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Summary The weekly incidence of headaches among office workers was compared when the offices were lit by fluorescent lighting where the fluorescent tubes were operated by (*a*) a conventional switch-start circuit with choke ballast providing illumination that pulsated with a modulation depth of 43–49% and a principal frequency component at 100 Hz; (*b*) an electronic start circuit with choke ballast giving illumination with similar characteristics; (*c*) an electronic ballast driving the lamps at about 32 kHz and reducing the 100 Hz modulation to less than 7%. In a double-blind cross-over design, the average incidence of headaches and eyestrain was more than halved under high-frequency lighting. The incidence was unaffected by the speed with which the tubes ignited. Headaches tended to decrease with the height of the office above the ground and thus with increasing natural light. Office occupants chose to switch on the high-frequency lighting for 30% longer on average.

Fluorescent lighting, headaches and eyestrain

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1 Introduction

An intermittent light no longer appears to flicker when the frequency exceeds some limit commonly referred to as a flicker 'fusion' threshold. When the light is bright and diffuse and stimulates a large retinal area this threshold can be as high as 90 Hz but is rarely higher[1]. The 'fusion' threshold cannot, however, be taken as a limit above which intermittent light has the same effect as continuous light. First, Greenhouse and colleagues[2] have recorded human electroretinogram responses to intermittent light at frequencies higher than 100 Hz. Second, Brindley[3] demonstrated psychophysically that the nervous system resolves intermittent light at frequencies at least as high as 125 Hz. He stimulated the retina electrically so as to produce the appearance of flashes of light (phosphenes). When he increased the frequency of electrical stimulation sufficiently the phosphenes appeared continuous. Brindley combined electrical stimulation and stimulation from flickering light simultaneously, at frequencies at which both forms of stimulation appeared continuous when presented on their own. When the frequencies of the combined electrical and visual stimulation were slightly different observers reported seeing the beat between the two. The beat was perceptible when the visual stimulation had a frequency as high as 125 Hz indicating that, at some level, the visual system was resolving the stimulation at this frequency.

Fluorescent lamps operating on an AC supply emit light that pulsates in brightness[4]. Twice with each cycle of the electricity supply (e.g. at 100 Hz) the light output varies between a maximum and about 60% of that maximum, depending on the decay rates (persistence) of the phosphors and the range of wavelengths measured. The light output also varies slightly at half this frequency (i.e. at the frequency of the AC supply) partly because the dark spaces in front of the cathode alternate between the ends of the tube, and partly because the electrodes may burn unevenly, and as the tube ages an asymmetrical discharge can result.

¶ The paper is a revised version of one presented to the 1988 National Lighting Conference, Cambridge, UK.

Eysel and Burandt have demonstrated that the pulsating light from a fluorescent tube affects the firing of nerve cells in the visual pathways[5]. Cells in the optic tract and the lateral geniculate nucleus of the cat fire more strongly under fluorescent lighting than they do in response to daylight or the light from a filament lamp. The firing rate under fluorescent light is almost twice that under incandescent light with the same time-averaged luminance. Not only do the cells fire more strongly, they fire with each pulse in light output from the tube. Some cells respond at the same frequency as the light modulation (i.e. 100 Hz), others at lower frequencies, but the firing of each cell occurs at the same point in the light cycle, about 9 ms after the peak.

As Eysel and Burandt point out, neurons connected to optic tract or geniculate cells by short neural chains should show a similar phase-locked response. These include cells in the superior colliculus, a body associated with the control of eye movements. For this reason Wilkins[6] investigated the effects of the pulsations from fluorescent light on eye movements across text. He asked observers to move their eyes repeatedly between two specified letters on the same line in a page of text and measured the size of the high-velocity eye movements (saccades). He found that the saccades were slightly larger under conditions of conventional fluorescent lighting than under conditions in which the light was relatively steady. The increase was very small, only about 4%, and it was also very weak, accounting for only about 4% of the experimental variance. Nevertheless the increase in saccade size may help explain the findings of Rey and Rey[7] who measured the performance of a complex visual search task under fluorescent lighting. They reported slightly poorer performance when the light pulsated in the conventional manner. They also reviewed a number of early studies showing small effects of the light pulsation on vision and visual performance. The effects were small and not always consistent.

The complaints which have been associated anecdotally with fluorescent lighting have not concerned the ability to see or to read: they have concerned headaches and eyestrain. In a recent survey of office workers[8] 41% reported that the lighting gave them headaches or affected their eyes. There are several lines of evidence to link these complaints with the pulsations from fluorescent lighting. The visual evoked potential in response to intermittent light is abnormal in headache sufferers. Golla and Winter[9] and Smyth and Winter[10] showed that the amplitude of the potential measurable on the scalp when an observer looks at a flickering light was greater in people suffering from headaches than in controls. These findings have since been replicated using modern techniques[11]. Brundrett[12] extended the findings to high frequencies. He measured the amplitude of the occipital voltage as flash frequency increased, and showed that in a small sample of headache sufferers the reduction in amplitude with increasing frequency was less than in controls. At high flash rates the response in headache sufferers may therefore be unusual.

