EFFECTS OF LIGHTING ON THE WELFARE OF DOMESTIC POULTRY: A REVIEW

C E Manser

Department of Clinical Veterinary Medicine, University of Cambridge, Madingley Road, Cambridge CB3 0ES, UK

Final acceptance: 1 March 1996

Abstract *Animal Welfare 1996, 5:* 341-360

Four aspects of lighting which may influence the behaviour and physiology of housed poultry are light intensity, photoperiod, light source and wavelength. These factors are frequently manipulated in an attempt to improve productivity and to facilitate management practices. This review examines the effects of such manipulation upon the welfare of the birds. The majority of papers on lighting in poultry houses deal with their effects upon performance, rather than on factors associated with behaviour and health which may impinge upon welfare. Data about the preferences of birds for different lighting conditions are almost entirely lacking, but the practice of housing birds in relatively low light intensity is considered likely to lead to sensory deprivation in species where vision is important. Tentative recommendations are given pending the results of future research as to appropriate light intensity, photoperiod and light sources for domestic poultry.

Keywords: *animal welfare, behaviour, hens, lighting, physiology, turkeys*

Introduction

Vision is important to birds, as is shown by their relatively large eye size (Appleby *et al* 1992) and the fact that they can be trained to discriminate visually between different objects in experimental situations. Colour vision is particularly good in birds: both electrophysiological and behavioural tests have shown that birds are more capable than man of distinguishing between different wavelengths (Nuboer 1993).

Birds kept outdoors are exposed to sunlight of varying intensity and duration. However, most domestic birds are housed indoors where both the intensity and duration of light may be manipulated in order to increase growth rate, alter reproductive parameters, modify behaviour or simply to save fuel costs. The use of coloured bulbs, which alter the wavelength of artificial light, has been investigated experimentally and red light sources are sometimes recommended to reduce aggressive behaviour among housed poultry. The quality of the light may also vary according to its source; for example, light may be provided by fluorescent or incandescent bulbs. Thus, four aspects of lighting which can be altered artificially are intensity, photoperiod, wavelength and source.

Manipulations of lighting can have profound effects upon both behaviour and physiology, and the purpose of this review is to consider how these may affect the welfare of housed chickens and turkeys.

Light intensity

Poultry have a high proportion of cones in their retinas, indicating that they have better vision in bright than dim light (King-Smith 1971). One can therefore anticipate that keeping birds in very low light intensity may deprive them of some sensory input and contribute to a barren environment.

It is common practice to keep broiler birds at light intensities of below 10 lux in order to discourage activity and hence maximize productivity, as well as to save fuel costs (Fox 1984; Appleby *et al* 1992). For the same reasons, and also to minimize aggression, turkeys are usually reared at a light intensity of 1 to 4 lux (Farm Animal Welfare Council 1995). A minimum light intensity of 5 to 10 lux is required to stimulate egg-laying and lighting is usually kept close to this level for laying hens (Appleby *et al* 1992). As can be seen in Table 1, all of these light intensities are very much lower than those used during hours of activity, in buildings occupied by humans.

Table 1 Examples of light intensities in buildings used by humans and in poultry houses.

Recommended light intensities in buildings used by humans (lux[1])		Commonly used light intensities in poultry houses (lux)	
Office	500-750	Laying poultry	5-10
Living room (general)	100	Broilers	5
Hospital corridor in day	300	Turkeys	0.5-5
Hospital corridor at night	5-10		

[1] Martin *et al* (1980)

Effects on behaviour

There is some evidence that low light intensities can have deleterious effects upon the behaviour of birds. Pullets housed in a light intensity of 17 to 22 lux were found to be more fearful, showing marked avoidance activity in response to novel objects, compared with birds housed in brighter light (55 to 80 lux) (Hughes & Black 1974).

Maintaining light intensity at 10 lux or below is considered likely to inhibit feather pecking (Appleby *et al* 1992), and this was borne out by a study in which light intensity was identified as a major factor affecting the incidence of feather pecking in laying hens. Birds kept near to light sources, at a light intensity of 11 to 44 lux, were more likely to feather peck than those further away, where the light intensity ranged from 1 to 11 lux (Hughes & Duncan 1972). However, another study showed that laying hens were more likely to feather peck if they were kept at 50 lux as opposed to 500 lux. The lower level of feather pecking at 500 lux was correlated with a relatively higher level of floor pecking in both cages and deep litter. The author suggested that this level of lighting enabled the birds to visualize and peck at particles on the floor, whereas they were more likely to re-direct pecking at other birds in the lower light intensity (Martin 1989). Since these studies used very different light intensities from each other, it is difficult to draw any firm conclusion. As well as the possibility that both very high and very low light intensities can inhibit feather pecking, other environmental effects and strain differences between birds may also have affected the results. The incidence of feather pecking in turkey poults aged 3 to 12 weeks was also related to light intensity since those housed at 0.11 lux were less likely to be affected than others of the same age kept at 11 or 33 lux (Bacon & Touchbarn 1976). Another study recorded more social pecking among male turkeys aged 56 to 168 days kept at 86.1 lux than those kept at 10.8 lux, although the incidence of aggressive behaviour was said to be low in both groups (Leighton *et al* 1989).

The relationship between light intensity and aggressive behaviour in turkeys is unclear. Birds aged from 12 to 132 days of age which were kept at a light intensity of 20 lux were more likely to suffer cannibalism than those housed at 2.5 lux. Cannibalism accounted for 33 per cent of deaths in the former group but only 2.9 per cent of deaths in the latter, although there were no differences in overall mortality between the two groups (Hester *et al* 1987). A parallel study in female birds of the same age revealed no differences in performance, behaviour or mortality which were attributable to light intensity (Denbow *et al* 1990). Cannibalism was also encountered in a study of heavy male turkeys (reared to 188 days) and was considered to be related to housing the turkeys in small pens, with little opportunity of escape from an aggressor. The problem was successfully eliminated by reducing light intensity from 5 to 1.5 lux (Classen *et al* 1994).

Some investigations have been made as to the preferences of laying birds for nest-boxes of differing light intensities. One such study showed that hens did not prefer to nest in dark (5 lux) as opposed to brighter (20 lux) nest boxes, as was anticipated (Appleby *et al* 1983). Conversely, a study using turkey hens found that these were more likely to choose dimly lit boxes (0.5 lux) rather than more brightly lit (650–1000 lux) ones (Millam 1987). However, it does appear likely that the very high light intensity of the latter could have been aversive to the birds.

A specific type of behaviour which is linked to light intensity is the propensity of some bird species, including hens, to be attracted to and 'sun-bathe' in brightly lit areas. This sometimes leads hens to form large, dense aggregations in such sites, both on patches of sunlight in partly covered yards (Gibson *et al* 1985) and in sites of bright artificial light in enclosed buildings (Huber & Fölsch 1985). This aggregating behaviour may lead to mortality, since up to 50 birds per square metre may assemble in one place. The reasons why birds 'sun-bathe' in this way is unknown but the behaviour is particularly likely to occur when the hens have been kept in relatively low light intensities (Huber & Fölsch 1985). The implications for welfare are that there may be a danger of such behaviour developing and leading to increased mortality in large groups of birds, if relatively few, bright light sources are provided rather than a uniform level of light intensity.

