UNIVERSITY OF COPENHAGEN
FACULTY OF LIFE SCIENCES
DEPARTMENT OF LARGE ANIMAL SCIENCES

The effects of light intensity, gradual changes between light and dark and definition of darkness for the behaviour and welfare of broiler chickens, laying hens, pullets and turkeys.

- A Review for the Norwegian Scientific Committee for Food Safety

Helle Halkjær Kristensen
University of Copenhagen
Department of Large Animal Sciences
Grønnegårdsvej 8
DK-1870 Frederiksberg C.
Denmark

Description of the request

The Norwegian Scientific Committee for Food Safety requests for recommendations based on risk assessments of animal welfare as follows:

1. *Minimum light intensity requirements in directive 2007/43 for chicken kept for meat production, applied to broiler chickens, turkeys, laying hens and pullets.*
2. *A gradual change of the light intensity compared to the light simply being turned on and off, and the optimal dimming time between maximum light and dark and vice versa. Applied to broiler chickens, turkeys, laying hens and pullets.*
3. *Maximum light intensity in the dark period applied to broiler chickens, turkeys, laying hens and pullets.*

Summary of the main findings in the report

The light environment may affect the welfare of poultry via many different routes. This report reviews the evidence for the effects of 1) light intensity, 2) gradual changes between light and dark, and 3) the definition of darkness, on the welfare of broiler chickens, laying hens and pullets, and turkeys in three chapters according to the above request.

The light intensity may affect many aspects of welfare in broiler chickens, laying hens and turkeys. Poultry may develop eye abnormalities if reared in dim and/or continuous lighting. There is conflicting evidence for the effects of light intensity on feather pecking; some studies have found increased feather pecking in high light intensity, although others have found no effects of light intensity, which may be due to confounding different aspects of the light environment. Birds appear to show reduced fear of humans in 5 lux, but it is uncertain whether this is due to the light intensity *per se* or to relative changes in light intensity. Layers, broilers and turkeys prefer brightly lit (200 lux) environments at two weeks of age, whereas 6-weeks old layers and broilers prefer dimmer light environments (6 lux). Turkeys maintain their preference for the brighter environments (20-200 lux) and avoid entering environments lit by <1 lux. The findings on the effects of light intensity on poultry welfare require commercial scale validations before firm conclusions can be drawn.

Poultry may indeed benefit from a gradual transition between light and darkness, particularly to signal the oncoming night (dusk), whereas there is less evidence for the benefits of signalling the oncoming day (dawn). Although more work is needed on this topic, the evidence reviewed here all suggest that providing a dusk period will allow particularly laying hens in non-caged systems to find a suitable perch for the night whilst the visual environment permits this. In addition, the signal of the oncoming dark period has been shown to stimulate feeding behaviour in broilers and laying hens which may prevent food deficit occurring during the night. In the wild, fowl has been shown to fly onto their perches 30-60 minutes before darkness, although even much shorter periods of artificial dusk (5-10 minutes) have been shown to be beneficial to laying hens in experimental studies. The optimal lengths of the dusk and dawn periods need confirmation.

Very few scientific papers have defined the light level during the dark period, and there is great variability in how darkness has been defined in these papers. From the sources available, it is not possible to give an absolute threshold for darkness perception in poultry; this is likely to depend on whether the process in question is the lower limit for visual abilities, maintaining the circadian rhythm, based upon the nocturnal behaviour or the physiological responses of the birds. This is indeed an area in urgent need of research attention, due to the potential effects on animal welfare.

Index:

Background

For decades, there has been much focus on the effects of lighting on different aspects of poultry production, behaviour, physiology and welfare. In addition, several comprehensive reviews exist on the subject, dealing with animal welfare (Manser 1996, Martrenchar 1999), vision (Prescott et al. 2003), and production (Lewis and Morris 1999) in laying hens (Morris 1994), broilers (Buyse et al. 1996; Kristensen 1999) and turkeys (Nixey 1994). Much is known about the effects of lighting on poultry, although some essential questions still need addressing, as will become apparent in this report.

Several recommendations and regulations on lighting for poultry exist, both for broiler chickens, laying hens and turkeys. The request from the Norwegian Scientific Committee for Food Safety is based upon the recent Council Directive 2007/43/EC, and the exact wording of this directive (CEU 2007) with regards to lighting is given below. In addition, there are several recommendations and regulations on lighting for poultry, some of which are summarised in the following.