Recently, 240 V circuitry suitable for the high-frequency operation of fluorescent lamps has become generally available. This new form of lighting uses an electronic ballast to drive the discharge tubes at about 32 kHz and therefore with 64 kHz pulsations. Amplitude modulation of the high frequency waveform occurs at a frequency of 100 Hz due to fluctuations in the oscillator supply voltage, but these do not result in a fluctuation of more than 7% in the light output. The light does not evoke phase-locked responding in cat neurons (U T Eysel, personal communication). The present study was designed to discover whether this form of lighting would be associated with fewer complaints of headaches than lighting from the more conventional choke circuitry.

Volunteers were recruited from the staff of a government legal department. The site was chosen on the basis that (*a*) there was a large number of small offices receiving little daylight, (*b*) the occupancy was stable, (*c*) the staff undertook close visual work almost entirely without the use of computer displays; (*d*) the luminaires already installed were of a kind which permitted the ready exchange of the ballast circuitry without altering the outward appearance of the fitting. The volunteers were asked to complete a weekly headache questionnaire for one year beginning April 1986.

Three forms of lighting were compared: (i) conventional choke ballast with switch start; (ii) choke ballast with electronic start; (iii) high-frequency (32 kHz) solid-state ballast. The first two provide illumination with a peak–peak modulation of more than 40% and a principal frequency component at 100 Hz, although the first ignites more slowly and less consistently than the second. The third ignites almost immediately and the peak–peak modulation at 100 Hz is less than 7%. The first two forms of lighting will be referred to as 'conventional' and the third as 'new'.

The lighting conditions were allocated at random at the end of April 1986 and then changed over in January 1987, halfway through the winter period during which the days were short. The new (high-frequency) ballast was replaced by conventional, and some of the conventional by new. The change was made without informing the occupants. The study therefore had the features of a double-blind cross-over design. The electronic start was included as a 'placebo': a form of lighting which was noticeably different from the existing lighting. The fact that the 'placebo' differed only with respect to the speed of ignition meant that it was possible to ascertain whether the speed of ignition or other associated effects were relevant to the comparison of the new and conventional lighting. In addition the (conventional) lighting in some offices remained unchanged throughout the study so as to provide a baseline control.

2 Methods

2.1 *Characteristics of the lighting*

The lighting from the lamps controlled by conventional choke ballast, both switched start and electronic start, had a principal component of modulation at 100 Hz. The depth of modulation was measured using an eye-response (V_λ) corrected photodiode connected to an oscilloscope via circuitry appropriate for a linear output. The modulation depended on the phosphors of the lamps in the (pre-existing) installation. Most lamps were cool white (Thorn Cool White) and gave a light modulation of 49–50% of maximum. The remainder were white (Wotan 23) and gave a modulation of 43–47%. Figure 1 shows an example of the light output as a function of time. The modulation at 50 Hz relative to total light output was measured using the Thorn flicker meter FM101 incorporating a matched filter. The 50 Hz modulation (defined as the average amplitude of the 50 Hz component expressed as a proportion of the timed-averaged total light) was in the range 0–2%, and was typically less than 1%.

The new high-frequency lighting had a component of modulation at 100 Hz but the peak–peak amplitude was less than 7%. The circuitry consumed 28% less power but emitted slightly less light. The time-averaged luminance of a section of a tube controlled by new high-frequency circuitry was about 5% lower than that from conventional circuitry, suggesting a 5% lower light output. This would mean that the glare index was 0.1 lower.

The installation consisted mainly of Thorn Clipper I twin-tube luminaires which had the advantage that the controlling circuit could be altered without affecting the outward appearance simply by exchanging the luminaire body (spine). All luminaires were fitted with prismatic refractors which partially concealed the spines (Figure 2). Most offices had two luminaires suspended from the spines on chains, at a distance of about 0.4 m from the ceiling, which was 2.8 m high. The rooms mostly had one window, with three walls painted white and one coloured, typically a high chroma orange or mustard. The luminaires could be turned on or off by the occupants by means of a combination of switches at the door and pull cords from the luminaires. All the luminaires within a room were connected to the same phase of the electricity supply.

The illuminance of the work surface depended on the reflectance and positioning of room surfaces and varied from room to room between 400 and 900 lux when one nearby luminaire

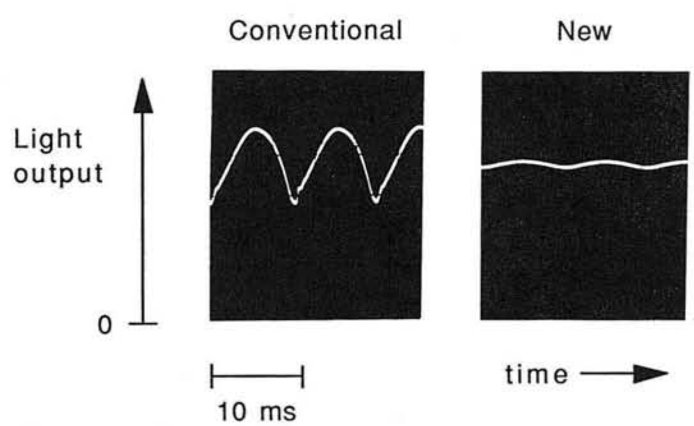

Figure 1 Light output from a conventional and new high-frequency circuit as a function of time