Effects on health

Newly hatched birds, both domestic poultry and turkeys, may die of malnutrition in dimly lit brooders. Not only will the young birds have difficulty in seeing the feeders, but low light intensity reduces overall activity and exploration, thus reducing the chance of finding a feeder. For example, the incidence of mortality was found to be higher in chicks brooded at a light intensity of 5 lux than in those brooded at 75 lux (Deaton *et al* 1981). Growth rate in turkeys from hatching until six weeks of age and housed at 1.1 lux was shown to be poorer than in those at a light intensity of 11 lux or higher. Inactivity, huddling and continuous vocalization were observed in these poults. Mortality was noted to be particularly high at around one week of age when the yolk sacs would become depleted, leading to starvation in birds which had not yet learnt to feed (Siopes *et al* 1983).

The relative inactivity of birds housed at low light intensities can also lead to certain diseases. For example, broiler chickens housed in a light level of 6 lux were found to be less active than those housed at 180 lux and the former had a higher incidence of leg abnormalities (Newberry *et al* 1988), such as angular deformities of the tibia and tarsus, enlarged hocks and tibial dyschondroplasia (Classen *et al* 1991). A study by Davis and Siopes (1985) showed that leg abnormalities developed in turkeys kept in artificial light but not in those kept in daylight. It is likely that this difference was related to light intensity since the artificial lighting had a maximum of 19 lux whereas the maximum daylight intensity was 220 lux. Another study showed that the incidence of tibial dyschondroplasia was not affected by light intensities of either 2.5 or 20 lux (Hester *et al* 1987). The authors found this surprising since the latter birds had earlier growth plate closures and shorter legs, factors which were expected to reduce the incidence of lameness (Klingensmith *et al* 1986).

When birds housed on deep litter are relatively inactive, as may occur in low light intensities, they spend much time in contact with the litter. If this is damp, with a high ammonia content, there is a risk of birds developing breast blisters. Indeed, broiler chickens housed in a light level of 6 lux showed a higher incidence of breast blisters than those housed at 180 lux (Newberry *et al* 1988). Cherry and Barwick (1962) also noted that breast blisters were seen more commonly in birds housed at 1.1 lux than in those kept at 180 lux.

Eye abnormalities have been found to occur in chickens kept at very low light intensities; these include buphthalmos (eye enlargement and protrusion) and increased thickness of the choroid layer. After prolonged periods in dim light, retinal detachments may also be observed (Harrison & McGinnis 1967). Similar changes have been recorded in birds reared in continuous darkness (Jenkins *et al* 1979) and in continuous light (Oishi & Murakami 1985). Turkey poults reared in a light intensity of 1.1 lux developed eye abnormalities, including increased transverse diameter of the globe and corneal flattening; these changes were not found in birds reared at light intensities of 11 lux or higher (Siopes *et al* 1984). Similar eye abnormalities were also recorded in turkey poults kept in photoperiods of 23 or 24 hours provided by artificial lighting (light intensity 19 lux) but not in those receiving daylight for 9 to 11 hours daily. The authors of this study did not comment upon whether they considered the longer photoperiod or the lower light intensity predisposed the birds to eye disorders (Davis *et al* 1986).

Effects on performance

Since activity is correlated with light intensity, producers have anticipated that keeping birds in dim light would reduce activity so that energy could be channelled into growth. In fact, growth rates and food conversion in male broiler chickens were not affected by light intensities of between 0.1 and 100 lux inclusive during rearing (Newberry *et al* 1986). Very low light intensities (3 lux or lower) were found to have an adverse effect on food intake and growth rate in female though not in male chickens (Gordon 1989). Possibly some birds in the latter study had difficulty in finding food, a factor which was avoided in Newberry's study by gradually decreasing light intensities during the first three weeks, so that birds aged 9 days or less were never exposed to a light intensity of less than 5 lux. It also appears possible that female chickens are more susceptible to inanition at low light intensities than are males.

Growth rate in turkeys housed during the first six weeks at 1.1 lux was found to be poorer than in those provided with a light intensity of 11 lux or higher. Mortality among birds aged two weeks or less was high at the lower light intensity, probably due to low food intake (Siopes *et al* 1983). However, another study showed satisfactory results in terms of production when turkeys aged over three weeks were kept at very low light intensities. Growth rate was better in birds aged three to twelve weeks kept at 0.11 lux than in those at 11 or 33 lux, although after twelve weeks of age, optimal growth rate was achieved at a light intensity of 11 lux (Bacon & Touchbarn 1976).

Turkey poults aged from 12 to 132 days of age which were kept at 2.5 lux, grew more slowly than those at 20 lux but showed better feed conversion (Hester *et al* 1987). Other studies showed no differences in performance between male birds (Leighton *et al* 1989) or female birds (Denbow *et al* 1990) aged 56 to 168 days, kept at 86.1 lux or 10.8 lux.

Effects on management

When poultry are housed at a light intensity of 1 lux or less, stockmen are unable to see the birds clearly, and may be unaware of individuals becoming sick (Appleby *et al* 1992). Levels of 7 lux or below are considered likely to lead to stockman fatigue (Phillips & Weiguo 1991). Indeed, at any level below 20 to 30 lux, the stock-keeper entering the building from outside in the daylight is likely to have difficulty in seeing the birds clearly until dark adaptation of the eyes occurs. Carrying out routine maintenance will require temporary increases in light intensity which may alarm the birds, and excitement and fighting have been found to occur at these times (Bacon & Touchbarn 1976; Newberry *et al* 1986).

Since the activity of birds is known to be positively correlated with light intensities between 0.5 and 120 lux (Boshouwers & Nicaise 1987), one might anticipate that there could be advantages in dimming the lights when birds are to be handled. Indeed, catching end-of-lay hens was found to be easier and faster in a light intensity of 2 lux than 12 lux, although no advantages were found in dimming the light below 2 lux (Gregory *et al* 1993).

Conclusions and recommendations

In order to draw some conclusions from this part of the review, welfare problems associated with low and high light intensities have been summarized in Tables 2 and 3.

Although vision is important to domestic poultry, and birds have better visual acuity in bright than dim light, they are often kept in light intensities of 5 to 10 lux or lower. Some impairment in the ability of the birds to engage in exploratory behaviour and social interaction is likely at these levels. Furthermore, intensities of 6 lux or below can lead to increased mortality in brooded chicks and turkey poults. These light levels are also associated with leg problems, eye abnormalities, and breast blisters in growing birds. Leg abnormalities have been seen more commonly in turkeys at 19 lux than at higher light intensities. Hens have been shown to be more fearful when housed at light intensities of up to 22 lux, as compared with higher levels. One must also consider the ability of the stockman to monitor the health of birds at low light intensities. Conversely, the possibility of inducing aggressive behaviour by increasing light intensity must be considered.

