Illuminance of neonatal units

J Robinson, M J Moseley, A R Fielder

Abstract

We have measured the illuminance (brightness) of seven neonatal units during both the day and the night. When the units were lit solely by fluorescent tubes the mean illuminance was 348 lux (range 192-690). During the day the mean illuminance was 470 lux (range 236-905). The high dependency regions in four of the seven units were significantly brighter than the corresponding low dependency nurseries at all times. In two of these units there is a policy of reducing the amount of artificial light in the low dependency areas at night, and in these the normal mean illuminance was 50 lux. We have measured the general levels of illumination to which a neonate might be exposed; the ocular exposure to light of a neonate depends, however, on both physical and biological factors and more research is required before an accurate estimate can be made.

Preterm infants are cared for in neonatal units that are usually lit by a combination of natural and artificial light, the latter provided by fluorescent tubes. The guidelines governing the lighting of these units are set by the Chartered Institute of Building Services in the United Kingdom.¹ These guidelines state that the lighting of all interiors should fulfil three functions. Firstly, it should ensure the safety of the people in the interior; secondly, it should facilitate the performance of visual tasks; and, finally, it should create an appropriate visual environment. For neonatal units the 1989 recommendations for lighting and luminaires (plastic shields in front of fluorescent tubes) were:

'In cot areas, the lighting and luminaires should be positioned as far away from the cots as practicable to avoid direct glare into the cots. Additional luminaires may be required over the cots to provide higher illuminance depending on the width and shape of the room and the cot layout.

Blinds should be provided in areas where day-lighting from side windows or roof lights could cause glare to babies suffering from retinopathy of prematurity.

In incubator areas, higher levels of illuminance are required for the examination and care of babies and this should be provided by low glare luminaires'.²

These guidelines also define the mean illumination of the areas within a neonatal unit. Illuminance levels of 50-100 lux for low dependency and 1000 lux for the high dependency regions are recommended. Between the hours of

2000 and 0800 (night) the guidelines suggest that the mean illumination should be reduced to 5 lux. It is not clear whether this applies to both high and low dependency regions.

Contrary to the guidelines, most neonatal units are usually lit both day and night, with no cyclic variations in intensity. Surprisingly, the levels of light to which preterm neonates are exposed are one of few environmental variables which are not monitored. Moseley and Fielder have recently reviewed the literature about the potential toxicity of light to the eyes of neonates, and noted that there is little data on the exposure to light of babies undergoing treatment in neonatal units.³

Abramov *et al* showed that there were deficits in both photopic contrast sensitivity (a reduction of 0.2-0.3 log units) and photoreceptor function in a group of children tested at the age of 7 years, who had been born preterm and had been exposed to continuous illumination as neonates.⁴ The colour vision deficits resembled those of tritanopia, suggesting damage to the short wavelength (blue) cones. Glass *et al* reported a reduction in the incidence of retinopathy of prematurity among a group of neonates exposed to reduced lighting.⁵ This study has been criticised on several grounds: it was sequential and infants were not randomised into clinical study groups; the light reduction was achieved by placing a filter over the incubators; the method was not accurately described, and the observers were aware of which babies were having which treatment.⁶ Others studies have suggested that continuous exposure to bright light affects sleep states⁷ and hormonal biorhythms,⁸ and may increase the incidence of patent ductus arteriosus.⁹⁻¹⁰ The absence of day and night cycles may be partly responsible for the delayed onset of periodicities and sleeping problems in preterm neonates.¹¹

During the past two decades light intensities recorded in hospital neonatal units have increased by five to tenfold. In 1969 Giunta and Rath reported mean illuminances of 10 foot candles (~100 lux) in a standard dim nursery environment in England,¹² and by the 1980s levels were reported ranging from 200 lux in England,¹¹ through 630 lux in Australia,¹³ to a peak of 10⁴ lux in a neonatal unit in the United States, where daylight supplemented the artificial illumination.¹⁴ No study has been carried out to examine specifically the illumination of neonatal units in the United Kingdom or the variations between high and low dependency regions of neonatal units.