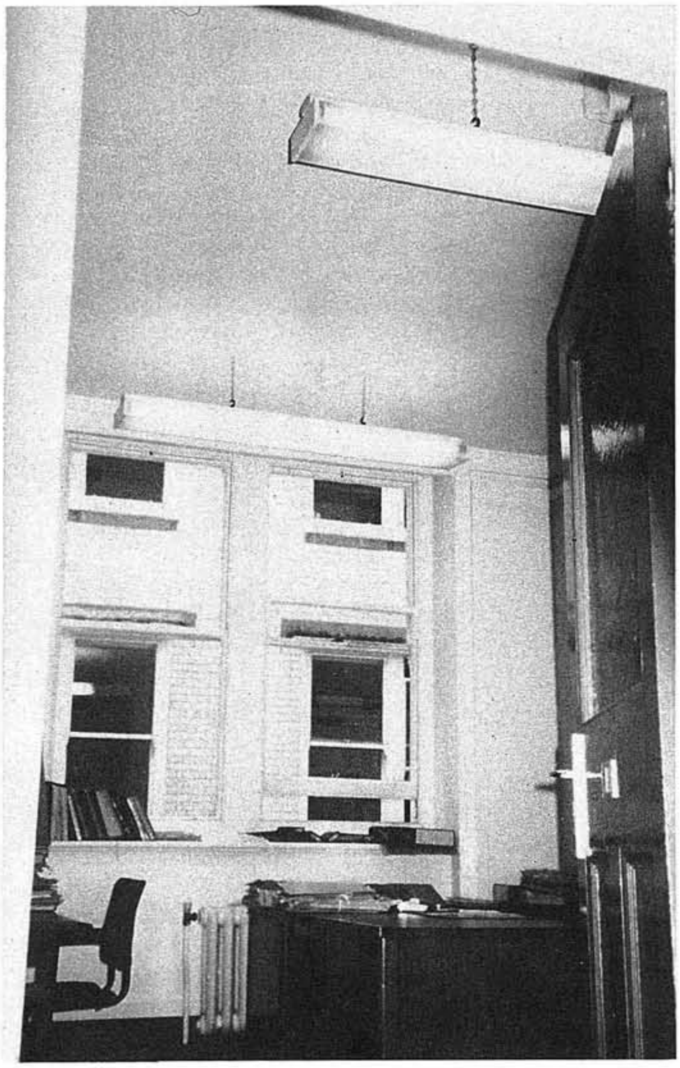

Figure 2 Typical office, showing lighting fixtures

was illuminated and there was no daylight. Because each room had a window and many luminaires could be switched on and off individually, the variability in the illuminance of the work surfaces was almost certainly greater than the above figures would suggest.

Timers were added to a sample of luminaires to measure the number of hours during which the luminaire was switched on. Four were noisy and had later to be removed.

2.2 Recruitment of subjects

The entire staff of a government legal department (about 300 people in all) received a letter inviting them to participate in a headache survey. The letter informed them (*a*) that although fluorescent lighting had been associated anecdotally with complaints of visual discomfort there had been little scientific study of the complaints; (*b*) that recent evidence had suggested that the discomfort might be due in part to the operation of the lighting; (*c*) that a new form of circuitry had now become available which changed the method of operation; (*d*) that the new lighting nevertheless had exactly the same appearance as that from the conventional circuitry currently installed in the building; (*e*) that if they agreed to participate in the study the lighting in their office would be changed from one type to the other over the course of the next 12 months; (*f*) that if they agreed to participate they would be asked every week to complete a two-minute questionnaire and leave it in their 'out'-tray; (*g*) that every completed questionnaire would result in the donation of 10p to the Civil Service Benevolent Fund; (*h*) that for scientific reasons it was essential to ensure that participants were unaware as to when the lighting conditions were changed and that therefore the conventional circuitry would initially be altered slightly so that the manner in which the tube ignited would not distinguish one method of operation from the other.

2.3 Questionnaires

The questionnaire asked the respondent to put an S to represent a severe headache, an M to represent a mild headache, or a 0 to represent 'no headache' against each day of the week (Monday–Sunday), and then to do the same for episodes of 'eye-strain'. They were asked to say whether they knew of any reason for the episodes, and, if they had been absent from the office all week, to indicate as much. They then entered their room number, signed the questionnaire and placed the sealed envelope in their 'out'-tray, where it was collected by the internal mail service. The questionnaires were distributed every Monday morning and collected the following week.

Note that the questionnaire did not request subjective ratings of visual discomfort. In pilot studies in which visual acuity was measured and discomfort rated, no reliable differences between the new and conventional lighting had been obtained.

At the end of the study an additional questionnaire was circulated asking participants to indicate whether they thought the lighting in their office had been changed, and if so to indicate how many different types of lighting had been used and when they had been installed.

2.4 Sample

One hundred and seventy-eight people initially agreed to complete the weekly questionnaire. Over the course of the following 5 months 19 were lost to the study and will not be considered further. In the autumn there were 159 regular respondents, 92 men and 67 women, aged 20–60 (mean 38, SD 11). Twenty-four dropped out before the January change-over in lighting, and a further 2 afterwards. The data from 6 could not be used owing to the inadvertent installation of luminaires with more than one type of ballast within one office. Five participants were telex operators and used visual display terminals.