Table 2 Summary of light intensity effects upon the welfare of housed laying and broiler hens.

Recorded at light intensity (lux)	But not at light intensity (lux)	Problem	Author(s)
Problems of 'low' light intensities; recorded more frequently than at higher light levels			
3	15	Reduced food intake in female chicks	Gordon 1989
5	75	Mortality in brooded chicks	Deaton *et al* 1981
6	180	Leg problems and breast blisters in broilers	Newberry *et al* 1988
7	35	Difficult for stockmen to see birds	Phillips & Weiguo 1991
17–22	55–80	Fearfulness in laying hens	Hughes & Black 1974
50	500	Feather pecking in hens	Martin 1989
Problems of 'high' light intensities: recorded more frequently than at lower light levels			
6–44	1–11	Feather pecking in hens	Hughes & Duncan 1972

At present, only tentative recommendations for appropriate lighting intensities in poultry houses can be made because such widely differing parameters have been studied experimentally. For example, although hens housed at 17 to 22 lux were more fearful than those housed at 55 to 80 lux (see remarks about effects on behaviour), there is no information as to what effect housing at, say 35 or 45 lux would have upon fearfulness. One major reason why laying hens and turkeys are currently housed at relatively low light intensities is that aggressive behaviour is anticipated in brighter lighting. However, experimental evidence on the correlation between feather pecking and light intensity is conflicting. Since aggressive behaviour is not generally a problem in broiler birds, there seems to be no reason why higher light intensities should not be used forthwith. Any resulting reduction in leg problems would be a major welfare improvement in this type of bird.

The following recommendations are made:

1 Taking into account the facts summarized above, a minimum light intensity of 20 lux is recommended for all poultry, pending further research.

2 Higher light intensities in some systems, particularly for turkeys and laying hens, may result in increased levels of aggressive behaviour and cannibalism. Rather than relying upon dimming the lights or beak trimming, management strategies such as the provision of adequate space allowance, suitable group size and low energy diets are recommended for the control of aggressive behaviour. Genetic selection for less aggressive birds may also permit the use of higher light intensities in the future.

3 Light sources should be evenly distributed so as to avoid pools of intense light where large numbers of birds are housed together. So-called sunbathing may otherwise lead to large aggregations of birds and death by smothering.

4 Research is needed to determine at what level birds are unable to carry out normal exploratory and social behaviour. Knowledge is required, not only of the preferences of hens and turkeys for different light intensities, but whether the birds are prepared to work in operant tests for these preferred intensities. Investigations should aim to demonstrate whether birds have a preferred light level for different activities. A greater insight is also needed into the reasons for sun-bathing behaviour and an understanding of how important this activity is to birds.

Table 3 Summary of light intensity effects upon the welfare of housed turkeys.

Recorded at light intensity (lux)	But not at light intensity (lux)	Problem	Author(s)
Problems of 'low' light intensities; recorded more frequently than at higher light levels			
1.1	11	Mortality in birds under 2-weeks-old	Siopes *et al* 1983
1.1	11	Eye abnormalities in young birds	Siopes *et al* 1984
7	35	Difficult for stockmen to see birds	Phillips & Weiguo 1991
19	220	Leg abnormalities in growing birds	Davis & Siopes 1985
Problems of 'high' light intensities; recorded more frequently than at lower light levels			
11	0.11	Feather pecking in birds aged 3 to 12 weeks	Bacon & Touchbarn 1976
20	2.5	Cannibalism in birds aged 2 to 19 weeks	Hester *et al* 1987
86.1	10.8	Mortality in birds aged 8 to 24 weeks	Leighton *et al* 1989

Photoperiod

In general, daily photoperiods can range from 0 (continuous dark) to 24 hours (continuous light). Intermittent light patterns are also used and these are defined as providing more than one period of light and one of dark within each 24 hours (Lewis *et al* 1992). For example, lights may be on for 8 hours then off for 4, on again for 2 hours then off for 10 (8L:4D:2L:10D), or they may be on for 1 hour then off for 2 hours throughout the 'light' period (Sykes 1988). A more extreme form of intermittent lighting is the 'biomittent'[1] pattern, where lights are on for 15 minutes and off for 45 minutes in every hour of the light period (Lewis & Perry 1990).

Photoperiods are sometimes altered throughout the life of the bird. For example, broiler chickens may be maintained for 6h light daily (6L:18D) during the first two to three weeks, before increasing the photoperiod to 23h daily (23L:1D). So-called step-up and step-down lighting regimes, where the photoperiod is increased or decreased in stages, are also used for turkeys.

In practice broilers and turkeys are most often kept in the light for 23h daily whereas layers need a minimum of 10h light daily in order to maintain egg production (Appleby *et al* 1992). At least one period of darkness in every 24h is recommended so that birds become accustomed to the dark and are less likely to panic in case of power failure (Sykes 1988). Domestic fowl can adapt to a variety of photoperiods; however, Savory and Duncan (1982) have shown that when given a choice between light and dark, hens prefer to spend at least 80 per cent of their time in light. In an operant experiment, the birds worked by pecking a key every one minute or three minutes in order to maintain illumination for approximately four hours daily, whereas they did not work to achieve darkness.

In conventional poultry houses, the onset of light and dark periods is instantaneous, and Bryant (1987) has questioned whether this may be more stressful for birds than the progression of a gradual dawn and dusk. This question has been addressed by Tanaka and Hurnik (1991), who observed the behaviour of hens in cages and aviaries at the time of sudden light onset and offset, or in simulated dawn and dusk in which the light intensity was gradually changed over a five minute period. In both cases, birds show an increase in feeding before dark, then begin to move towards resting places. When the lights were suddenly extinguished, some birds, particularly in the aviary, had not found a roost before light offset and continued to search in complete darkness. This problem did not occur in the simulated dawn. After light onset, the birds became active and commenced feeding; in conventional lighting, some birds appeared alarmed by the sudden onset of lighting and of movement around them. Thus the authors conclude that a gradual onset and offset of lights might increase the comfort of housed birds. However, they warn that birds should be allowed to become accustomed to a sudden offset of lights, since otherwise a power failure could result in panic.

Effects on behaviour

Very few studies have examined the effects of different photoperiods upon the behaviour of poultry. However, birds kept in continuous light were shown to be less active than those in intermittent lighting (Simmons 1982). This has implications for the health of the birds since a correlation has been found between low activity and a high incidence of leg problems (Wilson *et al* 1984).

The behaviour of laying birds kept in an interrupted lighting schedule (8L:4D:2L:10D) was compared with that of birds on 14L:10D. Those in the former group were observed to be passively resting, rather than actually sleeping, during the 4h dark period (March *et al*

[1] Term registered by the Ralston Purina Company, St Louis, USA.