Council Directive 2007/43/EC wording regarding light

The Council Directive 2007/43/EC states in Annex 1 (Requirements applicable to holdings) that "…6. All buildings shall have lighting with an intensity of at least 20 lux during the lighting periods, measured at bird eye level and illuminating at least 80 % of the useable area. A temporary reduction in the lighting level may be allowed when necessary following veterinary advice.
7. Within seven days from the time when the chickens are placed in the building and until three days before the foreseen time of slaughter, the lighting must follow a 24-hour rhythm and include periods of darkness lasting at least six hours in total, with at least one uninterrupted period of darkness of at least four hours, excluding dimming periods." (CEU 2007). This directive (CEU 2007) covers animals of the species *Gallus gallus* kept for meat production, and thus does not include laying hens or turkeys (*Meleagris gallopavo ssp*.). Where recommendations and regulations on laying hens and turkeys have been found, these are given in the appropriate sections below.

Examples of other regulations and recommendations on light and poultry

The Council of Europe's recommendation concerning domestic fowl (both layers and broilers) (CoE 1995) states in article 14 that "all buildings shall have light levels sufficient to allow all birds to see one another and be seen clearly, to investigate their surroundings visually and to show normal levels of activity. It is therefore recommended that the minimum illumination level should be 20 lux at bird eye level, measured in 3 planes at right angles to each other. As far as practicable, natural light shall be provided. In this case light apertures should be arranged in such a way that light is distributed evenly within the accommodation." and "...A twilight period should be given in the dimming of lights sufficient to permit birds to settle without disturbance or injury" (CoE 1995). The Norwegian "Forskrift om Hold af Høns og kalkun (2001)" covers broilers, layers, pullets and turkeys and states in § 12 that rooms in which poultry are kept should be sufficiently lit for the animals to perform normal activities and see each other clearly, but not so sharp that it stimulates pecking and feather-pulling. The light should be evenly distributed in the room and it should be possible to adjust the light intensity. It is allowed to dim the light in periods or particular areas where doing so can reduce health- and behaviour problems. Poultry should also be given an uninterrupted period of darkness after the first few days, and specification for the length of the dark period are given in the text (§ 12, Forskrift om Hold af Høns og kalkun 2001).

Broiler chickens

The Council Directive (CEU 2007) is based upon a report by the Scientific Committee for Animal Health and Animal Welfare (SCAHAW 2000) entitled: The Welfare of Chickens Kept for Meat Production (Broilers). This report includes a review of the evidence for the effects of light intensity on the health and welfare of broiler chickens (amongst many other aspects of broiler housing and lighting), and concludes that "…Brighter lighting (e.g. more than 100 lux) is important to stimulate activity and is essential for survival in the first week of life. There are various welfare problems at light intensities below 20 lux. Equivalent light intensities in lux units are 25% lower with fluorescent than with incandescent lighting" (SCAHAW 2000). The Farm Animal Welfare Council in the UK (FAWC 1992) also considered 20 lux as a suitable average light intensity to allow all broilers to see and be seen clearly, but also set the absolute lowest average intensity of 10 lux throughout the broiler house (FAWC 1992).

Laying hens and pullets

The Council Directive 1999/74/EC for laying hens (CEU 1999) states in the annex that “All buildings shall have light levels sufficient to allow all hens to see one another and be seen clearly, to investigate their surroundings visually and to show normal levels of activity. Where there is natural light, light apertures must be arranged in such a way that light is distributed evenly within the accommodation. After the first days of conditioning, the lighting regime shall be such as to prevent health and behavioural problems. Accordingly it must follow a 24-hour rhythm and include an adequate uninterrupted period of darkness lasting, by way of indication, about one third of the day, so that the hens may rest and to avoid problems such as immunodepression and ocular anomalies. A period of twilight of sufficient duration ought to be provided when the light is dimmed so that the hens may settle down without disturbance or injury.” (CEU 1999).