2.5 Installation and design

Most offices had two twin-tube Thorn Clipper I luminaires. In April 1986 high-frequency ballasts were installed during the quiet hours in the offices of 35 randomly selected participants, 7 of whom shared a room with another. During the same period electronic starting circuits were installed in the offices of a further 33 randomly selected participants, four sharing. The lighting remained unchanged in the offices of the other participants, 14 sharing. For 6 of these participants the pre-existing installation included electronic starters. The allocation of offices to experimental conditions was random, with the constraint that offices on the top floor, which received more daylight than the remainder, were not altered in any way.

In January 1987 the ballasts and starters were changed. For 15 participants the change was from high-frequency ballast

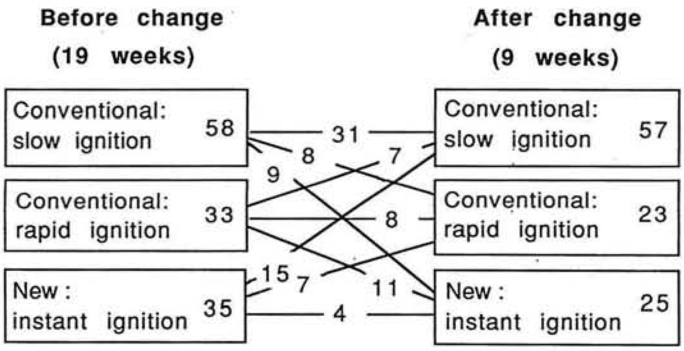

Figure 3 Schematic representation of the design of the study, showing the number of subjects in each condition at each period, and the number who changed from one condition to another

to choke ballast with switch start, and for 9 the change was in the opposite direction. For 7 the change was from high-frequency ballast to choke ballast with electronic start, and it was the reverse for 11. Seven participants were changed from electronic to switch start, and 8 the reverse. The remaining participants did not receive any change: these included 4 who continued to receive high-frequency lighting after the changeover because their rooms were inaccessible during the changeover period.

Figure 3 summarises the details of the design, including the sample sizes before and after the changeover and the number undergoing change. Note that the number of subjects in a condition is greater than the number who changed from or to that condition because a few subjects occupied offices in which the luminaires were of mixed types and a few dropped out after the change in lighting.

Two administrative personnel in the building knew the dates and times of the lighting changes but not the detail or the nature of the changes. These were known only to the study organisers and the electrical contractors. Unfortunately the latter left wiring debris in a few offices. Although this may have alerted some participants to the fact that work on the lighting had been undertaken, the nature of the work was not, of course, disclosed.

2.6 Data preparation

The sealed envelopes were posted to Cambridge weekly and the data entered on a microcomputer using a simple database program. Episodes of headache or eyestrain were included regardless of whether the respondent noted a reason for the episode, but if respondents had been absent from the office all week their data were excluded. Mild and severe categories were combined and weekend headaches excluded. Over the course of the year three different assistants performed the data entry task, none of whom knew any of the participants or had access to the condition codes. The data were transferred to a mainframe computer for reduction and analysis.

Data were analysed for 19 weeks before the January change in lighting and 9 after.

3 Results

Responses to the questionnaire distributed at the end of the study indicated that participants were uncertain as to when or how often the lighting had been changed. 40% of the subjects whose lighting was changed thought a change had been made, as compared with 29% whose lighting had not been changed (chi-square = 0.73, $p = 0.39$). When dating the change, only 3 participants chose the appropriate month. The weekly questionnaires asked the volunteers whether they knew of any reason for reported episodes of headache or eyestrain. Few subjects completed this section of the questionnaire but those who did so attributed the episodes to factors other than the lighting. For example, during the week beginning 23 February, 24 subjects reported headache or eyestrain and 8 attributed these episodes variously to colds or infections (3 subjects), strain and pressure of work (2 subjects) or other less common factors such as late nights or people smoking.

The mean weekly incidence of headaches or eyestrain was obtained by dividing the number of reported episodes by the number of weeks for which data were available. The correlation between the means and the number of weeks contributing to the means was negligible (the Spearman rank correlation coefficient before the changeover was +0.02, $n = 127$, and after, −0.08, $n = 107$) suggesting that participants who were relatively susceptible to headaches or eyestrain were not disproportionately diligent about completing their questionnaires.

The distribution of the incidence of episodes of headaches and eyestrain was highly skewed (see Figures 4 and 7), many people reporting few episodes and a few reporting many. Distribution-free Mann-Whitney U-tests were used to compare the groups, except where indicated.

3.1 Baseline

Data were available from 54 participants who experienced the same lighting conditions throughout (including those who experienced lighting from luminaires of mixed types). The mean weekly incidence of headaches was 0.53 (standard deviation 0.88) before the January changeover in lighting and 0.41 (SD = 0.74) after. The difference does not approach significance.

3.2 Speed of lamp ignition

The difference between the switched start and the electronic start conditions was small, inconsistent and did not approach significance. Over the autumn period, before the changeover in lighting, the weekly incidence of headaches (excluding those at weekends, and combining mild and severe categories) averaged 0.45 (SD = 0.86) for the 57 subjects exposed to lighting from choke circuitry with switch start, and 0.49 (SD = 0.73) for the 33 subjects using choke circuitry with electronic start. After the changeover the corresponding means were 0.51 ($N = 57$; SD = 0.86) and 0.50 ($N = 29$; SD = 0.59). In the analyses which follow the switched start and electronic start conditions are combined and jointly referred to as the 'conventional lighting' condition.