Clearly, before considering the possible effects of light on the developing eye or visual system, a knowledge of the light dose received by neonates (the retinal irradiance) is necessary. In this study we have measured the illuminance in seven neonatal units in central England, both at

Department of
Ophthalmology,
University of
Birmingham,
Birmingham and Midland
Eye Hospital,
Church Street,
Birmingham B3 2NS
J Robinson
M J Moseley
A R Fielder

Correspondence to:
Dr Robinson.

Accepted 5 March 1990

night and during the day, to obtain data on the general levels of illumination to which a neonate may be exposed.

Methods

INSTRUMENTS

Illuminance was measured with a Macam Digital Photometer, Model L103. The sensor in the detector head unit is a large area photodiode that has long term stability and is not damaged by sudden exposure to high levels of light. Cosine correction was used in the diffuser to simulate an ideal 180° field of view detector. A Commission Internationale d'Eclairage (CIE) photopic filter was fitted in front of the diode to give a spectral response similar to that of the human eye.

All measurements of lighting contain several sources of error that may accumulate to give a possible uncertainty in the measurement, which may often exceed 20%. In this study the Macam photometer was calibrated against a standard that was traceable to the National Bureau Standard (USA) with an accuracy of 5%; the photometer itself is only accurate to 10%. Further uncertainty in the measurement is introduced by the number of samples taken.¹

SURVEY OF NEONATAL UNITS FOR POSITIONING OF MEASUREMENT POINTS

A lighting survey to measure the average illuminance of each neonatal unit was carried out. In field surveys of lighting the number of measurement points is determined by the 'room index', which is calculated as follows: room index = $L \times B / [H_m(L + B)]$ where L = length of room (m), B = breadth of room (m), and H_m = height from luminaire to working plane (m).

The minimum number of measurement points necessary to give an error of less than 10% in the estimate of mean illuminance in a room is then obtained from the Chartered Institute of Building Services guidelines for field surveys—that is, for a room index <1 and an error of <10% four measurement points are required, similar figures for room indices of 1–2, 2–3, and ≥ 3 are 9, 16, and 25. As we required an error of less than 5% the number of data measurement points was doubled.²

An accurate scale plan of each neonatal unit was prepared. The room indices for each nursery in the seven neonatal units were then calculated using the height above the floor of the mattress in the cot or isolette as the working plane. Each room was then divided into the correct number of segments and the illuminance measured at the centre of each segment, which was as nearly square as possible. The measurement positions were then plotted on to the floor plans at the centre of each segment.

TIMING OF MEASUREMENTS

Illuminance levels were surveyed under three lighting conditions in each unit. Firstly, at night when the units were lit solely by artificial illumination. Secondly, on dull overcast or rainy days, and finally on dry and bright or

sunny days. All measurements were made between February and April 1989.

Artificial lighting only

Each of the seven neonatal units were visited at night on a single occasion. During this visit the ambient lighting was surveyed throughout the unit with the lighting set as normal by the nursing staff. In addition, in units 5 and 6, (which have a policy of dimming the lights in the low dependency regions between 2000 and 0700) measurements were made both with the fluorescent lamps turned on and under the dimmed lighting.

Total illuminance during the day

The units were visited on four occasions separated by intervals of about one week. The survey was carried out once during each visit, either in the morning or the afternoon. If the survey was carried out in the morning on the first visit, the second survey was made in the afternoon.

Timing of measurements: effect on readings

Repeated measurements of illuminance were made at hourly intervals between 0700 and 1800 in one neonatal unit. This was to provide an estimate of the variability in illuminance due to timing of the surveys on the measured values.

All illuminance data were obtained at the approximate height of the upper surface of the infant in a cot or isolette, as close to the exact position of the infant as possible (table 1).

METHOD OF ANALYSIS

The mean, median, and range of illuminances were calculated in three ways: firstly, for each unit as a whole; secondly, with the high and low dependency regions considered separately; and, finally, for every room in each of the seven neonatal units surveyed. The uniformity ratios (defined as minimum/mean, and minimum/maximum measurements) were calculated for each room, and the results compared with the Chartered Institute of Building Services guidelines.

Analysis of variance was used to compare the mean illumination for the units studied, both when each unit was considered as a whole, and after subdividing the units into high and low dependency regions as separate blocks.