1990). Birds in the more extreme form of intermittent lighting known as 'biomittent lighting' have also been studied. Laying hens were maintained in this type of lighting during a 14h day. The birds were found to be inactive during the dark periods, but in a state of 'passive wakefulness' rather than actually resting. The birds were more restless at night than those on continuous 14h photoperiods. It was considered that this lighting regime was restrictive of the bird's potential activity during the day, since their activity was curtailed whenever the lights were switched off (Coenen *et al* 1988). Blokhuis (1983) has also pointed out that intermittent lighting in general is likely to disturb the sleep patterns of birds and suggested that this could be deleterious to their welfare.

Effects on health

Eye abnormalities can be a problem in chickens kept in continuous lighting (Shutze *et al* 1959; Lauber & McGinnis 1966; Whitley *et al* 1984; Oishi & Murakami 1985) as well as in those on a 22-hour photoperiod (Oishi & Murakami 1985), independent of light intensity. The eyes of affected birds were larger than normal, with a shallow anterior chamber, reduced corneal diameter and increased thickness of the choroid layer. It has been suggested that these changes are precursors of glaucoma (increased intraocular pressure), which would probably develop when the size of the globe had reached the extent of its elastic limit (Whitley *et al* 1984). In fact Lauber and McGinnis (1966) rarely saw evidence of glaucoma in hens kept in continuous light for over two years, but by this age all birds were blind due to retinal detachment.

Buphthalmos (swelling of the globe), corneal flattening and thinning of the retina and choroid were observed in 70 per cent of turkeys kept in continuous light but not in those given only 12h of light daily (Ashton *et al* 1973). The changes developed within one week of age but they were reversible if the birds were later placed in a 12h dark: 12h light cycle. The eye condition induced in this study was very similar to that observed in the so-called turkey blindness syndrome, indicating that the latter is probably due to the use of prolonged exposure to light. A photoperiod of 23h daily has also been found to lead to the same type of eye abnormality in turkeys (Davis *et al* 1986).

Much effort has been directed at reducing the incidence of leg abnormalities, which are common among broiler birds and turkeys. Several authors have reported that such abnormalities can be reduced in broilers by housing them in intermittent lighting (Buckland *et al* 1976; Simmons 1982; Whitley *et al* 1984; Wilson *et al* 1984). This may be related to the fact that birds are more active in intermittent rather than continuous lighting (Simmons 1982).

Further evidence that health may be better in intermittent compared to conventional lighting is presented by Lewis *et al* (1992). Their review of the literature showed a consistently lower level of mortality in laying hens housed in intermittent lighting. Low mortality was also recorded in birds kept on 'biomittent' patterns (however, see comments on the effects of such regimes on behaviour, page 348).

Maintaining broiler chickens on 6h light daily during the first two to three weeks before increasing the photoperiod to 23h daily, has also been shown to have a beneficial effect on the incidence of leg abnormalities and mortality (Classen & Riddell 1989; Classen *et al* 1991; Renden *et al* 1991). Slowly increasing the photoperiod from 6h to 23h daily after the first week was similarly beneficial. Food intake and weight gain were lower in birds on a

6h photoperiod than in those on 23h light daily, and it was suggested that this lower weight gain may have helped to normalize skeletal growth. Birds on restricted photoperiods during the early weeks tend to catch up and attain similar body weights by slaughter to those on longer photoperiods (Renden *et al* 1991). The incidence of mortality and skeletal problems was also lower in chickens kept on increasing light regimes than in those kept in intermittent lighting (Classen 1991). However, a drawback to the increasing light regimes was pointed out by Newberry and Blair (1993) who found that birds reared in this way were significantly more fearful and difficult to handle prior to slaughter. Possibly this was related to the relative lack of stimulation for the birds during their first two to three weeks of life, when they spent 18 hours in darkness. Further investigations might show whether photoperiods could be less restricted at this time, or whether the feeding of low energy diets might lead to a sufficient moderation of growth to prevent leg problems.

Photoperiods which are gradually changed during rearing have also been used in turkeys. The effect of a step up[2] regime and light intensity of 20 lux on leg abnormalities in turkeys was compared with that of a step down[3] regime at 2.5 lux. It was anticipated that the increasing photoperiod and higher light intensity shortly before sexual maturity might encourage earlier maturation and hence earlier growth plate closure and stronger leg bones. This was found to be the case and the former group showed a significantly lower incidence of leg abnormalities (Hester *et al* 1983). Subsequently the activity of birds on step down and step up regimes, where the light intensity was 2.5 lux in both treatment groups, was compared. Although birds were observed to be more active in the step up regime, this had no effect upon the incidence of leg abnormalities. These birds had shorter day lengths during the earlier weeks so they would have had less time for activity and for feeding than those on the step down regime (Hester *et al* 1985). It was therefore concluded that the stepping up of lighting, *in combination with a higher light intensity*, was responsible for protecting against leg problems. Classen *et al* (1994) compared the behaviour, health and performance of heavy male turkeys reared in gradually increasing photoperiods (from 6L:18D at 7 days to 20L:4D at 63 days, then either remaining constant or gradually decreasing) with those in constant light. The former birds were found to be more active, with stronger bones, fewer leg abnormalities and a lower incidence of spontaneous cardiomyopathy.

There is some evidence that birds reared in continuous light are more stressed than those reared in restricted photoperiods. Freeman *et al* (1981) found that broiler chicks raised in continuous light from hatching to three weeks of age had adrenal glands which weighed 21 per cent more than those of chicks raised in 12 hours light daily, taking into account differences in body weight. There was also evidence that the adrenal glands of the former were more active than the latter since these birds developed higher plasma corticosterone concentrations in response to an injection of adrenocorticotrophic hormone (ACTH). Shutze *et al* (1959) reported 'signs of stress' in layer chicks reared in continuous light, though no details were given.

[2] Step up lighting – 24 hours daily on days 1 to 3; 9 hours daily on days 4 to 49. From day 50 onwards, increasing by 0.5 hours each week to 15.5 hours daily by day 127.

[3] Step down lighting – 24 hours daily on days 1 to 3; 23 hours on day 4, then decreasing by 1 hour daily to 12 hours on day 15 and thereafter.

The correlation between stress and immunity is well proven and stressful conditions in man and animals have frequently been found to lead to a reduced immune response (Griffin 1989). Providing further evidence that continuous light may be stressful to birds, the immune response of 10-week-old cockerels reared in such lighting was inferior to that of birds reared in a 12h light: 12h dark regime (Kirby & Froman 1991). Chicks reared in 16h light daily had a higher lymphocyte count and a more active lymphocyte response to a mitogen test than those provided with 8h light each day (Mashaly *et al* 1988). High lymphocyte counts (Gross & Siegel 1985; McFarlane & Curtis 1989) and active lymphocyte responses (Kristensen *et al* 1982) are generally considered to be indicative of a low 'stress level', suggesting that in this study, the chickens reared in the longer photoperiod were the less stressed.