3.3 Phosphor

The mean weekly incidence of headaches under conditions of conventional illumination from tubes with a white phosphor was 0.42 ($N = 20$; SD = 0.92) and from tubes with a cool white phosphor was 0.45 ($N = 47$; SD = 0.69). The difference does not approach significance, and in the analyses that follow the nature of the phosphor will be ignored.

3.4 Pulsation

Table 1 and Figure 4 summarise the data for the new and conventional lighting conditions, from which it is evident that conventional lighting was consistently associated with

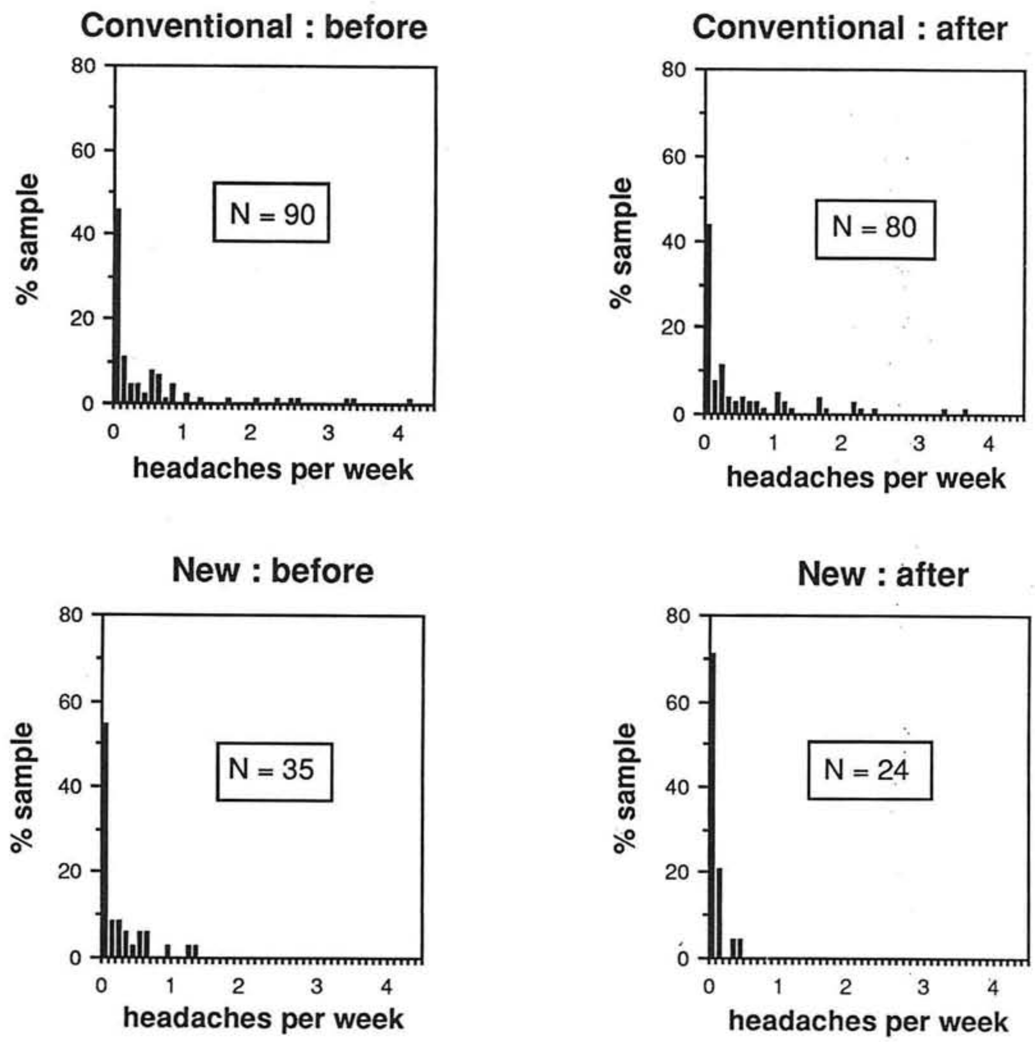

Figure 4 Histograms of the weekly incidence of headaches among subjects exposed to new and conventional lighting, before and after the changeover from one form of lighting to the other

an incidence of headaches approximately twice that under the new lighting: $z = 1.12$, $p = 0.12$, one-tailed, before the changeover and $z = 2.90$, $p = 0.0018$, one-tailed after.

Of the 42 subjects for whom data were available for both new and conventional lighting, 20 experienced the conventional lighting before the changeover and 22 the reverse. The distribution of the differences in subjects' headache incidence under the two lighting conditions was not appreciably skewed and t-tests based on the mean of the differences were therefore appropriate. The difference in headache incidence was significant for the group which experienced the conventional lighting first, (paired-$t(19) = 2.31$, $p = 0.02$, one-tailed), but not for the group which experienced the reverse order (paired-$t(21) = 0.35$, $p = 0.36$, one-tailed). When the two groups were combined the aggregate difference was marginally significant, $t(40) = 1.60$, $p = 0.059$, one-tailed. Figure 5 shows the headache incidence under the two conditions.