Results

The uniformity ratio, the minimum divided by the maximum recorded light levels ($UR = \min/\max$), was calculated for each room studied. Values of greater than 0.79 were obtained for every room irrespective of time or day of measurement.

Table 1 Selected radiometric and photometric quantities

Quantity	Units
Irradiance (radiant power incident upon a surface/unit area of surface)	Watts/cm ²
Spectral irradiance (irradiance in a narrow wavelength band centred at a specific wavelength)	Watts/cm ² /nm
Illuminance (photometric analogue of irradiance weighted for the visual response of the eye)	Lux

Table 2 Variations in mean illuminance with weather conditions. The mean (SEM) unit of illumination is shown for each of the seven neonatal units studied on dry, sunny days; dull, overcast or wet days, and at night

Neonatal unit	Dry and sunny	Dull and overcast and rainy	Mean illuminance at night (2000 to 0800)		
			Throughout the unit	High dependency area	Low dependency area
1	288 (17.2) (n=188)	443 (13.6) (n=188)	301 (15.4) (n=94)	461 (22.2) (n=34)	222 (6.5) (n=60)
2	752 (35.3) (n=94)	905 (46.1) (n=94)	690 (42.6) (n=47)	900 (42.8) (n=16)	452 (32.2) (n=31)
3	288 (16.8) (n=90)	383 (14.6) (n=90)	192 (17.4) (n=45)	227 (19.0) (n=16)	183 (21.1) (n=29)
4	369 (15.2) (n=108)	452 (20.9) (n=108)	278 (19.2) (n=54)	365 (5.2) (n=36)	189 (14.5) (n=18)
5	625 (5.8) (n=114)	837 (14.9) (n=114)	225 (6.1) (n=57)	255 (11.3) (n=25)	215/50* (6.5) (n=32)
6	358 (33.6) (n=112)	399 (25.7) (n=112)	560 (23.2) (n=56)	691 (12.7) (n=25)	233/50* (6.5) (n=32)
7	236 (10.1) (n=102)	246 (14.6) (n=102)	193 (11.9) (n=51)	210 (14.5) (n=27)	141 (8.5) (n=24)
Total mean	417	524	348	444	233

*The amount of light with the fluorescent lights switched off; n=the number of measurement points.

ARTIFICIAL LIGHTING ONLY

The contribution of the artificial lighting to the total illuminance in the units was assessed by visiting each unit during the night when the level of ambient (natural) illumination was minimal.

Mean (SEM) illuminance for all units was 348 (74) lux. Significant differences were found between the seven units studied, however, the mean for the individual units ranging from 192 lux in unit 3 to 690 lux in unit 2 ($p<0.001$) (table 2). When the data from each special care baby unit were divided into high and low dependency regions these differences became more apparent. In general the units were uniformly bright or dim, with the most recently opened having the highest mean unit illuminances. The high dependency nurseries of units 1, 2, 4, and 6 were significantly brighter than their corresponding low dependency nurseries (table 2). Similar differences among units were found in the illumination of the low dependency nurseries. With the exception of units 5 and 6, the data in table 2 represent the normal minimum night time illuminance. Both these units have a policy of reducing the levels of light and noise in the low dependency nurseries whenever possible. When a second survey was carried out at these units, the mean illuminance in the low dependency nurseries was about 50 lux.

TOTAL ILLUMINANCE DURING THE DAY

The mean illuminance of the neonatal units when calculated from measurements taken during the day (0700 to 2000) was 470 lux (range 236–905). Two series of illuminance measurements were made, firstly when the weather conditions outside were either dry and bright (mean (SEM) 524 (94) lux), or secondly, when it was wet or cloudy, that is greater than three quarters of the sky covered with low cloud (mean (SEM) 417 (74) lux) (table 2). Each unit was visited on four separate occasions, twice on bright sunny days and twice when it was dull, overcast, or raining. Except for unit 7, which has no external windows, the ambient illumination caused a significant rise in the mean level of neonatal unit illumination (table 2). It was noted that the nursing staff usually drew the

curtains (if present) to reduce the level of light falling on those babies directly facing a window on bright days. In units 1, 3, 4, and 6, some of the lights were switched off routinely on bright days by the nursing staff.

