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# Lighting and discomfort in the classroom

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ABSTRACT

Aspects of classroom lighting and décor that can promote discomfort and impair task performance through glare, and imperceptible 100 Hz flicker from fluorescent lighting, were examined in a sample of UK schools. In 90 classrooms, across eleven secondary schools and six local education authorities variables measured included flicker, illuminance at desks, and luminance of whiteboards. Results showed that 80% of classrooms are lit with 100 Hz fluorescent lighting that can cause headaches and impair visual performance. Mean illuminance (from excessive day- and artificial lighting) was in excess of recommended design illuminance in 88% of classrooms, and in 84% exceeded levels beyond which visual comfort decreases. Lighting could not be adequately controlled due to classroom design and infrastructure. Ceiling-mounted data-projectors directed at whiteboards mounted vertically on the wall resulted in specular reflection from the whiteboard, visible as a glare spot with luminance high enough to cause discomfort and disability glare. The intensity of the glare spot varied between different brands of whiteboard. Ambient lighting, needed for close work at pupils' desks, reduced image contrast. Venetian blinds in 23% of classrooms had spatial characteristics appropriate for inducing pattern glare. There was significant variation between schools and local authorities. These findings may provide insights into small-scale reports linking pupils' attainment, behaviour and learning to classroom lighting, and may also help explain some of the benefits of coloured overlays for pupils' reading.



## 1. Introduction

There is evidence that classroom lighting may be important for pupils' learning. Teachers and pupils can have clear preferences about classroom lighting (Schneider, 2003); for example, Hathaway (1983) found that teachers had preferences for daylight, whilst Lang (2002) indicated that teachers liked to have *control* over lighting levels. Small-scale studies have also proposed a link between lighting and attainment. For example, Hathaway (1994) found links between use of full spectrum fluorescent lamps and attainment. Using a large sample, Heschong and Knecht (2002) found significant correlations between attainment and both (1) the extent to which daylight could be controlled by the teacher, and (2) the extent to which daylight was diffuse throughout the classroom. A number of studies have also noted changes in behaviour under particular lighting regimes. Fenton and Penney (1985) found that autistic children engaged in more repetitive behaviours under fluorescent light; Schreiber (1996) suggested that children became more relaxed and interested in classroom activities when brightness was reduced; Shapiro, Roth, and Marcus (2001) found that children's maladaptive behaviour became less frequent under indirect diffuse full spectrum fluorescent lamps; whilst Treichel (1974) suggested that fluorescent lighting may aggravate hyperactivity in school children. Finally, other authors have concerned themselves with the effect of environmental variables such as lighting on the learning process itself. Dyck (2002) suggested that aspects of lighting are necessary to establish a state of "flow" (Csíkszentmihályi, 1990); Lyons (2002) suggested that full spectrum fluorescent lighting can benefit learning; Rittner and Robbin (2002) indicated that daylight helps students to retain and learn information; whilst Schulz (1977) examined the importance of avoiding excessive illumination. Some authors place most emphasis on the importance of daylighting, but the need for integrated systems of day- and artificial lighting is broadly accepted (see Woolner, Hall, Higgins, McCaughey, & Wall, 2007).

The manner in which the above studies were conducted is very variable, with some being based on very small sample sizes, limiting generalisation. Although recommendations for best practice do exist (CIBSE, 2004; DfEE, 1999), classroom lighting has continued to change (including for example, developments in fluorescent lighting and introduction of data-projectors to

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classrooms), whilst research in the field has been neglected by comparison (Woolner et al., 2007).

Establishing causative links between aspects of classroom environment and the factors mentioned above is difficult, in part because of the practical and ethical difficulties in conducting controlled trials in classrooms. Hence, this study takes a different approach; that is, to assess the extent to which pupils in UK classrooms are exposed to some of the aspects of classroom lighting and décor which have been shown to cause discomfort and impair task performance, and which may therefore begin to inform the debates above. These aspects are imperceptible 100 Hz flicker from fluorescent lighting, and glare induced by (1) daylight and fluorescent lighting, (2) interactive whiteboards (IWBs) and dry-wipe whiteboards (DWBs), and (3) patterns from Venetian blinds.

### 1.1. *Imperceptible 100 Hz flicker in light from fluorescent lamps*

Electric lamps that operate on an AC supply (50 Hz in Europe) have inherent modulation in light output at twice the supply frequency (100 Hz in Europe) (CIBSE, 2004). Conventional incandescent lamps show a small modulation because the filament takes time to cool between cycles, whereas fluorescent discharge lamps show a modulation in illuminance (peak-trough) between 17% and 100% (CIBSE, 2004) one hundred times per second (100 Hz).

