lighting took the more conventional form of opportunities to switch lights on or off, or to dim their levels. Exercised control to create desired working conditions, either to remove a stressor such as a glare source, or to make minor adjustments to already acceptable lighting (to suit personal preference), would be expected, based on these investigations, to have beneficial effects on satisfaction. By extension from the environmental stress literature, beneficial performance effects or after-effects might also be predicted.

A replication of Veitch and Gifford’s (1996b) laboratory experiment seemed warranted, given the consistency of opinion among environment-behaviour researchers and office occupants. Instead of a choice presented by the experimenter, and a limited possibility to change lighting conditions by rejecting the seat assignment, the experiment reported here used a matched yoked design to allow one individual in a pair to choose their preferred luminous conditions for that day's work by both members of the pair. This procedure maintained the same visual conditions for both participants during the task session, while also allowing for the collection of lighting preference data from both participants. (The second participant indicated his or her preferred lighting conditions at the end of the session.)

Lighting research has yet to reach firm conclusions concerning lighting preferences (Veitch & Newsham, 1996), although there is considerable interest in Baron's positive affect theory, (Baron, 1990; Baron, Rea, & Daniels, 1992) and in demonstrating that preferred luminous conditions create a state of positive affect that leads to desirable outcomes such as improved cognitive task performance and prosocial behaviour. This experiment could not conclusively answer that question, but did permit comparisons between chosen luminous conditions and existing recommended practice documents. Lighting conditions were expected to show wide individual differences, as in the literature (Halonen & Lehtovaara, 1995; Tregenza, Romaya, Dawe, Heap, & Tuck, 1974). Both indirect and direct lighting sources were included in the space, as both have been found to be acceptable (Ellis, 1986; Katzev, 1992; Yearout & Konz, 1989). The observation that individuals might prefer light levels higher than recommended practice (Begemann, Aarts, & Tenner, 1994; Leslie & Hartleb, 1990) is associated with concern that individual control might lead to excessive energy use for lighting; consequently, both the chosen luminous conditions and their associated energy consumption were included as dependent measures.

Method

This experiment was a two-level (choose session lighting [CS] vs. post-session preferred lighting [PP]) matched, yoked, between-subjects experiment. A detailed report of the method, data, and results is available in Veitch & Newsham (1998a).

Participants

Participants were recruited in 60 matched pairs, by age (age difference between pair members was 5 years or less) and sex, through two temporary-employment agencies in a large Canadian city. Participant ages ranged from 18 to 62, and there were thirty pairs of each sex. The agencies pre-screened potential participants to ensure that they met the following criteria: minimum 18 years of age; normal or corrected-to-normal vision; normal hearing; no mobility impairments; experience with Windows™-based word-processing and spreadsheets; and, a minimum score on the agency's word fluency test (to ensure that all participants had were sufficiently fluent in English to complete the tasks). Participants were paid at the standard clerical rate for a 7.5-hr workday, with the right to end participation at any time without penalty.

Despite the pre-screening procedure, it was apparent from examination of the performance data that several participants did not meet the screening criteria, particularly for English language skills. Consequently, data from 13 pairs were excluded from data analysis, for a total sample size of 94 participants (47 in each condition), 52 women and 42 men. This imbalance was judged not to be problematic because of the absence of sex differences in performance in a related experiment using the same outcome measures (Veitch & Newsham, 1998b). Details concerning the identification of outliers are available in Veitch & Newsham (1998a).

Setting and Lighting Conditions

The experiment took place in a mocked-up 12.2 x 6.7 m (40 x 22 ft) windowless office designed for acoustics, lighting, ventilation, and indoor air quality research (Shaw, Barakat, Newsham, Veitch, & Bradley, 1995), furnished as a typical mid-level clerical or administrative office. Modular systems furniture with 1.67 m partitions (66") provided six open-plan workstations of approximately 6 m^2 (65 ft^2), with space for shared file cabinets and printers at the ends of the room. Each workstation had a 486 computer with a 14-inch colour monitor (.28

inch dot pitch). The furnishings and contents of the workstations were identical. Only the two centre workstations were used for this experiment. The office space is acoustically shielded from building noise; therefore, simulated ventilation noise was added to keep the ambient noise (measured at the ceiling) at 48 dB(A) when empty, which is equivalent to approximately 42 dB(A) at the occupant's ear. Temperature, humidity, ventilation, and noise conditions were monitored continuously to ensure that they remained within the accepted range of conditions for offices. A dedicated reception room outside this space was used for initial instructions and for coffee and lunch breaks.

A hybrid lighting system was installed on four controllable circuits, as illustrated in Figures 1 and 2. These circuits controlled: (1) recessed 1' x 4', deep-cell parabolic louvered luminaires overhead; (2) recessed 1' x 4', deep-cell parabolic louvered luminaires at the perimeter; (3) partition-mounted indirect lighting; and (4) undershelf task lighting. The first three circuits were continuously dimmable (circuits (1) and (2) from 10 - 100 % of full light output; circuit (3) from 30 - 100 % of full light output, according to manufacturer's specifications); the task lighting was simple on-off control. All ballasts were high-frequency electronic ballasts, and all lamps had CCT=3500K and CRI=80. Table 1 provides details of the lighting equipment used.

At the start of the day one participant adjusted the lighting system to his or her preference, using a procedure described below. The configuration of workstations and luminaires was such that the second participant received the same lighting conditions as the first, but was unaware that the first participant had chosen those conditions. The initial settings for the dimmers were the same for all participants: task lights on, with the other circuits nominally at half way as determined by the settings on the control panel (not necessarily 50 % light output). This initial setting produced a lighting power density equivalent to current energy code value for an open plan office (16.3 W/m^2) (American Society of Heating, Refrigeration, and Air Conditioning Engineers [ASHRAE] / Illuminating Engineering Society of North America [IESNA], 1989; Canadian Commission on Building & Fire Codes [CCBFC], 1997), and a desktop illuminance in accordance with guidelines for office work (IESNA, 1993).

Procedure and Dependent Measures

Experimental sessions. One member of each matched pair was randomly assigned to the choose-session-lighting (CS) or post-session preferred lighting condition (PP). In addition, assignment of CS and PP to two workstations was counterbalanced, to protect against the confounding effects of any slight differences between the two locations. The day-long session consisted of a variety of computer-based clerical and creative writing tasks, mood, and satisfaction questionnaires, all chosen from previous research. Both participants worked under the lighting conditions chosen by the CS participant, although PP was unaware that CS had selected the lighting. At the end of the day, PP was asked to complete the same lighting choice procedure as had been used in the morning, to indicate the lighting conditions that this individual would have preferred to work under. The detailed experimental procedure and dependent measures are outlined in Table 2 to conserve space.