VARIATION IN ILLUMINANCE DURING THE DAY

Repeated measurements of illuminance were made in unit 1. Measurements were made at hourly intervals between 0700 and 1800. No significant variations were found between the mean unit illuminance throughout the day. The uniformity ratio (min/max) fell to 0.65 (below the recommended value of 0.8) because of high illuminance readings at measurement positions near the windows.

OTHER GENERAL INFORMATION

All study hospitals used fluorescent lights in the units as the primary source of illumination. Plastic shields (luminaires) were located in front of the fluorescent tubes in all the neonatal units. At night the artificial illumination was said to be maintained at the same level as during the daytime hours, except for two centres in which it was reduced to roughly one tenth (2–3 lux). In all the units, however, the nursing staff would often reduce the number of fluorescent tubes switched on if the monitoring of the babies would not be impaired.

Discussion

The data obtained from this survey of neonatal units show the levels of illumination to which preterm neonates were exposed during their inpatient stay in any of the seven units studied.

The mean illuminance at night (2000 to 0800) was 348 lux (range 192–690). Illuminance measurements made at night may be considered to be the minimum to which preterm neonates will be exposed during their stay in a neonatal unit. But in the case of units 5 and 6 these values are potentially misleading because the lights were normally dimmed to about 50 lux in the low dependency nurseries between 2000 and 0700 hours each day.¹¹

The total mean illuminance of the neonatal

units when measured during the day (0700 to 2000) was 470 lux (range 236–905). The levels of illumination for unit 6, obtained during the day were similar to estimates made previously.¹¹ The range of mean unit illuminances (236–905 lux) was similar to that previously noted by Landry *et al* for neonatal units in the United States (285–1485 lux).¹⁵ We did not, however, record any light levels in the region of 10⁴ lux—a value quoted by Hamer *et al* for a unit in which daylight could supplement the artificial light sources.¹⁴

The interunit variability that we found seems partly to reflect the age of the neonatal unit—the newest, which opened in 1988, had the highest level of artificial illumination and the dimmest was the oldest unit studied.

All high dependency nurseries were illuminated throughout the 24 hour period and thus showed little variation and were brighter than their corresponding low dependency nurseries (table 2). The illuminance in the low dependency rooms was cycled routinely in units 5 and 6 at the time of the survey.¹¹ The reduction in illumination between high and low dependency nurseries probably reflects the improving health of the neonates, as less intense monitoring is required for these babies.

The effect of external weather conditions was studied briefly and our results suggest that additional ambient light entering the units through windows can make an important contribution to the amount of light in the units (table 2). Infant positions with high illuminance values, when compared with the averages, were located near outside windows, an effect that has been noted previously.^{15 16} The data recorded from points not in direct line with the windows, however, were similar, and independent of external weather conditions.

Our results merely report the illumination levels at the time of the survey. The total light exposure of an infant during treatment in a neonatal unit is dependent on many factors. For example, babies are moved from high to low dependency nurseries as their conditions improve. Babies may also be moved round randomly within a nursery depending on the number of infants in each region at the time. Thus a baby could be located at a point associated with a high illuminance at one stage and then be relocated at another position associated with low illuminance.

The light dose to the eyes of preterm neonates is dependent on many physical and environmental variables. These include the position of the infant in the neonatal unit; whether he or she is in the high or low dependency region; the position of the cot, isolette, or incubator in the nursery in relation to outside windows; external weather conditions; the use of eyeshields; the baby's head position, and the possibility of shading from equipment near the cot or incubator.

Most of the lighting comes from overhead fluorescent tubes, but in addition neonates are exposed to other lights. These include a variety of warming and procedure lights (their eyes may not necessarily be shielded), and exposure to phototherapy lights for the treatment of

neonatal jaundice during which the eyes are covered with patches, which have a tendency to slip.¹⁷ Also, because of the risk of developing retinopathy of prematurity, preterm infants are often examined ophthalmoscopically while they are in the neonatal unit. The instrument normally used is the binocular indirect ophthalmoscope, with a maximum intensity of light about one log unit greater than that needed for 100% rhodopsin bleach¹⁸; Noell found that a 10% bleach is sufficient to damage the photoreceptors. However, the infant's retinas will usually be exposed for less than 60 seconds, and generally as the setting used is not maximal, the potential hazard is less.