100 Hz modulation can adversely affect visual search performance (see Jaen, Sandoval, Colombo, & Troscianko, 2005), even though subjects do not consciously experience it as flicker (Berman, Greenhouse, Bailey, Clear, & Raasch, 1991). Subjects who report adverse effects from fluorescent lights show higher sensitivity to 100 Hz flicker (Dakin, Hargroves, Ruddock, & Simons, 1994), and indeed to visible flicker at lower frequencies (Brundrett, 1974). Fluorescent lamps are housed in lighting fixtures, or luminaires, within which is control circuitry that operates the lamps, determining the rate of flicker. Increasing the frequency of flicker into the kHz range, using the same lamps but driving them with high frequency control circuitry, can reduce headaches under double-masked conditions (Wilkins, Nimmo-Smith, Slater, & Bedocs, 1989) and enhance task performance; individuals read more accurately (though more slowly) than under 100 Hz flicker (Küller & Laike, 1998) and display improved visual search performance (Jaen & Kirschbaum, 2001; Jaen et al., 2005). Interestingly, Lindner and Kropf (1993) found younger individuals demonstrated relatively high sensitivity to 100 Hz flicker. The choice of fluorescent circuitry for school classrooms could therefore be very significant, and may adversely affect pupils' task performance and learning.

Neurophysiological responses suggest mechanisms for the effect of flicker on performance. Berman et al. (1991) demonstrated electroretinogram responses to 100 Hz flicker. Küller and Laike (1998) reported attenuation of EEG alpha waves. In cats, neurons in the lateral geniculate nucleus (LGN: a subcortical structure in the visual system) show phase-locked firing in response to 100 Hz flicker, suggesting timing of neural responses in subcortical structures connected to the LGN may be disrupted (Eysel & Burandt, 1984). These structures include the superior colliculus, which is responsible for eye movements. It is already known that control of human eye movements can be affected by flicker; Baccino, Jaschinski, and Bussolon (1999) found changes in saccade velocity and extent in response to flickering CRT monitors, whilst Wilkins (see Wilkins, 1986; Wilkins et al., 1989) found enlarged saccadic movements in response to flicker from fluorescent lights.

### 1.2. *Disability and discomfort glare*

Glare happens when one part of the visual scene is much brighter than the general brightness of the rest of the field of view. A high source luminance, large source area, low background luminance and a position close to the line of sight all increase glare. Such glare can be of two types: disability glare and discomfort glare.

Disability glare refers to a decrease in visual performance, which results from a decrease in contrast due to light scattered within the eye. Scatter is greatest when a bright light source is close to the direction of gaze. The light is scattered mainly by the lens of the eye, but also by the cornea, reducing the contrast of the retinal image. Even without reduction in visual performance, glare may also result in discomfort (discomfort glare), with symptoms including eyestrain and headaches. Effects may be immediate, or recognised only after prolonged exposure.

#### 1.2.1. *Illuminance at pupils' desks*

CIBSE (2004) provide recommended design illuminances for different types of classroom, which range from 300 lux to 500 lux; adoption of such values helps to restrict glare to reasonable levels (it is worth noting that a new installation with new lamps and clean surfaces may give an illuminance 25% greater than the design illuminance, but only half this initial value when lamps are old and dirt has accumulated). There is some evidence for increased discomfort at illuminance above 1000 lux and separate evidence above 2500 lux (Rea, 1982, 1983; Smith & Rea, 1980) in uniformly lit rooms. The data reported in this paper are analysed against these values, but do not take into account uniformity ratios across task area and classroom. However, in rooms that are not uniformly lit, with the immediate task area much brighter than the surrounding area, discomfort effects may be exaggerated.

#### 1.2.2. *Luminance and glare from data-projection screens*

By 2004, data-projectors and IWBs had been installed in 92% of English secondary schools (see DfES, 2004). Some reports suggest that children can find data-projected images difficult to see (Hall & Higgins, 2005; Smith, Higgins, Wall, & Miller, 2005). Difficulties may arise from ambient light (daylight and fluorescent light) reflecting off the whiteboard; as well as glare from direct reflectance of the projector beam itself. Conventional slide projector screens have a matt surface that reflects incident light in every direction so the image can be seen from any viewing angle. More glossy surfaces do not scatter light so well: they reflect some of the light at an angle equivalent to the angle of incidence in the same way as a mirror (specular reflection). If a data-projector shines from the ceiling at a vertical surface such as a whiteboard, specular reflection is directly visible to the audience, appearing as a bright 'glare spot' on the board (see Fig. 1), which may cause disability and

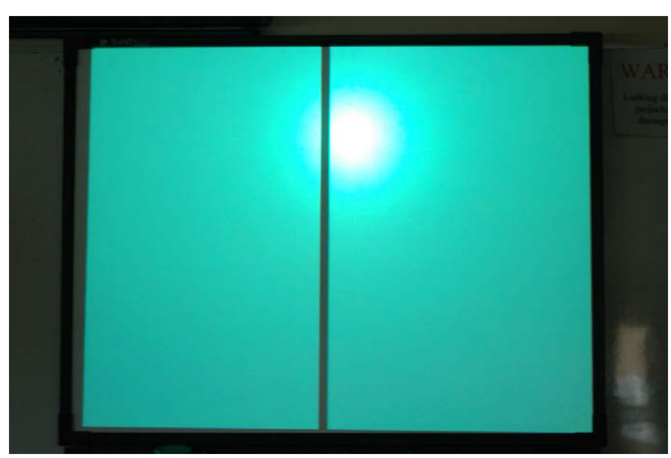

**Fig. 1.** Interactive whiteboard (Brand 2) with projected vertical stripe. The glare spot is clearly visible.