During the tasks and questionnaires, on-screen instructions dictated the day's activities, with some interaction with one of the two experimenters (E1, a woman). Custom software automated most of the data collection and controlled the duration of each task (Newsham, Veitch, & Scovil, 1995a, 1995b, 1995c). E1 left the room for most of the time, but monitored progress from an adjacent control room using a security video camera system. Participants could contact E1 by telephone.

Photometric data. Detailed photometric data were collected for the lighting preferences of both CS and PP participants. The lighting control system permitted the recording of the settings selected by the participants, so that on a non-testing day each scene could be replicated and measured using a variety of systems. The photometric data were used to calculate various descriptors of the luminous conditions. Figure 3 illustrates these measurements. See Veitch and Newsham (1998a) for details concerning the photometric procedures and derived values.

Results

This experiment used a straightforward analysis of variance design. There was one independent variable, availability of choice over lighting, with two levels: lighting choice (CS) and no-choice (PP). Analysis focused on conceptually-related groups of dependent variables (e.g., three mood subscales; or, measures of typing speed and accuracy) using multivariate analyses of variance (MANOVA) to minimise Type I error. We interpreted significant univariate tests only if the multivariate test had also reached significance ($\alpha = .05$). Only those results directly related to the hypothesis are reported in detail here; complete details are available in Veitch and Newsham (1998a).

Manipulation Checks

Perceived control. The 11 perceived control items from the closing questionnaire were examined using principal components analysis (PCA) with Varimax rotation. Each question was worded as a statement with which the participant indicated agreement or disagreement on a scale from 0 to 4. When two items had been reverse-scored, the scales were uniformly defined such that lower values indicate less control. The results of the rotated PCA led to the creation of three subscales using 10 items: Perceived Lighting Control, Perceived Session Control, and Environmental Control (Table 3). The latter scale measures the extent to which the individual believed that physical conditions and control over them influences their performance and well-being. This could be considered a trait variable, one that is little influenced by immediate events. Perceived Session Control is an index of the degree to which the individual felt in control of events during the testing day. Perceived Lighting Control assessed the degree of control individuals believed themselves to have had over the lighting for that session.

The scores on all three subscales were analysed for between-groups differences using MANOVA. The multivariate test was significant, and examination of the univariate tests revealed that the effect was associated with differences on both the Perceived Session Control and the Lighting Control scale (Table 4). In particular, CS participants perceived that they had had strong control over the lighting, whereas PP participants perceived themselves to have had no control over the lighting. This is a very large effect in terms of the percentage of variance accounted for (R^2). Although smaller, the difference between CS and PP participants on the Perceived Session Control is also a large effect in terms of variance explained. Apparently, having the opportunity to make lighting choices in the morning contributed to feeling more in control of events all day.

Qualitative impressions. Overall, the responses to the end-of-day open-ended probes did not reveal any expectancy biases in the data. Only four participants identified control as one of the variables examined in this study. Two CS participants reported having been more productive because of having had control over the lighting, and one PP participant lamented not having had lighting control. Of the 47 PP participants, 14 identified lighting as a particular interest for the investigators, but none specified that the issue was control over lighting.

Demographics and individual differences. As part of the data screening, we examined the data for between-groups differences on fourteen health conditions, both for the participants' own health and the family incidence of heritable conditions that might influence visual processing. There were no differences between the CS and PP groups on these variables; nor were there on the incidence of visual or hearing problems, use of decongestants, or smoking status. Responses to the Survey of Personal Influence in Common Environments (Gifford & Eso, 1988) were converted to two scales: Perceived Influence, a measure of the degree of control participants believe themselves to have at home, at work, and in public places; and, Desired Control, a measure of the importance to them of having such control. Participants generally perceived that they had little control over environmental features (M=1.21, SD=0.84), but desired more control (M=2.40, SD=0.84). MANOVA revealed no between-groups differences in these variables (Wilks' Λ = 0.994, $F(2,91)$= 0.29, n.s.).

General lighting preferences. As part of the last computer-based questionnaire, participants answered 11 questions about their general lighting preferences. The responses did not fall into an interpretable pattern when analysed using PCA; therefore, between-groups differences were examined using MANOVA with the individual questions as dependent variables. The significant multivariate test (Wilks' Λ = 0.783 $F(6,87)$= 1.99, $p<.05$) was associated with significant between-groups differences on two questions. CS participants reported a higher preference for making continuous adjustments over the course of a workday (M=3.19; SD=0.68) than PP participants (M=2.70; SD=0.79) [$F(1,89)$= 9.74, $p<.05$]. This response is understandable given that they knew that lighting changes had been made earlier in the day and no further changes had been permitted.

For the item, "Lighting in offices is not very important to me." (which was reverse-scored so that higher values reflect greater importance for lighting), PP participants reported giving greater importance to lighting in the workplace [$F(1,89)$= 6.21, $p<.05$; CS M=2.83 (SD=1.12), PP M=3.32 (SD=0.78)]. However, the median answer for this item for both groups was 3 on a scale of 0-4. The lower mean value for CS reflects a few low scores in this group, rather than a systematically lower value. Overall, differences in lighting preferences between the groups appeared unlikely to have influenced the outcomes.

Lighting Choices

CS participants. The morning lighting choices of the CS participant determined the luminous conditions under which both participants completed the tasks and questionnaires during the rest of the day. Almost all participants used the task lamp, creating a brighter area on the opposite side of the workstation, where the mean illuminance was 595 lx (directly under the task lamp). The systems would have permitted a maximum of 690 lx at that location. Seventy per cent of CS participants in this experiment chose desktop illuminance levels (measured away from the task lamp, and unobstructed in any way) equal to or lower than the IESNA RP-1 (1993) level of 500 lx (Figure 3).

There was considerable variety in their use of the three circuits for ambient lighting (Table 5). The indirect system appears to have been a preference for CS participants, as 50% used it at 76% or greater output. The perimeter and centre parabolic systems were used at lower levels. The luminous conditions created by these lighting choices have been summarised in Table 6. This table shows the means and standard deviations for the photometric values measured and derived from digital image analysis. One encouraging finding was the lighting power density value, a measure of energy consumption. For CS participants, the 75th percentile of energy consumption was within the limits of existing standards in Canada and the United States (ASHRAE/IESNA, 1989; CCBFC, 1997), suggesting that these limits are not too low to satisfy most people. Further analyses of the lighting choice data in relation to lighting codes and standards are planned.

Examination of these variables reveals that participants created a wide range of different luminous conditions, as one would expect from the variability in usage of the different systems. Seven CS participants managed to create no reflected luminaire images ($^{VDT}\mathbf{G_l}$ = 0).