The total amount of light reaching the eyes of preterm babies while they are in the neonatal unit must be greater than that received by a fetus, but before any relation between light exposure and any ocular pathophysiology is suggested an accurate estimate of the quantity of light actually reaching the eye or retina must be made. To obtain such estimates a knowledge of both physical or environmental (for example, illuminance, area of luminaires, and shading effects) and physiological factors (for example, eyelid opening, transmission of light through the eyelid, pupil area, and transmission of light through the optic media) is required. This study is part of a larger project examining each of these factors and their influence on the ocular light dose.

J Robinson is a research student supported by the Royal National Institute for the Blind. We thank R Reece for assistance in part of the data collection, D Shaw for advice on the analysis, and all the paediatricians who cooperated with us during this study.

- 1 The Chartered Institution of Building Services. *CIBS code for interior lighting*. London: Yale Press, 1984.
- 2 The Chartered Institution of Building Services Engineers. *CIBS lighting guide: hospitals and health care buildings LG2*. London: Collins and Wilson, 1989.
- 3 Moseley MJ, Fielder AR. Light toxicity and the neonatal eye. *Clinical Vision Sciences* 1988;3:75–82.
- 4 Abramov I, Hainline L, Lemerise E, Brown AK. Changes in visual function in children exposed as infants to phototherapy. *J Am Optom Assoc* 1985;56:614–9.
- 5 Glass P, Avery GB, Kolinjivadi N, *et al*. Effect of bright light in the hospital nursery on the incidence of retinopathy of prematurity. *N Engl J Med* 1985;31:401–4.
- 6 Stobie PE. Bright light and retinopathy of prematurity. *N Engl J Med* 1986;314:448–9.
- 7 Glass P, Avery GB. Light, sleep and development (reply). *Pediatrics* 1987;79:1053–4.
- 8 Sisson TRC, Glauser SC, Glauser EM, Tasman W, Kuwabara T. Retinal changes produced by phototherapy. *J Pediatr* 1970;77:221–7.
- 9 Clyman RT, Rudolph AM. Patent ductus arteriosus: a new light on an old problem. *Pediatr Res* 1978;12:92–4.
- 10 Rosenfeld W, Sadhev S, Brunot V, Jhaveri R, Zabaleta I, Evans HE. Phototherapy effect on the incidence of patent ductus arteriosus in premature infants: prevention with chest shielding. *Pediatrics* 1986;78:10–4.
- 11 Mann NP, Haddow R, Stokes L, Goodley S, Rutter N. Effect of day and night on preterm infants in a newborn nursery: randomised trial. *Br Med J* 1986;293:1265–7.
- 12 Giunta F, Rath J. Effect of environmental illumination in prevention of hyperbilirubinemia of prematurity. *Pediatrics* 1969;44:162–7.
- 13 Lawson KR, Turkewitz G, Platt M, McCarton C. Infant state in relation to its environmental context. *Infant Behaviour and Development* 1985;8:269–81.
- 14 Hamer RD, Dobson V, Mayer MJ. Absolute thresholds in human infants exposed to continuous illumination. *Invest Ophthalmol Vis Sci* 1984;25:381–8.
- 15 Landry RJ, Scheidt PC, Hammond RW. Ambient light and phototherapy conditions of eight neonatal care units: a summary report. *Pediatrics* 1985;75(suppl):434–6.
- 16 MacLeod P, Stern L. Natural variations in environment illumination in a newborn nursery. *Pediatrics* 1972;50:131–3.
- 17 Robinson J, Moseley MJ, Thompson JR, Fielder AR. Eyelid opening in preterm neonates. *Arch Dis Child* 1989;64:943–8.
- 18 Noell WK, Walker VS, Kang Bok Soon, Berman S. Retinal damage by light. *Invest Ophthalmol Vis Sci* 1986;5:450–73.