Effects on performance

Many studies have examined the effects of manipulating photoperiod on the performance of various classes of poultry. Photoperiods of 12h, 23h or 24h daily had no effect upon growth rate, food conversion or mortality in turkeys (Davis & Siopes 1985). However, photoperiods of less than 12h can lead to a reduction in food intake and weight gain, since turkey poults kept on a step up lighting regime showed lower food intake and weight gain than those on a step down regime (Hester *et al* 1985). Food intake and weight gain were also lower in broiler chickens kept on a 6h photoperiod than those kept in 23h light daily (Renden *et al* 1991). One may conclude that short photoperiods must limit the amount of time which a bird has for feeding, and rapidly growing birds are most likely to be affected by any factor which limits feeding time.

The effect of intermittent lighting upon performance has also been studied. Turkeys aged 12 weeks or over, kept in intermittent lighting (2h dark: 2h light) were found to grow more rapidly than those provided with 12h dark: 12h light daily (Gill & Leighton 1984).

Conclusions and recommendations

In order to draw some conclusions from this part of the review, the welfare advantages and disadvantages of different types of photoperiod have been tabulated (see Table 4).

In trying to determine the optimum length for the daily photoperiod, the problem that widely varying parameters have been used experimentally is again encountered. For example, although eye abnormalities have been recorded in birds housed in 22 to 24 hours of light daily (see page 349), the effect of housing them in photoperiods of, say 20 or 21 hours is not known. Although birds reared in 6h photoperiods in early life appear to be more flighty in later life, the effect of rearing in 7 or 8 hours of life is not known. Since birds reared outdoors in temperate climates are not likely to encounter a day length shorter than 8h, even in the winter, this has been taken as a suitable minimum photoperiod. The welfare codes issued by the Ministry of Agriculture, Fisheries and Food for the UK also recommend that birds should be provided with a minimum of 8h lighting daily where there is no access to natural daylight; however, they do not suggest any maximum photoperiods (MAFF 1988; MAFF 1990).

Table 4 **Welfare advantages and disadvantages of different photoperiods for housed poultry.**

Type of photoperiod	Advantages	Disadvantages	Author
22–24 hours		Eye abnormalities in chickens	Whitley *et al* 1984 Oishi & Murakami 1985
		Eye abnormalities in turkeys	Ashton *et al* 1973 Davis *et al* 1986
		Increased adrenal weights	Freeman *et al* 1981
		Possibility of panic in cases of power cut	Sykes 1988
Intermittent	Reduced mortality in laying hens		Lewis *et al* 1992
	Reduced incidence of leg problems		Whitley *et al* 1984 Wilson *et al* 1984
		Disturbed rest/sleep cycle	March *et al* 1990 Coenen *et al* 1988
Gradually increasing from 6 to 20 hours	Reduced incidence of leg problems in chickens		Classen *et al* 1991 Renden *et al* 1991
	Reduced incidence of leg problems in turkeys		Classen *et al* 1994
	Reduced incidence of cardiomyopathy in large male turkeys		Classen *et al* 1994
		Difficult to handle broiler birds pre-slaughter	Newberry & Blair 1993

The following recommendations are made:

1 Poultry are diurnal birds in which vision is important. They have been shown to work in an operant study to obtain light. Considering the evidence available, a daily photoperiod of at least 8 hours is recommended, although this may be modified with further research. Where birds are housed in intermittent lighting, the total light received daily should be not less than 8 hours in duration.

2 Since photoperiods of 22 hours or more can cause eye abnormalities and blindness, it is recommended that birds be provided with not more than 20 hours light daily.

3 Poultry kept in intermittent lighting regimes tend to be more active than those in continuous light and this is correlated with a reduction in the incidence of leg problems. However, research is needed to show whether intermittent lighting regimes can be stressful to birds because of their effect on sleep and activity patterns.

4 Providing relatively short photoperiods during the first two or three weeks and then increasing them gradually, has also been shown to be beneficial as regards leg abnormalities in both broiler hens and turkeys. It is probable that these lighting regimes would be less disturbing to birds than intermittent ones. The photoperiod at the beginning of the rearing period should be of at least 8 hours duration.

Wavelength

The wavelength of light determines its colour and a mixture of all wavelengths gives rise to so-called white light, which is similar to the visible light emitted by the sun. It is often difficult to distinguish between the direct effects of wavelength and the fact that wavelength can alter the apparent intensity of the light to the birds. Birds in comparison to man have a different sensitivity to the spectral quality of light, and they apparently have better visual acuity in light which is towards the red end of the colour spectrum. There may thus be effects of wavelength upon behaviour and physiology. Since it has been shown that birds are so sensitive to different wavelengths, Nuboer (1993) has urged that studies be carried out to determine the preferred wavelength and light intensity for poultry, in order to ensure their good welfare. He has also suggested that there may be a case for providing zones differing in wavelength for activities such as dust bathing and egg laying as well as for delineating escape areas for birds which are under attack from others.

Effects on behaviour

The wavelength of light can affect birds' behaviour; young turkeys were found to be less active in blue than white, green or red light (Levenick & Leighton 1988). When broiler chickens were reared from one to four weeks of age in white, green, blue or red light the incidence of aggression, wing stretching and pecking at the cage was found to be highest in the red light and lowest in blue or green light, probably because of the birds' greater visual acuity in red light; the light thus appeared brighter to the birds and led to greater activity (Prayitno *et al* 1994). It may be surprising that aggression should be more prevalent in red light since using light of this colour has been recommended as a treatment for feather pecking and cannibalism. However, the rationale for the latter recommendation is that the birds cannot easily see red blood or wounds in red light (Appleby *et al* 1992). Furthermore, Wells (1971) pointed out that the application of red filters or red paint to light sources may simply be effective in reducing aggression because of a marked reduction in light intensity.

Domestic fowl appear to have some preferences for colour. When broiler chicks were reared in white, green, blue or red light of equal intensity, then placed into a pen providing a choice of these four wavelengths, they initially chose to dwell in light of the wavelength to which they were accustomed. However, after one week, all of the birds preferred to be in the blue or green light (Prayitno *et al* 1993). Widowski *et al* (1992), who observed that pullets chose to be in a room with fluorescent rather than incandescent light, also suggested that this may have been because of the blue wavelength of the former.

Effects on health

Broiler birds reared in red light were more active, had greater bone strength and suffered fewer leg problems than those reared in blue light. Even rearing in red light for the first 16 days had a beneficial effect in reducing lameness in the finished birds (Prayitno 1994).

Effects on performance

Rearing broiler chickens in white, green, blue or red light has been shown to have no effect on food intake or growth rate (Wathes *et al* 1982; Prayitno *et al* 1994). However, in turkeys aged up to 16 weeks and housed in blue light, growth rate was found to be higher than in those kept in red or white light. After this age, growth was more rapid in white or red light. In both age groups, mortality was higher in the most rapidly growing birds, although the causes were not given (Levenick & Leighton 1988). In a comparison of pullets reared in white or green lighting, Cave (1990) observed a lower mortality both before and during the laying period in birds reared in the green light.