PP participants. Tables 5 and 6 also show the same data for the end-of-day lighting choices of the PP participants. Examination of the use patterns shows that PP participants tended to make less use of the perimeter parabolic system than the CS participants, resulting in lower desktop illuminance and lower power consumption. PP participants were better able to prevent reflected images on the computer screen: 16 achieved $^{VDT}\mathbf{G_l}$ = 0. They also made somewhat less use of the task lamp, probably because they knew that the entirely computer-based tasks had not required it. Consequently the mean illuminance under the task lamp was lower, 543 lx.

Between- groups comparison. Two MANOVA models were run to test the statistical significance of the differences between lighting choices made without (CS) and with (PP) experience in the space. In the first model, the dependent variables were the use fractions for the three ambient lighting systems (Table 7). This test revealed that the degree of use of the three circuits of ambient lighting was different only for the perimeter parabolic luminaires. PP participants, after a day's experience working the space, chose a lower output for this system than the CS participants when they made their choices in the morning. This is a medium-sized effect (Cohen, 1988).

The second MANOVA considered the effects of lighting control on five measures of luminous conditions and power consumption. The luminous condition measurements were LMM; average luminance ($\mathbf{l_{ave}}$); VDT screen glare luminance ($^{VDT}\mathbf{G_l}$); desktop illuminance away from the task lamp (E_D); and, maximum ceiling luminance ($^{CEIL}\mathbf{l_{MAX}}$). This analysis revealed that the CS and PP groups' different lighting choices led to significant differences in the intensity of reflected luminaire images in the VDT screen and in power consumption (Table 7). The lower use of the perimeter parabolic luminaires by PP participants reduced the intensity of the reflected luminaire images in the VDT screen and reduced overall power consumption.

Re-analysis of the data is planned, using regression analyses to explore the relationships between these luminous conditions and the performance and satisfaction outcomes, separately from the effects of lighting control.

End-of-day CS report. The qualitative questionnaire completed by CS participants at the end of the day provided further confirmation that reflected images on the VDT screen during the day led to the difference in PP participants' lighting choices. Only 13 individuals reported wanting no changes at all in their lighting choices. Participants most often reported wanting to dim one or more of the systems, and the most frequent of these was the perimeter parabolic system. In open-ended comments, 15 reported glare-related problems, particularly reflections on the VDT screen, and three others wanted to dim the lights for unspecified reasons. Only five commented that they would have preferred a brighter environment, and three of these noted the trade-off between increasing intensity and controlling reflected images.

Visual Performance

The visual performance scores consisted of the number of correctly-identified Landolt rings (max score 13) for each contrast row (there are 6 contrast levels, from .90 to .08). An overall score was calculated as the sum of correct rings on all rows (maximum 78). Afternoon scores were analysed using morning scores (these stand in for pre-existing visual acuity) and age as covariates, with the CS/PP comparison as the independent variable. This analysis revealed a significant effect, $F(1,90)=5.44$, $p<.05$, $R^2=5.7\%$. Afternoon VALiD scores for the PP group (M_{adj}= 60.02) were higher than those for the CS group (M_{adj}= 58.20), indicating greater visual fatigue for CS than PP participants.

Task Performance

Creative writing. For the writing task, the stories written in response to the pictures were analysed using Grammatik™ IV, a grammar-checking software package (Reference Software International, 1990)/ Grammatik scores for average word length, average sentence length, and grade level were obtained for each completed creative writing trial using the Document Statistics function. The in-house software that automated the experimental session collected information about typing speed and the number of characters typed in each trial. These values were then averaged over all completed creative writing trials for the morning and afternoon session, creating five dependent variables at each time period: creative writing speed (characters/second); total number of characters typed; average word length (characters/word); average sentence length (words/sentence); and, grade level.[1] Where necessary, the scores were transformed to achieve normal distributions. (Veitch & Newsham, 1998a). The analysis was a 2 x 2 (Choice X Session) MANOVA. Choice is the between-groups contrast (CS versus PP) and Session is a within-groups contrast (morning versus afternoon). There were no significant multivariate effects; therefore, no univariate tests were interpreted (for Choice, Wilks' $\Lambda=0.897$, $F(5,88)=2.02$, n.s.; for Session, Wilks' $\Lambda=0.917$, $F(5,88)=1.60$, n.s.; for Choice X Session, Wilks' $\Lambda=0.959$, $F(5,88)=0.76$, n.s).

Typing and proofreading. Measures of speed and accuracy were created for both the typing and proofreading tasks. Gross typing speed was measured in characters per second. There were two error scores for typing; typing errors was the total number of error correction keystrokes, and error rate was the number of error keys per second of total typing time. Proofreading speed was the length of time (sec) spent checking each screen of 20 lines; accuracy was the number of errors per screen. In both cases, scores were created by averaging across all trials in the morning and afternoon sessions separately. The data were transformed to improve the distribution of skewed variables. The analysis was a 2 x 2 (Choice X Session) MANOVA. There were no effects for Choice (Wilks' $\Lambda=0.901$, $F(5,88)=1.93$, n.s) or Session x Choice (Wilks' $\Lambda=0.936$, $F(5,88)=1.20$, n.s).

Only the Session effect was statistically significant (Wilks' $\Lambda=0.436$, $F(5,88)=22.75$, $p<.001$). The multivariate effect was associated with significant univariate tests on all five dependent variables. In all cases, performance improved from the morning to the afternoon, which suggests a learning effect (for details, see Veitch & Newsham, 1998a). These effects are large in terms of the variance accounted for ($R^2_{ave}=.235$). In earlier work (Veitch and Newsham , 1998b) we also observed a learning effect for proofreading speed and accuracy, although not for typing.

Trials and rest breaks. The task scheduling software recorded the number of trials completed in each session (morning and afternoon) of typing, proofreading, and creative writing tasks. It also recorded the duration of rest breaks between trials. These were binned to provide average values for the rest breaks following each task type, in each session. The trials and rest breaks data were combined into one 2 x 2 (Choice x Session) MANOVA. As for the typing and proofreading data, there were no Choice (Wilks' $\Lambda=0.956$, $F(6,87)=0.68$, n.s) or Choice X Session (Wilks' $\Lambda=0.989$, $F(6,87)=0.16$, n.s) effects; only the Session effect was statistically significant (Wilks' $\Lambda=0.480$, $F(6,87)=15.71$, $p<.001$). Participants completed more trials of all types in the afternoon than in the morning, which is consistent with the learning effect explanation for the observations for typing and proofreading accuracy and speed. Their rest breaks after typing trials became longer in the afternoon, but those after creative writing trials became shorter. This suggests a change in strategy or motivation (for details, see Veitch & Newsham, 1998a).