The Farm Animal Welfare Council (FAWC 1997) recommended a light intensity for laying hens of 10 lux but at least 5 lux for laying hens in cages (measured at the feed trough), whereas hens in alternative systems should be provided with at least 10 lux measured at bird eye height in the perching walking and feeding areas (FAWC 1997, paragraph 49). DEFRA (2002) recommend the same light intensity as described by FAWC (1997), but adds that “A period of twilight should be provided to give birds time to roost; this is of particular importance in alternative systems and enriched cages” (DEFRA 2002, paragraph 56). It is not specified whether the period of twilight should be given at the end of the dark period or how long the twilight period should be.

Turkeys

FAWC calls for further research on the optimum light intensity and pattern for turkeys reared indoors (FAWC 1995, point 46), but recommends brooding poults should be lit by a minimum of 25 lux for the first few days, after which they should be maintained with a minimum light intensity of 5 lux, measured on a horizontal plane at bird eye height (FAWC 1995, paragraph 41 and 44). The light level should not seriously impair normal investigatory and other behaviour (FAWC 1995, paragraph 42). FAWC also recommends that turkeys are given a period of darkness of about 8 hours in each 24 hours, and that lighting is gradually reduced from light to darkness (FAWC 1995, paragraph 45).

The Council of Europe (CoE 2001) states (article 16, 1) that 1)”All buildings shall have light levels sufficient to allow all birds to see one another and be seen clearly, to investigate their surroundings visually and to show normal levels of activity. The minimum illumination level shall be 10 lux at bird eye level, measured as the average in 3 planes at right angles to each other…" and further "…Reduction in light level may be used as an emergency measure only if a significant amount of injurious pecking is occurring." And "…3) To avoid injury to the birds, twilight periods should be provided in the dimming and raising of light." (CoE 2001).

The importance of light for poultry

Light is important for poultry for many reasons. Vision is the predominant sense in birds, where a large proportion of the total brain size is devoted to eyes and visual cortex (Güntürkün 2000). Light provides the main exogenous regulator for the diurnal rhythm of most animals (Nuboer et al. 1983; Robbins et al. 1984). Chickens recognise conspecifics via visual signals, which requires light (Houser and Huber-Eicher 2004) and also use vision to forage and explore their environment (Osorio et al. 2001; Maddocks et al. 2001). Naive chicks will avoid conspicuously coloured prey insects and the evolution of such aposematic signals confirms the adaptive value of visual selection of prey items (e.g. Guilford 1990; Osorio et al. 1999a). Indeed, responding to light may have had an adaptive value for chickens and turkeys through evolution and may still influence the visual perception and behaviour of the birds today.

Light perception in poultry

Poultry possess simple diurnal eyes, where light reaches the retina after passing through the cornea, anterior chamber, lens and the vitreous body (Güntürkün 2000). The outer segments and outer nuclear layer of the retina contain the photoreceptor cells, which initiate visual information processing by converting light into action potentials which then travel via various inter-neurons to the ganglion cells, whose axons form the optic nerve, and further to the visual cortex in the brain (Güntürkün 2000). The two main classes of photoreceptors, rods and cones, differ in anatomical structure as well as in their ability to absorb light of different wavelengths and illuminances (e.g. Osorio et al. 1999b).

In addition to retinal light perception, poultry may receive light through other routes, for example via the pineal gland (epiphysis cerebri), situated on the dorsal surface of the brain between the telencephalon and the cerebellum (Gwinner and Hau 2000). The avian pineal gland is particularly involved in the control of circadian rhythms (Lu et al. 1995) and has the ability to absorb light, penetrating the skull (Nyce and Binkley 1977). Long wavelengths penetrate the skull more efficiently than short wavelengths, which may aid the synchronisation of circadian activity (Nuboer et al. 1983) since long wavelengths are particularly abundant at dusk under natural light (Théry 2001).

Artificial light

Artificial light can vary in at least four respects: 1) The photoperiodic regime describes the number of hours of light and dark in each 24-hour period. 2) The spectral composition describes the distribution of wavelengths of the light, which varies between light sources. 3) The light intensity (also known as the illuminance or light level) describes the total amount of power emitted from the visual part of the light spectrum. 4) The flicker of light can be described as temporal modulations due to the electrical current and its perception depends on the light intensity, the modulation depth as well as the modulation frequency. In addition, the temporal and spatial variation in the light environment may be important in relation to each of the four characteristics of light. For example, the changes between light and dark (dawn and dusk) and the variations in light conditions over the different areas of the poultry house may affect the behaviour and welfare of the birds.