Conclusions and recommendations

Those responsible for the husbandry of domestic poultry should be aware that the wavelength of light can influence its apparent intensity to birds; in this way, wavelength may affect the activity and health of birds.

Further research is recommended to determine the effects of light wavelength, independent of intensity, upon the behaviour and welfare of domestic poultry.

Light source

Fluorescent lighting in poultry houses is often preferred by owners and managers because it is less costly to run than incandescent bulbs which provide an equivalent amount of light.

Effects on behaviour

Physical activity in hens kept in fluorescent light was found to be greater than in incandescent light of the same intensity, as measured by a light meter. This shows that the birds can detect a difference between these types of light source (Boshouwers & Nicaise 1993).

The incidences of social encounters and mortality were both higher in male turkeys aged 8 to 24 weeks kept in fluorescent light, than in those housed in incandescent or sodium vapour lighting. However, it is not clear whether there was any correlation between social encounters and mortality, and the incidence of aggressive behaviour was said to be low in all groups (Leighton *et al* 1989). A parallel study carried out in female birds showed no effect of light source on performance or behaviour (Denbow *et al* 1990).

Fluorescent lighting units may be of low or high frequency and learning experiments have shown that chickens are able to distinguish between the two. The level at which birds can detect a difference between continuous and discontinuous lighting, known as the critical fusion frequency (CFF), is approximately 105Hz (Nuboer *et al* 1992) to 120Hz (Widowski & Duncan 1996). This means that birds can detect the flicker of low frequency fluorescent lighting which is not apparent to humans, whose CFF is much lower. Since this flicker could be aversive to chickens, Boshouwers and Nicaise (1992) compared the behaviour of birds in low frequency (100Hz) and high frequency (26,000Hz) fluorescent lighting. The birds had been reared in high frequency lighting until two weeks of age. Those subsequently placed in low frequency light were significantly less active than those in high frequency light; they also showed some freezing responses, indicative of fear. The birds were evidently able to distinguish between the two types of lighting; however, it is difficult to know whether the lighting was actually aversive to the birds or whether they were simply responding to an unfamiliar stimulus. Another study revealed that hens showed no preference for dwelling in high frequency (30,000Hz) or low frequency (120Hz) fluorescent lighting (Widowski & Duncan 1996).

Effects on health

Although Hulan & Proudfoot (1987) recorded no differences in weight gain or feed conversion rate between broiler chicks reared in white incandescent or pink fluorescent lighting, the incidence of total leg abnormalities was found to be lower in the latter group. It has already been pointed out that birds have improved visual acuity in red light, so it is likely that these chicks would have been stimulated to greater activity than the birds in white light and that this would have helped to protect against leg problems.

Effects on performance

No differences have been found in growth rate, feed efficiency and mortality between broilers housed in fluorescent or incandescent lighting (Le Menec & Launay 1988; Zimmermann 1988; Scheideler 1990), or between breeding turkeys of both sexes in these types of lighting (Felts *et al* 1990). Light source (fluorescent or incandescent) was found to have no effect upon egg production, hatchability and feed conversion in broiler breeders (Coleman & Minear 1981).

Conclusions and recommendations

1 Costs can be reduced by using fluorescent light, rather than other sources of lighting, in poultry houses. In general, fluorescent light appears to be as satisfactory as incandescent light for domestic fowl and one study showed that it was preferred by the birds. However, more research is required in turkeys, since one study revealed a higher mortality in male birds kept in fluorescent compared with those in incandescent light.

2 Hens can distinguish between high and low frequency fluorescent light and are probably aware of the flicker produced by the latter; however, they do not appear to find this aversive.

Final conclusions

The effects of lighting upon behaviour, health, performance and management of poultry have several implications for the welfare of housed poultry. For example, light intensities currently used in poultry houses may contribute to inactive behaviour, a high incidence of leg abnormalities and fearfulness. These problems could be reduced if light intensities of 20 lux or more are employed. However, management strategies to prevent aggressive behaviour in higher light intensities, particularly in turkeys and laying hens, may have to be adopted. Those responsible for the care of poultry are urged to employ methods such as the provision of adequate space allowance, suitable group size and low energy diets to control aggressive behaviour, rather than resorting to dimming the lights or beak trimming birds.

Suitable photoperiods for housed poultry are likely to lie between 8 and 20 hours daily. There is some evidence of improved health in birds housed in intermittent lighting but questions have been raised as to the effects of such lighting patterns upon rest/activity cycles in birds. Photoperiods which employ gradually increasing day length appear to have several advantages to birds in terms of health and reduced leg abnormalities. The use of a gradual onset and offset of lights appear to be less stressful to birds than a sudden change between light and dark, and vice-versa.

The wavelength of light sources in poultry houses can affect the apparent intensity of the light to the bird. Since birds apparently have greater visual acuity in the red end of the light spectrum, sources with a relatively large component of red light may increase the apparent intensity of the light and hence increase bird activity. Conversely, sources with a large component of blue light may reduce activity.

The use of fluorescent lighting in poultry houses is unlikely to affect the welfare of the birds, and although hens have shown an ability to detect the flicker of high frequency fluorescent lighting, they do not appear to find this aversive.

Further research is needed to determine what light intensities and photoperiods are required for different classes of poultry to carry out normal exploratory and social behaviour. Investigations are also needed to assess the preferences of hens and turkeys for different light intensities, and to find out whether birds are prepared to work in operant tests for these preferred intensities. Researchers should also aim to demonstrate whether birds have a preferred light level for different activities.

Acknowledgements

This review was carried out through the generosity of the Farm Animal Care Trust who provided funding. The following provided helpful and constructive comments on the manuscript: Dr H Bradshaw, Professor D M Broom, Mrs R Harrison and Dr J Marchant.

References

Appleby M C, Hughes B O and Elson H A 1992 *Poultry Production Systems: Behaviour, Management and Welfare*. CAB International: Wallingford, UK.