Task difficulty and productivity ratings. The six end-of-day estimates of the difficulty of the tasks and questionnaires were scored on 5-point scales with minimum 0 and maximum 4. Overall, participants reported that the tasks were easy; only the creative writing (M=1.61) had a mean score greater than 1. The productivity estimate was one question, and used a 9-point scale (0 to 8). Its overall mean was 5.1, indicating a 10% improvement in participants' perceived productivity that they attributed to the work environment as compared to other places where they usually work. These seven dependent variables were analysed using the MANOVA model comparing CS and PP responses. There were no significant differences; the two groups did not perceive the tasks differently, nor did they hold different views as to the effects of the physical environment on their productivity that day (Wilks' Λ=.934; $F(7,85)=0.85$, n.s.).

Mood and Satisfaction

Mood. Arousal, Pleasure, and Dominance were the three mood scores, each calculated as the mean response on six semantic differential pairs. The range of possible scores is from 0 to 8. For Pleasure, internal consistency reliability (Cronbach's alpha) was .82 (a.m.), .91 (p.m.). For Arousal, alpha was .57 (a.m.), .72 (p.m.). For Dominance, it was .64 (a.m.), .75 (p.m.). These values are consistent with previous research (e.g. Mehrabian & Russell, 1977; Veitch & Newsham, 1998b).

The three scale scores were analysed in a 2 x 2 model (Choice x Session), as for the task performance variables. Again, there were no Choice (Wilks' Λ=0.978, $F(3,90)=0.69$, n.s) or Session X Choice (Wilks' Λ=0.966, $F(3,90)=1.06$, n.s) effects. The only significant multivariate effect was the Session effect comparing morning and afternoon scores (Wilks' Λ=0.555, $F(3,90)=24.10$, $p<.001$), associated with significant univariate tests for all three scales. Scores on all three mood scales dropped from morning to afternoon (for details, see Veitch & Newsham, 1998a). That is, by the end of the afternoon session, participants felt less aroused, less pleasant, and less in control of the situation (the effect for Dominance was small, R^2=.055; for Pleasure, R^2=.405; for Arousal, R^2=.161). Veitch and Newsham (1998b) also found a drop in all three subscales from morning to afternoon, although in that experiment the drop in both Pleasure and Dominance was greater than in the present experiment.

Satisfaction. Two sets of ratings assessed aspects of satisfaction: Environmental Satisfaction and Lighting Quality. For Environmental Satisfaction, possible scores ranged from 0 to 4. Its internal consistency reliability was good (Cronbach's alpha=.84). The overall mean Environmental Satisfaction score was 2.77 (SD=0.76). This is slightly greater than the neutral point (2) on the scale, indicating mild satisfaction with the overall environment.

There were seven questions in the Lighting Quality ratings in this experiment. PCA revealed a simple structure without need of rotation, in which two components explained 69.8% of the variance (Table 8). Subscale scores relating to the two components, which were labelled Lighting Quality and Glare, were created by taking the average of responses on the items contributing to the components. For Lighting Quality, possible scores ranged from 1 to 5, with higher values indicating better quality; for Glare, possible scores ranged from 1 to 5 with higher scores indicating more bothersome glare. For the group overall, lighting quality was high and glare only mildly bothersome.

MANOVA of the satisfaction data included three dependent variables: Environmental Satisfaction, Lighting Quality, and Glare, with one independent variable, Choice. The multivariate test was not statistically significant (Wilks' Λ=.976, $F(3,90)=0.73$). There were no differences between CS and PP participants in terms of their satisfaction with the workplace nor with the lighting, including glare.

Health

The 12-item Physical Sensations Questionnaire was presented at two times of day, at the end of the morning and afternoon sessions. Each item was a symptom rated for its severity from 0 to 4. The modal morning scores were zero (no symptoms); therefore, change scores were calculated for each item. The change scores exhibited better distributions, and were used for further analyses. The change scores had a theoretical range from -4 through +4. These scores were reduced to 4 subscale scores: visual fatigue, physical symptoms, mental fatigue, and nasal and throat symptoms, using PCA and internal consistency item analysis (details are available in Veitch & Newsham, 1998a).

The means are greater than, yet close to 0, indicating little increase in physical symptoms from the morning to the afternoon. The four subscale scores were included in the MANOVA of these data. Choice was the sole independent variable. The multivariate test was not statistically significant (Wilks' Λ =.975, $F(4,89)=0.58$). CS and PP participants did not differ in the incidence of physical symptoms over the course of the day.

Discussion

In the psychology literature, beneficial effects of perceived control over physical conditions are generally observed for aversive physical conditions that, left unchecked, cause stress reactions. This is true for noise (Glass & Singer, 1972), heat (Bell & Greene, 1982), air pollution (Evans & Jacobs, 1982), and crowding (Sherrod, 1974). In some cases, the performance relationships are complex, in that people maintain their performance during exposure to the stressor, but show after-effects later (e.g., Glass & Singer, 1972). In both the psychology and the environment-behaviour research communities, the desirability of personal control conditions is widely lauded, even over conditions that are not obviously stressful.

There are few published investigations concerning control over non-stressful environmental conditions. However, in one case, performance declined for people given control over lighting (Veitch & Gifford, 1996b) when control was exercised under the watchful eye of an authority figure (the graduate student experimenter). In the present experiment, without such social pressures, we had hypothesised that participants in the Choose Session Lighting (CS) condition would exhibit performance and satisfaction improvements during the work session over those in the Post-session Preferred Lighting (PP) condition. This outcome would be consistent with the general opinion of many lighting designers and, indeed, many in the general public.

The results of the present experiment do not support this hypothesis. The non-stressful nature of the working conditions is confirmed by the low grand mean for bothersome glare (1.83 , between "not at all bothersome" and "a little bothersome" on a scale from 1-5) and by the high grand means for both lighting quality (4.1 out of 1 to5) and environmental satisfaction (2.8 out of 0 to 4). Control over the physical environment was important to all the participants and they believed that it contributes to their well-being, according to their scores on the Environmental Control subscale and Desired Control measure. However, although participants in the CS condition reported greater perceived control over lighting and over the session itself than their PP partners, there was no difference between the two groups on task performance, mood, satisfaction, or physical health reports. Having had the freedom to choose the lighting for the work session -- within a wide range of realistic, but non- stressful, conditions -- did not lead to the beneficial effects for the CS participants we had predicted.

One explanation for these results could be that the environmental conditions were too good. The luminous conditions for the most part met the recommended practices for office lighting with computers (IESNA, 1993), meaning that most participants would have had no visual difficulties working on a self-luminous, vertical VDT task. Additional control over lighting, although clearly desirable to the participants, could have made little difference to the working conditions, at least as far as visibility is concerned.