The general picture was unchanged when data from the top floor were excluded from the analysis.

Figure 6 shows the correlation between individual subjects' reports of headaches and of eyestrain. As can be seen, subjects who reported many headaches tended also to report frequent eyestrain. The correlation is not high, however: the Spearman rank correlation coefficient was only +0.51 despite the large number of subjects who reported neither type of pain. The reports of eyestrain were therefore analysed separately.

Table 1 The average weekly incidence of headaches before and after the changeover in lighting, shown separately for new and conventional lighting. The standard deviation (SD) and the number of subjects (N) for whom data are available are also shown.

Population	Conditions	Before			After		
		N	Mean	SD	N	Mean	SD
(a) All subjects (including those for whom data are available for only one of the lighting conditions)	Conventional	90	0.47	0.82	80	0.51	0.79
	New	35	0.24	0.35	24	0.06	0.11
(b) Subjects for whom data are available for both conditions before and after the changeover between new and conventional lighting	Conventional/new	20	0.23	0.33	20	0.06	0.12
	New/conventional	22	0.31	0.40	22	0.34	0.60

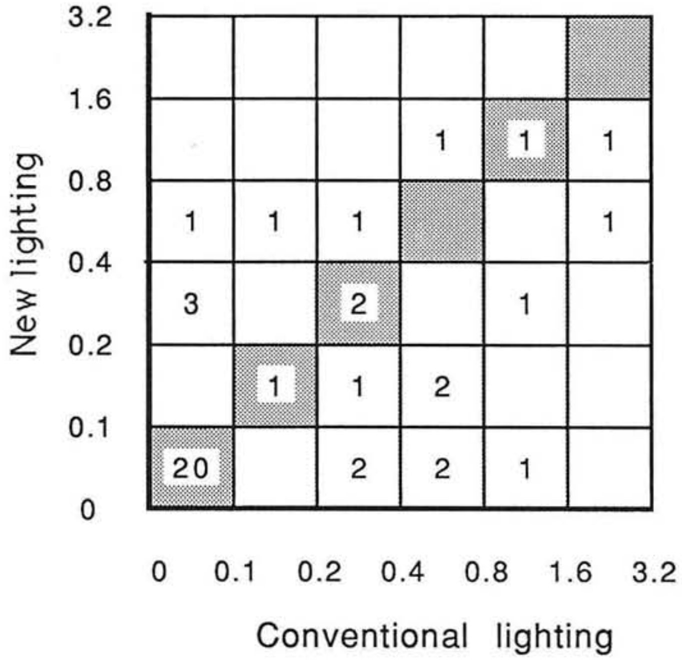

Figure 5 Scatterplot showing the weekly incidence of headaches under new and conventional lighting for the 42 subjects who experienced both conditions. The number in each cell indicates the number of subjects. There is a weak tendency for data to lie below the diagonal, suggesting a slightly greater susceptibility to headaches under conventional lighting

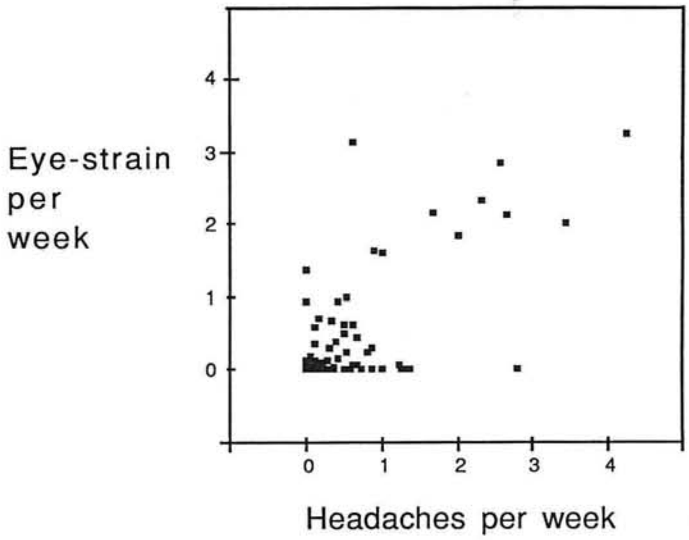

Figure 6 The correlation between individual subjects' reports of headaches and of eyestrain. The Spearman rank correlation is 0.51.

The incidence of episodes of 'eyestrain' was, in general, lower than that of headaches. The data are summarised in Table 2 and Figure 7. Comparing the incidences in Table 2(a) and (b), it is evident that some subjects who reported frequent eyestrain were among those in the baseline condition who did not experience a change in lighting. The difference before the changeover was significant ($z = 2.09$, $p = 0.018$, one-tailed) but not afterwards ($z = 1.24$, $p = 0.11$, one-tailed). For the subjects who crossed over from one condition to the other, a t-test (based on difference scores, for which the distribution was not skewed) showed the aggregated difference to be significant, $t(38) = 1.83$, $p = 0.037$, one-tailed. Figure 8 shows the incidence of eyestrain under the two conditions; although the numbers are small there is the suggestion that subject who reported frequent eyestrain tended to do so more under the conventional lighting.