Appleby M C, McRae H E and Peitz B E 1983 The effect of light on the choice of nests by domestic hens. *Applied Animal Ethology 11:* 249-254

Ashton W L G, Pattison M and Barnett K C 1973 Light-induced eye abnormalities in turkeys and the turkey blindness syndrome. *Research in Veterinary Science 14:* 42-46

Bacon W L and Touchbarn S P 1976 Effect of light intensity on confinement rearing of male turkeys. *Poultry Science 55*: 999-1007

Blokhuis H J 1983 The relevance of sleep in poultry. *World's Poultry Science Journal 39:* 33-37

Boshouwers F M G and Nicaise E 1987 Physical activity and energy expenditure of laying hens as affected by light intensity. *British Poultry Science 28:* 155-163

Boshouwers F M G and Nicaise E 1992 Responses of broiler chickens to high-frequency and low-frequency fluorescent light. *British Poultry Science 33:* 711-717

Boshouwers F M G and Nicaise E 1993 Artificial light sources and their influence on physical activity and energy expenditure of laying hens. *British Poultry Science 34:* 11-19

Bryant S L 1987 A case for dawn and dusk for housed livestock. *Applied Animal Behaviour Science 18:* 379-382

Buckland R B, Bernon D E and Goldrosen A 1976 Effect of four lighting regimes on broiler performance, leg abnormalities and plasma corticoid levels. *Poultry Science 55:* 1072-1076

Cave N A 1990 Effects of feeding level during pullet-layer transition and of pre-transition lighting on performance of broiler breeders. *Poultry Science 69:* 1141-1146

Cherry P and Barwick M W 1962 The effect of light on broiler growth 1. Light intensity and colour. *British Poultry Science 3:* 31-39

Classen H L and Riddell C 1989 Photoperiodic effects on performance and leg abnormalities in chickens. *Poultry Science 68:* 873-879

Classen H L 1991 Increasing photoperiod length provides better broiler health. *Poultry Digest 50:* 14-28

Classen H L, Riddell C and Robinson F E 1991 Effects of increasing photoperiod length on performance and health of broiler chickens. *British Poultry Science 32:* 21-29

Classen H L, Riddell C, Robinson F E, Shand P J and McCurdy A R 1994 Effect of lighting treatment on the productivity, health, behaviour and sexual maturity of heavy male turkeys. *British Poultry Science 35:* 215-225

Coenen A M L, Wolters E M T J, van Luijteleer E L J M and Blokhuis H J 1988 Effects of intermittent lighting on sleep and activity in the domestic hen. *Applied Animal Behaviour Science 20:* 309-318

Coleman M A and Minear L R 1981 A comparison of the effects of fluorescent versus incandescent lighting on the reproductive performance of two strains of broiler breeders. *Poultry Science 60:* 1642

Davis G S and Siopes T D 1985 The effect of light duration on turkey poult performance and adrenal function. *Poultry Science 64:* 995-1001

Davis G S, Siopes T D, Peiffer R L and Cook C 1986 Morphologic changes induced by photoperiod in eyes of turkey poults. *American Journal of Veterinary Research 47:* 953-955

Deaton J W, Reece F N, McNaughton J L and Lott B D 1981 Effect of light intensity and low-level intermittent lighting on broiler performance, during a high density limited-area brooding period. *Poultry Science 60:* 2385-2387

Denbow D M, Leighton A T and Hulet R M 1990 Effect of light sources and light intensity on growth, performance and behaviour of female turkeys. *British Poultry Science 31:* 439-443

Farm Animal Welfare Council 1995 *Report on the Welfare of Turkeys*. Paragraphs 35 to 40. FAWC: Surbiton, UK

Felts J V, Leighton A T, Denbow D M and Hulet R M 1990 Influence of light sources on the growth and reproduction of large white turkeys. *Poultry Science 69:* 576-583

Fox M W 1984 *Farm Animals. Husbandry, Behavior and Veterinary Practice*. University Park: Baltimore, USA

Freeman B M, Manning A C C and Flack I H 1981 Photoperiod and its effect on the responses of the immature fowl to stressors. *Comparative Biochemistry and Physiology 68A:* 411-416

Gibson S W, Innes J and Hughes B O 1985 Aggregation behaviour of laying fowls in a covered strawyard. In: Wegner, R-M (ed) *Second European Symposium on Poultry Welfare* pp 296-298. German branch of the World's Poultry Science Association (WPSA): Celle, Germany

Gill D J and Leighton A T 1984 Effects of light environment and population density on growth performance of male turkeys. *Poultry Science 63:* 1314-1321

Gordon S 1989 Quality broiler production - Part 1 Gleadthorpe overview. *Agricultural Development Advisory Service (ADAS) Poultry Journal 3:* 33-45

Gregory N G, Wilkins L J, Alvey D M and Tucker S A 1993 Effect of catching method and lighting intensity on the prevalence of broken bones and on the ease of handling of end-of-lay hens. *Veterinary Record 132:* 127-129

Griffin J F T 1989 Stress and immunity: a unifying concept. *Veterinary Immunology and Immunopathology 20:* 263-312

Gross W B and Siegel H S 1985 Evaluation of the heterophil/lymphocyte ratio as a measure of stress in chickens. *Avian Diseases 27:* 972-979

Harrison PC and McGinnis J 1967 Light-induced exophthalmos in the domestic fowl. *Proceedings of the Society for Experimental Biology and Medicine 126:* 308-312

Hester P Y, Elkin R G and Klingensmith P M 1983 Effects of high intensity step up and low intensity step down lighting programs on the incidence of leg abnormalities in turkeys. *Poultry Science 62:* 887-896

Hester P Y, Sutton A L and Elkin R G 1987 Effect of light intensity, litter source, and litter management on the incidence of leg abnormalities and performance of male turkeys. *Poultry Science 66:* 666-675

Hester P Y, Sutton AL, Elkin R G and Klingensmith P M 1985 The effect of lighting, dietary amino acids, and litter on the incidence of leg abnormalities and performance of turkey toms. *Poultry Science 64:* 2062-2075

Huber H-U and Fölsch D W 1985 The hens' need for light In: Wegner, R-M (ed) *Second European Symposium on Poultry Welfare* pp 292-293. German branch of the World's Poultry Science Association (WPSA): Celle, Germany

Hughes B O and Black A J 1974 The effect of environmental factors on activity, selected behaviour patterns and "fear" of fowls in cages and pens. *British Poultry Science 15:* 375-380

Hughes B O and Duncan I J H 1972 The influence of strain and environmental factors upon feather pecking and cannibalism in the fowl. *British Poultry Science 13:* 525-547

Hulan H W and Proudfoot F G 1987 Effects of light source, ambient temperature and dietary energy source on the general performance and incidence of leg abnormalities of roaster chickens. *Poultry Science 66:* 645-661

Jenkins R L, Ivey W D, McDaniel G R and Albert R A 1979 A darkness induced eye abnormality in the domestic chicken. *Poultry Science 58:* 55-59

King-Smith P E 1971 Special senses In: Bell D J and Freeman B M (eds) *Physiology and Biochemistry of the Domestic Fowl* pp 1040-1060. Academic Press: London, UK

Kirby J D and Froman D P 1991 Evaluation of humoral and delayed hypersensitivity responses in cockerels reared under constant light or a twelve hour light: twelve hour dark photoperiod. *Poultry Science 70:* 2375-2378

Klingensmith P M, Hester P Y, Elkin R G and Ward C R 1986 Relationship of high intensity step up lighting to bone ash and growth plate closure of the tarso-metatarsus in turkeys. *British Poultry Science 27:* 487-492

Kristensen F, Kristensen B and Lazary S 1982 The lymphocyte stimulation test in veterinary immunology. *Veterinary Immunology and Immunopathology 3:* 203-277

Lauber J K and McGinnis J 1966 Eye lesions in domestic fowl reared under continuous light. *Vision Research 6:* 619-626