Although statistical artifact also cannot be ruled out as an explanation for the null results,[2] far more likely is the possibility that when lighting and other environmental conditions are acceptably good, as these were, the presence or absence of control is unimportant. This is consistent with the conclusions drawn by Leaman and Bordass (2000), that as overall satisfaction increases, the need to alleviate discomfort and the importance of perceived control drop. When choice would make possible an escape from bad lighting, then presumably one would observe the predicted benefits in the manner of Glass and Singer (1972).

Despite the absence of performance and satisfaction differences, the CS and PP participants differed in their lighting system choices. PP participants made less use of the perimeter parabolic system than CS participants. This difference lowered the energy consumption of their overall choice, and also lowered the intensity of reflected images on the VDT screen. Two explanations are possible for this finding. It is possible that the fact that the PP choices came at the conclusion of a rather long and dull day of computer work might have confounded the comparison with the CS choices, which were made at the start of the day. However, we prefer an alternative explanation based on the consistency between the PP choices and the written reports from CS participants concerning changes that they would have liked to make to their choices over the day. CS participants reported wanting to reduce screen glare, and when they stated how, they indicated that they would have dimmed the perimeter parabolic luminaires. These findings imply that employees do notice elements in the physical environment that are not optimal, and that they can determine the changes that are necessary to fix the problem.

The duration of the experiment, one working day, was longer than most other lighting experiments of this type, but not long in comparison to the day-in, day-out exposure that regular employees experience. This is an important limitation on these results. Beneficial effects of control over lighting might accrue over time, as conditions thought to be acceptable initially prove to be inadequate. Experience with the space and its lighting, particularly for a variety of tasks, could lead individuals to learn what works and what needs correction, and if there is sufficient need for correction the absence of lighting choices might itself become a stressor. This is the sequence Barnes (1981) described. The PP participants' end-of-day lighting choices, together with the CS participants' desired changes, demonstrate such a process. If longer-term stress processes are triggered by poor luminous conditions that cannot be changed, then perceived control over the luminous conditions would be expected to ameliorate the ill-effects as it does for other environmental parameters. Such effects are probably best studied with a longitudinal field experiment or quasi-experiment, as a laboratory paradigm would be impractical.

Although this experiment demonstrates no simple benefit of having control over lighting in the short term, there could be reason to consider providing individual control over lighting and other environmental features in order to reap benefits over the longer term. Environmental psychologists have long advocated giving individuals the freedom to make choices about the physical environment, and believe that repeated success with such choices leads to feelings of environmental competence and perceived control that can ameliorate the effects of other stressors (Barnes, 1981; Steele, 1973; 1980). The results of this experiment suggest that people can learn from their experiences in a space, even over periods as brief as one day. Enabling individuals to change, modify, or control their luminous environments in their own offices might result in better conditions that will lead to improved work performance and comfort. Future research should consider this possibility. If Barnes and Steele are correct, this experience will lead to an increased feeling of environmental competence that could have other benefits to individuals, much as self-efficacy can lead one to persist in the face of obstacles (Bandura, 1982).

In this experiment, participants knew that whatever their opinions and feelings during the session, it would last only one day; furthermore, they always had the option of leaving early. Present-day informed-consent procedures are known to obscure perceived control effects because all participants always have a choice (Gardner, 1978). In this regard, the experiment was entirely unlike a real workplace. Perhaps in a real workplace, where escape is less easily achieved, the consequences of environmental choice are greater. This might explain, in part, why preferences for environmental control are consistently high.

This possibility deserves further attention, as it could justify providing individual controls in workplaces. That environmental conditions can create affective responses is known (Baron, 1990), and these effects appear to extend to luminous conditions (Baron et al., 1992). If satisfying the desire for control (and thereby also achieving desired working conditions) leads to positive affect, the benefits to cognitive performance, creativity, and prosocial behaviours could be considerable (cf. Isen, 1987).

Environment-behaviour researchers could provide useful design guidance by learning the degree of choice wanted by individuals, and over which environmental conditions (cf. Becker, 1991). For example, individuals appear to have long-term preferences for lighting conditions, which they attempt to re-create each day (Carter, Slater, & Moore, 1999). This might mean that a scene-setting function would be a worthwhile feature in a lighting control system.

Desired levels of environmental control need not require expensive or complex technologies. Dimmable fluorescent lighting and sophisticated controls were used in this case, but window blinds, curtains, local switching, and designs emphasising local, rather than general, illumination (among other low-technology alternatives) might achieve the same end. Meaningful change in luminous conditions could also be achieved by providing flexible furnishings and flexible wiring that allow for a variety of possible locations for a VDT monitor and other working areas. The type of flexibility that this would require is not typical of most furniture systems, which require expert installation crews to maintain warranty protection; or which, at the least, require hand tools and physical strength. Human factors research has a role to play here.

Other researchers warn that experiences of failure can backfire, exacerbating the effects of other stressors (Jutras & Cullen, 1983). Fear of making the wrong choice could lead to unexpected effects, as when lighting choices made under the watchful eye of an authority figure reduced creativity (Veitch & Gifford, 1996b). Such fears could be aroused by complex controls that occupants do not know how to use, or systems that frequently fail; and when individuals are expected to create their own optimal conditions with no instruction in how to do so. Failed attempts to use controls to improve bad lighting (or other environmental) conditions could, in the extreme, lead to learned helplessness. Careful lighting and interior design, appropriate training for using new systems, and quick response when problem arise, are essential to avoid negative consequences (cf. Leaman & Bordass, 2000).

Finally, this experiment provides confirmation that energy-efficient lighting need not be poor-quality lighting. Although some studies have found that people prefer illuminance levels that are higher than current recommended practice (e.g., Boyce, 1979; Halonen & Lehtovaara, 1995), most participants here (70% of CS participants, and 66% of PP) chose luminous conditions consistent with or lower than current recommended practice for VDT office lighting (IESNA, 1993). (For a more detailed comparison of these results with other lighting standards, see Veitch & Newsham, 1999.) Higher levels were available, but these participants did not choose them. Overall, the results show high satisfaction with lighting conditions that generally met existing codes and standards for energy consumption.. Energy conservation efforts can take heart from this and other evidence (Veitch & Newsham, 1998b) that energy efficiency and quality are not incompatible goals for lighting design.

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Endnotes

[1] The Grammatik™ software calculates the grade level of written work using the following formula: (0.39 * average number of words/sentence) + (11.8 * average number of syllables per word). Writing in the range of grade 6-10 is considered most readable (Reference Software International, 1990), and was the range in which these participants wrote. More complex writing may be less effective; therefore, we assumed that for this task, lower grade scores would be preferable to higher ones.