3.5 Office height and daylight

The building was seven stories high, and although the offices all had windows, the windows looked onto buildings of similar height. The illumination from daylight increased with the height of the office above the ground by an average of 80 lux per storey (measured at the work surface on a sunny day). The decrease in headache incidence with height was assessed using a Jonckheere non-parametric trend test, excluding the data from participants exposed to new high-frequency lighting and from the telex operators on the 6th floor. The trend was significant both before ($z = 2.13$, $p < 0.02$, one-tailed) and after the change in lighting ($z = 2.41$, $p < 0.001$, one-tailed). Within this particular building the height of an office was not related to the age or seniority of its occupants.

3.6 Lamp usage

Data from hours-run meters were available for 132 luminaires for the period May 1986–January 1987, approximately 6000 hours. The mean hours usage per luminaire was 586 ($N = 72$, SD = 553) for conventional lighting and 785 ($N = 60$, SD = 771) for new. The difference is significant ($z = 1.81$, $p = 0.035$, one-tailed). Some of the occupants of offices in which meters were fitted dropped out of the study. The small size of the resulting sample precluded analysis of the covariation of lamp usage with headaches and eyestrain.

4 Discussion

The fact that the differences between the groups were not always significant both before and after the change from one

Table 2 The average weekly incidence of episodes of 'eyestrain' before and after the changeover in lighting, shown separately for new and conventional lighting. The standard deviation (SD) and the number of subjects (N) for whom data are available are also shown.

Population	Conditions	Before			After		
		N	Mean	SD	N	Mean	SD
(*a*) All subjects (including those for whom data are available for only one of the lighting conditions)	Conventional	91	0.36	0.74	78	0.23	0.52
	New	33	0.07	0.19	25	0.13	0.59
(*b*) Subjects for whom data are available for both conditions before and after the changeover between new and conventional lighting	Conventional/new	20	0.10	0.35	20	0.01	0.03
	New/conventional	20	0.08	0.22	20	0.18	0.15