Leighton A T, Hulet R M and Denbow D M 1989 Effect of light sources and light intensity on growth performance and behaviour of male turkeys. *British Poultry Science 30:* 563-574

Le Menec M and Launay M 1988 A comparison of three lighting methods in the production of broiler fowls. *Bulletin d'Information, Station Experimentale d"Aviculture de Ploufragan, France 28:* 119-127

Levenick C K and Leighton A T 1988 Effect of photoperiod and filtered light on growth, reproduction and mating behavior of turkeys. 1. Growth performance of two lines of males and females. *Poultry Science 67:* 1505-1513

Lewis P D and Perry G C 1990 Glossary of avian photoperiodic terminology and methods of expressing lighting regimens. *British Poultry Science 31*: 677-684

Lewis P D, Perry G C, Morris T R and Midgley M M 1992 Intermittent lighting regimes and mortality rates in laying hens. *World's Poultry Science Journal 48*: 113-120

March T I, Thompson L J, Lewis P D and Perry G C 1990 Sleep and activity behaviour of layers subjected to interrupted lighting schedules. *British Poultry Science 31*: 895-896

Martin D, Taylor J, Harrison D and Pearson J (eds) 1980 Lighting. In: *Specification 80. Building Methods and Products, Volume 3* pp 59-81. The Architectural Press Ltd: London, UK

Martin G 1989 Federpickhaufigkeit in Abhangigkeit von Draht- und Einstreuboden sowie von der Lichtintensitat. *Kuratorium fur Technik und Bauwesen in der Landwirtschaft Schrift 342*: 108-133

Mashaly M M, Trout J M, Sieminski-Brodzina L M and Siegel H S 1988 Effect of exposure to different light regimes on the immune response of immature female chickens. *Poultry Science 67 (Supplement 1):* 114

McFarlane J M and Curtis S E 1989 Multiple concurrent stressors in chicks. 3. Effects on plasma corticosterone and the heterophil:lymphocyte ratio. *Poultry Science 68*: 510-521

Millam J R 1987 Preference of turkey hens for nest-boxes of different levels of interior illumination. *Applied Animal Behaviour Science 18*: 341-348

Ministry of Agriculture, Fisheries and Food 1988 *Codes of Recommendations for the Welfare of Livestock: Turkeys*. MAFF Publications: London, UK

Ministry of Agriculture, Fisheries and Food 1990 *Codes of Recommendations for the Welfare of Livestock: Domestic Fowls*. MAFF Publications: London, UK

Newberry R C and Blair R 1993 Behavioral responses of broiler chickens to handling - effects of dietary tryptophan and two lighting regimens. *Poultry Science 72*: 1237-1244

Newberry R C, Hunt J R and Gardiner E E 1986 Light intensity effects on performance, activity, leg disorders and sudden death syndrome of roaster chickens. *Poultry Science 65*: 2232-2238

Newberry R C, Hunt J R and Gardiner E E 1988 Influence of light intensity on behaviour and performance of broiler chickens. *Poultry Science 67*: 1020-1025

Nuboer J F W 1993 Visual ecology in poultry houses. In: Savory C J and Hughes B O (eds) *Fourth European Symposium on Poultry Welfare* pp 39-44. Universities Federation for Animal Welfare: Potters Bar, UK

Nuboer J F W, Coemans M A J M and Vos J J 1992 Artificial lighting in poultry houses: do hens perceive the modulation of fluorescent lamps as flicker ? *British Poultry Science 33*: 123-133

Oishi T and Murakami N 1985 Effects of duration and intensity of illumination on several parameters of the chick eye. *Comparative Biochemistry and Physiology 81A*: 319-323

Phillips C J C and Weiguo L 1991 Brightness discrimination abilities of calves relative to those of humans. *Applied Animal Behaviour Science 31*: 25-33

Prayitno D S 1994 *Effects of Light on Broiler Behaviour and Performance.* PhD Thesis, University of Wales, Bangor, Wales

Prayitno D S, Phillips C J C and Omed H M 1993 The initial and longterm preference of broilers for red, blue or green light after being reared in red, blue, green or white light. *Animal Production 56:* 438

Prayitno D S, Phillips C J C, Omed H M and Piggins D 1994 The effect of colour of lighting on the performance and behaviour of broilers. *British Poultry Science 35:* 173-175

Renden J A, Bilgili S F, Lien R J and Kincaid S A 1991 Live performance and yield of broilers provided various lighting schedules. *Poultry Science 70*: 2055-2062

Savory C J and Duncan I J H 1982 Voluntary regulation of lighting by domestic fowls in Skinner boxes. *Applied Animal Ethology 9*: 73-81

Scheideler S E 1990 Effect of various light sources on broiler performance and efficiency of production under commercial conditions. *Poultry Science 69*: 1030-1033

Shutze J V, Jensen L S and Matson W E 1959 Effect of lighting regimes on growth and subsequent egg production of chickens. *Poultry Science 38*: 1246

Simmons P C M 1982 Effect of lighting regimes on twisted legs, feed conversion and growth of broiler chickens. *Poultry Science 61*: 1546

Siopes T D, Timmons M B, Baughman G R and Parkhurst C R 1983 The effect of light intensity on the growth performance of male turkeys. *Poultry Science 62*: 2336-2342

Siopes T D, Timmons M B, Baughman G R and Parkhurst C R 1984 The effects of light intensity on turkey poult performance, eye morphology and adrenal weight. *Poultry Science 63*: 904-909

Sykes A H 1988 Laying hens. In: *Management & Welfare of Farm Animals: The UFAW Handbook, 3rd edition* pp 197-219. Baillière Tindall: London, UK

Tanaka T and Hurnik J F 1991 Behavioral responses of hens to simulated dawn and dusk periods. *Poultry Science 70*: 483-488

Wathes C M, Spechter H H and Bray T S 1982 The effect of light illuminance and wavelength on the growth of broiler chickens. *Journal of Agricultural Science 98*: 195-201

Wells R G 1971 A comparison of red and white light and high and low protein regimes for growing pullets. *British Poultry Science 12*: 313-325

Whitley R D, Albert R A, McDaniel G R, Brewer R N, Mora E C and Henderson R A 1984 Photo-induced buphthalmic eyes 1. Continuous fluorescent light. *Poultry Science 63*: 1537-1542

Widowski T M and Duncan I J H In press. The absence of preference for high-frequency versus low-frequency compact fluorescent light sources by laying hens. *Canadian Journal of Animal Science*

Widowski T M, Keeling L J and Duncan I J H 1992 The preferences of hens for compact fluorescent over incandescent lighting. *Canadian Journal of Animal Science 72*: 203-211

Wilson J L, Weaver W D, Beane W L and Cherry J A 1984 Effects of light and feeding space on leg abnormalities in broilers. *Poultry Science 63*: 565-567

Zimmermann N G 1988 Broiler performance when reared under various light sources. *Poultry Science 67*: 43-51