[2] When null results are obtained, one obvious possible explanation is that the tasks and measures were not sensitive to changes. This is unlikely in the present case because the measures had been previously used to demonstrate some quite subtle lighting- and environment-related effects (e.g. Brill et al., 1984; Hedge et al., 1992; Nelson et al., 1984; Veitch & Newsham, 1998b); also, non-lighting effects were observed in this experiment that were consistent with previous research in both direction and size (Veitch & Newsham, 1998b). Another possibility is that the sample size was too small for the detection of a medium-sized effect. This cannot be conclusively eliminated. The target sample size of 60 pairs was selected because it gave close to the optimal power for the detection of a medium-sized effect (power=.78 [.80 is optimal; Cohen, 1988]). The loss of participants reduced the theoretical power of the experiment to .67; thus, it is possible that had the sample size been larger, statistically significant effects might have been observed. Indeed, examination of the mean scores for the two choice conditions shows that the trend for performance scores was towards slightly better performance for CS participants. For satisfaction, mood, and physical sensations, however, the differences are so small as to be meaningless.

Table 1
Lighting Fixture Characteristics

Circuit #	General Description	Position	Details
1	Direct parabolic	Ceiling (centre)	1’ x 4‘ fixture with 2-32 W lamps (x 10), dimmable (10 – 100 % maximum)
2	Direct parabolic	Ceiling (perimeter)	1’ x 4‘ fixture with 2-32 W lamps (x 10), dimmable (10 – 100 % maximum)
3	Indirect	Partition-mounted	4‘ fixture with 2-32 W lamps (x 8), dimmable (30 – 100 % maximum)
4	Task prismatic	Undershelf	2’ fixture with 1-17 W lamp (x 6), non-dimmable

Note. Circuit numbers are shown in Figure 1. All ballasts were electronic. All lamps were T8, 3500 K Colour Temperature, Colour Rendering Index =80.

Table 2
Experimental Procedure and Dependent Measures

Approx. Time	Task		Duration (min)
8:30 a.m.	Arrival, greeting, instructions, consent, all in reception room with E1.		15
9:00 a.m.	CS: In work area, received instruction for lighting choice procedure and made choices (also adjusted chair & keyboard) [E2]	PP: In reception room, completed baseline visual performance test, VALiD [Rea, 1988]; then waited for CS to return [E1].	20
	CS: In reception room, completed VALiD, then waited for PP. [E1]	PP: In work area, read general institutional information, adjusted chair & keyboard [E2].	20
9:25	Both participants in work area, Demographics questionnaire*: • age, sex, education, work history, personal & family health status		5
	Mood questionnaire (baseline) (Russell & Mehrabian, 1977): • 18-item semantic differential, 3 factors: pleasure, arousal, & dominance		5
	Physical Sensations Questionnaire (baseline): • headache, eyestrain, sore wrists/arms, general fatigue (adapted from Hedge, Ericson, & Rubin, 1992) • thermal sensations (Schiller et al., 1988)		5
	Coffee Break (reception room)		15
9:55	The tasks alternated for the 120-minute work period. • Typing (Newsham, Scovil, & Veitch, 1995a; Veitch & Newsham, 1998b) - 4 paragraphs or 30 minutes • Proofreading (Newsham, Scovil, & Veitch, 1995b; adapted from Rea, 1986) - 5 10-row lists of paired items for comparison, or 16 minutes • Creative writing (Murray, 1939; as used in Nelson, Nilsson, & Johnson, 1984). - a story for one picture, or 14 minutes • Rest screens (PC recorded duration of pauses between tasks [cf. Boyce & Eklund, 1996])		120
12:00	*Lunch (Reception room)*		*45*
12:45 p.m.	As in the morning, the tasks alternated: • Typing • Proofreading • Creative writing		120

<table>
<tr><th>Approx. Time</th><th colspan="2">Task</th><th>Duration (min)</th></tr>
<tr><td></td><td colspan="2">• Rest screens</td><td></td></tr>
<tr><td>2:45</td><td colspan="2">Mood Questionnaire</td><td>5</td></tr>
<tr><td>2:50</td><td colspan="2">Physical Sensations Questionnaire</td><td>5</td></tr>
<tr><td>2:55</td><td colspan="2">Satisfaction Questionnaires:
• Environmental Satisfaction (Brill et al., 1984)
• Lighting Quality (adapted from Collins, Fisher, Gillette, & Marans, 1990; Miller, McKay, & Boyce, 1995; Veitch, Miller, McKay, & Jones, 1996; Veitch & Newsham, 1998b)</td><td>5</td></tr>
<tr><td>3:00</td><td colspan="2">Coffee Break (reception room)</td><td>15</td></tr>
<tr><td>3:15</td><td colspan="2">Participants left the work area one at a time to do the second visual performance measure, in between questionnaires:
Survey of Personal Influence in Common Environments (Gifford & Eso, 1988):
• actual influence over environmental features in general
• desired influence over environmental features
Workday Experiences Questionnaire:
• manipulation checks concerning lighting, session, & environmental control (adapted from Veitch & Gifford, 1996)
• general lighting preferences
• self-rated productivity (% change in this environment compared to usual, 9-point scale [Wilson & Hedge, 1987])
• task and questionnaire difficulty ratings (5-point scale)
• open-ended probes for expectancy biases
2nd VALiD [E1] - in reception room.</td><td>20</td></tr>
<tr><td>3:35 p.m.</td><td colspan="2">Debriefing and farewell [E2] (reception room)</td><td>20</td></tr>
<tr><td>4:00 p.m.</td><td>CS completed exit questionnaire about desired lighting changes during the session, then departed [E1].</td><td>PP returned to work area to complete the choice procedure, reporting the lighting conditions he/she would have preferred [E2].</td><td>10</td></tr>
</table>

Note. VALiD = Vision and Lighting Diagnostic test for visual performance. E1 and E2 were female and male experimenters, respectively. CS = chose session lighting participant. PP = post-session preferred lighting participant. * All data collection in the work area was PC-based, using a Windows™ interface and black-on-white screen conditions, which optimise performance and are in common use today (Sanders & Bernecker, 1990; Veitch & Newsham, 1998b).

Table 3
Rotated Component Loadings and Subscale Statistics: Perceived Control

Item	Perceived Session Control	Environmental Control	Perceived Lighting Control
The NRC staff had all the control during the day. (R)	0.791		
I had some control over events today.	0.738		
Others controlled every aspect of what occurred during the session, including the environmental conditions. (R)	0.582		0.564
The type and amount of lighting where I work affects my work performance.		0.750	
Comfortable conditions allow me to work more effectively.		0.713	
I work better when I like the physical setting I am in.		0.691	
Being able to control my environment makes me feel better.		0.614	
My mood depends on the features of my environment.		0.516	
I had some control over the lighting in this office.			0.900
There were choices I could make about the lighting where I worked today.			0.875
How well I perform depends entirely on me.			
Cronbach's α	.77	.70	.96
Subscale mean (standard deviation), N=94	2.05 (0.90)	3.11 (0.53)	2.22 (1.48)

Note. One item loaded highly on two components. It was retained as part of Perceived Session Control in order to maximise the internal consistency reliability of both subscales. Subscale scores were computed as averages of contributing item scores. One item did not load on any component, and was disregarded. All scales are from 0-4, with 0 indicating no control and 4 indicating strong perceived control.