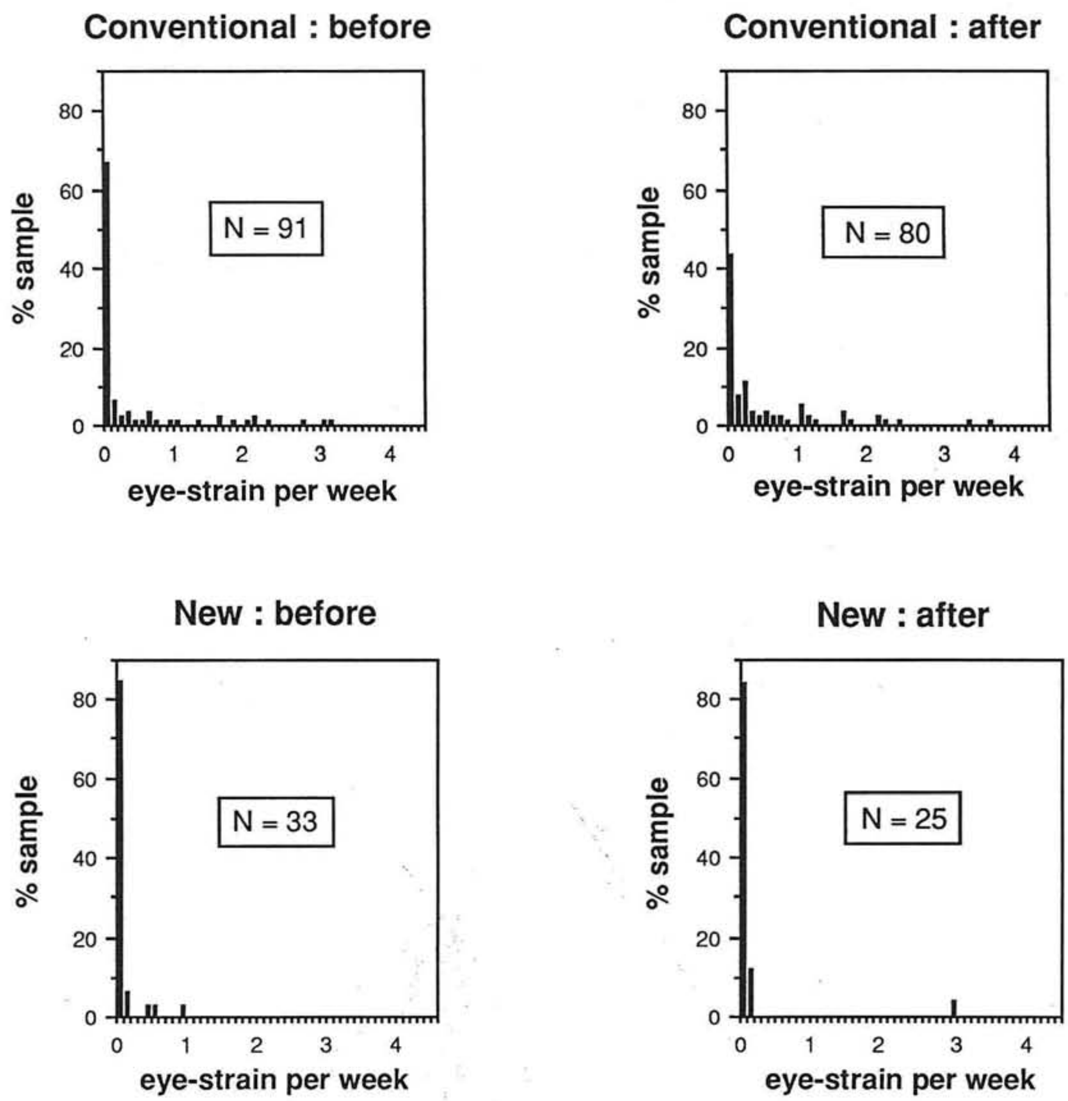

Figure 7 Histograms of the weekly incidence of episodes of eyestrain among subjects exposed to new and conventional lighting, before and after the changeover from one form of lighting to the other

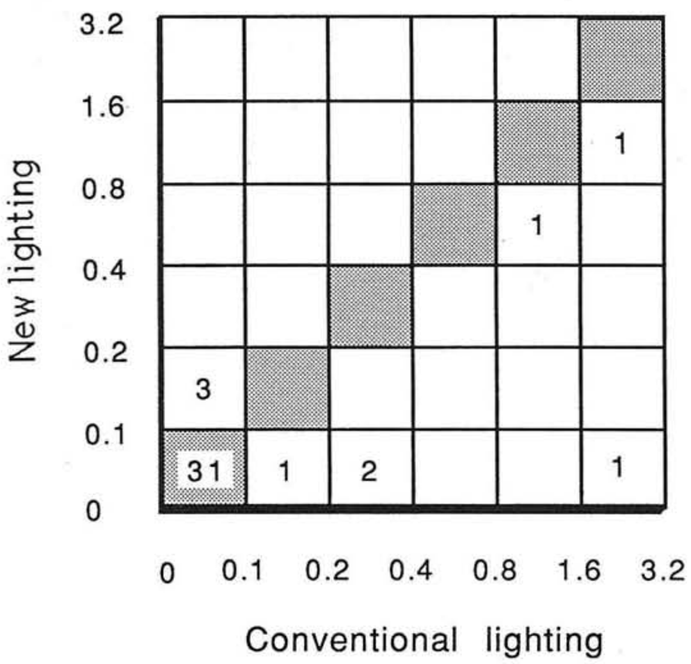

Figure 8 Scatterplot showing the weekly incidence of eyestrain under new and conventional lighting for the 40 subjects who experienced both conditions. Data tend to lie below the diagonal: the few subjects who experience frequent eyestrain tend to do so more under the conventional lighting than under the new

lighting condition to the other suggests that although the subjects in the various experimental conditions were allocated at random, they were not evenly balanced with respect to their liability to headaches and eyestrain.

For the subjects who experienced both new and conventional lighting the mean incidence of headaches and eyestrain changed with the changeover in lighting, showing a reduced incidence under the new lighting. Although the size of the groups is too small for much weight to be placed on these findings, comparisons between subjects can be made for a larger sample of subjects and these also show a reduced incidence of headaches and eyestrain under the new lighting. As can be seen from a comparison of the histograms for new and conventional lighting (Figures 3 and 6), the tail of the distributions is longer in the case of conventional lighting: a few subjects suffered headaches or eyestrain frequently and they did so mainly under conventional lighting. Note that the histograms for new lighting are similar before and after the change, although different subjects contribute.

Despite certain difficulties of interpretation, the data as a whole show a consistent pattern indicating that new high-frequency lighting may be preferable to conventional lighting: (*a*) headaches and eyestrain were reduced by a factor of two or more when the controlling circuitry was changed to the new high-frequency ballast and the light no longer fluctuated in intensity; (*b*) the nature of the phosphor, and the speed with which the lamps ignited did not appear to affect the incidence of headaches; (*c*) among participants exposed to conventional lighting there was a tendency for headaches to decrease as the amount of available natural light increased; (*d*) the conventional lighting was switched on for less time than the new; (*e*) subjects appeared to be unaware of the change of lighting and of its effects on headaches and eyestrain. Perhaps conventional fluorescent lighting contributes to 'building sickness'.

The physiological mechanisms reponsible for the association between headaches and the modulation of light can only be guessed at. Some migraine sufferers report an aversion to low-frequency intermittent light when the flicker is obvious, and this sensitivity may be reflected in the '*H*-response' of Golla and Winter[9]. However, the fluctuation from a properly functioning fluorescent light is not usually visible. The principal frequency component is usually above that at which a steady-state evoked potential in response to intermittent light is measurable in the scalp EEG[13], and the modulation is insufficient for epileptic seizures[14]. The 100 Hz fluctuation may affect subcortical structures, as suggested by the work of Eysel and Burandt[5], although headaches such as classical migraine begin with visual warnings suggestive of abnormal cortical rather than subcortical activity[15], and cortical neurons do not usually resolve frequencies higher than 20 Hz[16]. Of course, the fluctuating light illuminates surfaces such as text that have a spatial periodicity[17]. The eyes move across this surface with the result that the spatial and temporal periodicities interact. It may be interactions of this kind that both interfere with ocular motor control and cause headaches. The complaints of eyestrain may be related to those of headache by a common neurological mechanism[18].

Acknowledgements

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