Table 4
MANOVA Results for Perceived Control Subscales

Variable	Mean (Standard Deviation) CS	PP	Test Statistics	Effect Size R^2 (%)
Multivariate			Wilks' Λ = 0.176 *F*(3,90)=140.17 ***	34.2 (average)
Perceived Session Control	2.45 (0.76)	1.65 (0.85)	*F*(1,92)=23.37 ***	20.2
Environmental Control	3.13 (0.45)	3.09 (0.61)	*F*(1,92)=0.12	0.13
Lighting Control	3.55 (0.49)	0.88 (0.74)	*F*(1,92)=425.56 ***	82.2

Note. ****p*<.001. All scales are from 0-4, with 0 indicating no control and 4 indicating strong perceived control.

Table 5
Descriptive Statistics for Participants' Use of Lighting Systems, by Choice Condition

	Mean	SD	Percentiles		
			25th	50th (Median)	75th
CS Participants					
Furniture-Mounted	0.72	0.27	0.59	0.76	0.97
Perimeter Parabolic	0.56	0.30	0.38	0.50	0.86
Centre Parabolic	0.54	0.31	0.32	0.58	0.80
Task Lamp	0.94		1.00	1.00	1.00
PP Participants					
Furniture-Mounted	0.68	0.28	0.44	0.77	0.97
Perimeter Parabolic	0.35	0.34	0.01	0.24	0.54
Centre Parabolic	0.52	0.37	0.14	0.48	0.96
Task Lamp	0.83		1.00	1.00	1.00

Note. For Task Lamp, the mean value is the proportion of people choosing to use it: 94% of CS participants, and 83% of PP participants. For Lighting Systems, mean indicates the mean fraction of full light output for each dimmable system (also called "use fraction").

Table 6
Participants' Chosen Luminous Conditions, by Choice Condition

	Mean	SD	Percentiles		
Luminous Condition			25th	50th (Median)	75th
CS Participants					
LMM	2.98	0.27	2.75	2.94	3.14
$\mathbf{I}_{ave}$ (cd/m^2)	40.6	11.0	33.7	40.4	47.7
$^{VDT}\mathbf{G}_{l}$ (cd/m^2)	43.9	18.9	45.0	50.2	55.0
$^{VDT}\mathbf{G}_{\%}$ (%)	1.22	1.08	0.20	0.95	2.25
$^{VDT}\mathbf{I}_{B}$ (cd/m^2)	15.9	4.7	12.6	15.7	19.3
E_D	445	147	356	413	544
$^{CEIL}\mathbf{I}_{MAX}$ (cd/m^2)	432	181	323	438	546
LPD (W/m^2)	15.5	4.3	13.1	15.1	18.9
PP Participants					
LMM	3.05	0.37	2.75	3.01	3.16
$\mathbf{I}_{ave}$ (cd/m^2)	37.1	12.5	27.8	37.3	47.5
$^{VDT}\mathbf{G}_{l}$ (cd/m^2)	34.3	25.0	0.0	46.7	54.1
$^{VDT}\mathbf{G}_{\%}$ (%)	0.76	0.87	0.00	0.50	1.13
$^{VDT}\mathbf{I}_{B}$ (cd/m^2)	14.0	4.9	10.5	14.8	18.2
E_D	400	155	296	400	538
$^{CEIL}\mathbf{I}_{MAX}$ (cd/m^2)	425	208	278	425	542
LPD (W/m^2)	13.2	4.2	10.6	14.1	15.7

Note. LMM is the log(maximum:minimum luminance, 40-degree band). $\mathbf{I}_{ave}$ is the average luminance in the 40-degree band (field of view). $^{VDT}\mathbf{G}_{l}$ is the average luminance of VDT screen areas with luminance > 40 cd/m^2 (black screen). $^{VDT}\mathbf{G}_{\%}$ is the % of black screen area with luminance > 40 cd/m^2. $^{VDT}\mathbf{I}_{B}$ is the average black screen luminance. E_D is the desktop illuminance on an unobstructed point away from the task lamp. $^{CEIL}\mathbf{I}_{MAX}$ is the maximum luminance on the ceiling within the digital image. LPD is the lighting power density, calculated as measured power consumption/area.

Table 7
Summary of Lighting System Use and Luminous Conditions MANOVAs

Variable	Mean (Standard Deviation) CS	PP	Test Statistics	Effect Size R^2 (%)
Lighting Systems MANOVA			Wilks' Λ = 0.889 $F(3,90)= 3.36$ *	3.5
Partition-Mounted	0.72 (0.27)	0.68 (0.29)	$F(1,92)=0.46$	0.5
Perimeter Parabolic	0.56 (0.30)	0.35 (0.34)	$F(1,92)=10.30$**	10.0
Centre Parabolic	0.54 (0.32)	0.51 (0.37)	$F(1,92)=0.08$	0.1
Luminous Conditions MANOVA			Wilks' Λ = 0.870 $F(6,87)= 2.16$ *	2.8
LMM	2.98 (0.28)	3.05 (0.38)	$F(1,92)= 1.14$	1.2
$\mathbf{l_{ave}}$ (cd/m^2)	40.6 (11.2)	37.1 (12.6)	$F(1,92)= 2.03$	2.2
$^{\mathbf{VDT}}\mathbf{G_l}$ (cd/m^2)	43.9 (10.1)	34.3 (25.2)	$F(1,92)=4.30$ **	4.5
E_D (lux)	445 (147)	400 (155)	$F(1,92)= 2.06$	2.2
$^{\mathbf{CEIL}}\mathbf{l_{MAX}}$ (cd/m^2)	431.7 (183)	425.3 (211)	$F(1,92)=0.03$	0.0
POWER (W)	1265 (353)	1079 (346)	$F(1,92)=6.71$**	6.8

Note. * $p<.05$. ** $p<.01$.

Table 8
Component Loadings and Subscale Statistics: Lighting Quality Ratings

Item	Lighting Quality	Glare
Overall, how satisfied are you with the lighting at your work space?	.844	
Rate the lighting available to you for reading.	.808	
Rate your workstation on the amount of light for the work you did today.	.798	
How do you rate the acceptability of the lighting in this office?	.786	
Lighting at my desk hindered me from doing my job well. (R)	.561	
How much do the reflections in the computer screen bother you?		.881
How much does the glare bother you?		.868
% Variance	45.47	24.35
Cronbach's α	.85	.88
Subscale mean (standard deviation), N=94	4.07 (0.79)	1.83 (1.09)

Note. Scale minimum 1, maximum 5. Higher values indicate better lighting quality and more bothersome glare.

Figure 1. Photograph of the work area, NRC's Indoor Environment Research Facility. The photograph shows the furniture-mounted indirect luminaires and the recessed parabolic louvered luminaires in the ceiling. There were two circuits for the recessed luminaires, along the long axis of the room: one circuit at the perimeter of the room, and one for the luminaires in the centre of the room. Undershelf task lamps were attached to the binder bins in each workstation. Only the two centre workstations were occupied for this experiment.

Figure 2. Layout of furniture and reflected ceiling. Numbers indicate the individual circuits described in text and in Table 1.

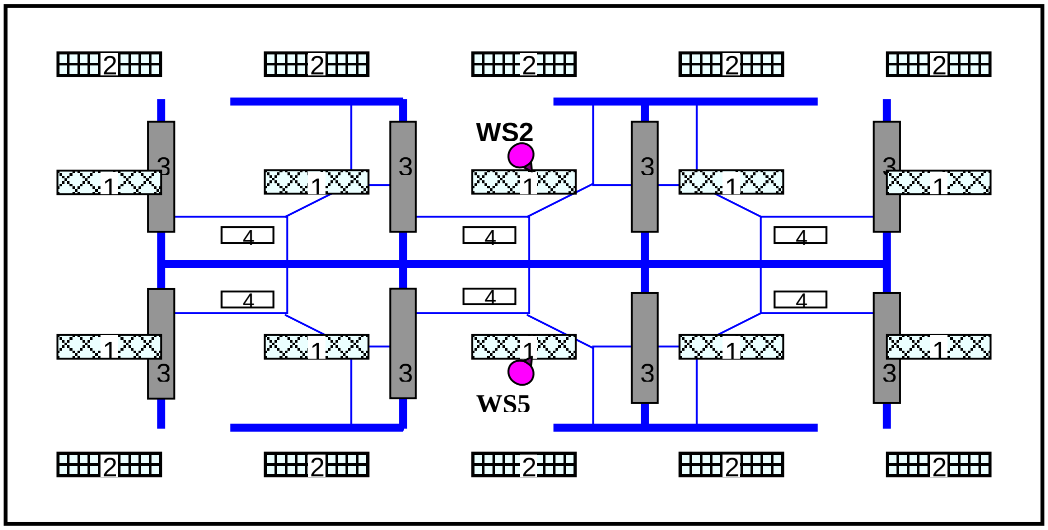

Figure 3. A and B. Photograph (A) of workstation view and line diagram (B), showing definitions of derived photometric values.

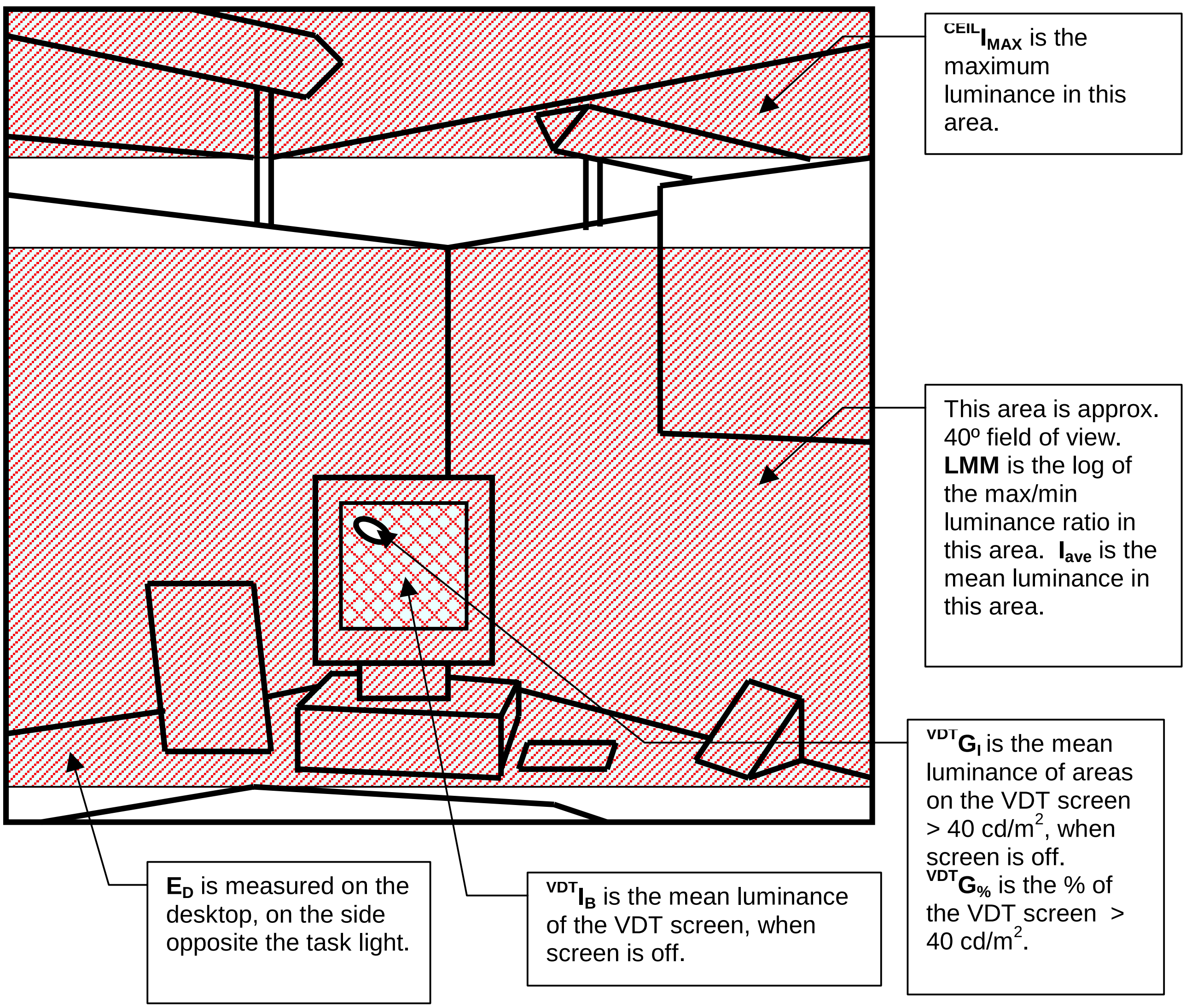

Figure 4. Frequency distribution of desktop illuminance levels (unobstructed side), by choice condition.