Light intensity and how is it measured

Light intensity is synonymous with illuminance and light level. It describes the quantity on light falling on a unit area and is measured with a light meter (or lux-meter) to produce the photometric unit “lux” (e.g. Lewis and Morris 2006). The readings of a lux-meter will depend upon several factors. Firstly, the readings from a lux-meter will largely depend upon the height of measurements, and most specify that the light intensity should be measured at bird eye height (CoE 1995; FAWC 1995; FAWC 1997; CoE 2001; CEU 2007). Secondly, the reading will depend on whether the sensor of the lux-meter is held horizontally, pointed towards maximum illuminance or measured in 3 planes at right angles to each other (Prescott et al. 2003; Lewis and Morris 2006). Current recommendations and regulations vary with respect to whether the light intensity should be measured horizontally (FAWC 1995), or given as the average between readings in 3 planes at right angles to each other (CoE 1995; 2001). The Council Directive for chickens kept for meat production (CEU 2007) specifies that light should be measured at bird eye level, but unlike the Council of Europe Recommendations (CoE 1995; 2001) it does not specify whether the minimum illuminance of 20 lux should be measured horizontally or as the average of measurements in 3 planes at right angles to each other.

The photometric unit for measuring illuminance (lux) is adjusted to the human spectral sensitivity. Since the spectral sensitivity of chickens and turkeys is different to that of humans (Wortel et al.

1987; Prescott and Wathes 1999b, Barber et al. 2006), it is not appropriate to use the lux-unit for these species. Indeed, the alternative unit of "clux" (chicken-lux) or "galluiminance" describes the illuminance adjusted to the spectral sensitivity curve of fowl (Prescott and Wathes 1999b, Lewis and Morris 2006) and a similar alternative unit could be suggested for turkeys (turkey-lux). Matching the perceived illuminance of different light sources for the particular poultry species is important in order to compare the independent effects of illuminance and light sources with different spectral contributions. For example, due to differences between human and chicken spectral sensitivity, chickens will perceive an incandescent light source as approximately 30% brighter than a fluorescent light source, when these are measuring the same lux-values. In addition, a common error in studies on light intensity has been to use a voltage dimmer to adjust incandescent light sources to different light intensity levels. This is problematic since this method of dimming an incandescent light source will change the colour of the light as well as the light intensity, and any effects of the different light conditions may be due to either the difference in light intensity or the difference in light colour.

Aims of the report

This report reviews the existing evidence in order to make risk assessment from scientific studies on the following three topics for broiler chickens, laying hens, pullets and turkeys, as described in the request from The Norwegian Scientific Committee for Food Safety. The report is divided into three chapters according to these specific aims.

1) The minimum light intensity recommendable for the types of poultry described above.
2) The optimal period of twilight between light and dark (dusk and dawn).
3) The maximum light intensity recommendable for the dark period.

Limitations of the report

The report is based on a review of international research papers, which strengthen the scientific basis for the recommendations made. However, the scientific studies cited in this report may not have been carried out under conditions comparable with the current commercial practice in Norway, with respect to commercial conditions as well as the strain, sex and age of the birds addressed. Caution should therefore be warranted in the application of the recommendations directly to the Norwegian Poultry Industry. In addition, it should be noted that although the author has tried to ensure correct interpretation of official documents, such as recommendations and regulations, these are referenced without consulting a legal expert, and these interpretations should thus be confirmed prior to further application.

1. Light Intensity and the behaviour and welfare of poultry.

1.1. The general effects of light intensity on poultry

This chapter will focus on the effects of light intensity on the visual, physiological and behavioural issues in poultry, which are important for assessing the welfare implications of light intensity for broilers, layers including pullets and turkeys. The effect of light intensity on poultry performance is reviewed comprehensively elsewhere (e.g. Lewis and Morris 2006).

Light intensity and visual abilities of poultry

Light is arguably the most important stimulus, which poultry receive from their environment (Perry and Lewis (1993). Several studies report that young birds require fairly bright light in order to increase general activity, exploratory behaviour and identification of the feeder (e.g. Deaton et al. 1981; Siopes et al. 1983; Manser 1996). Broiler chickens showed superior visual acuity in 100 lux than in 5 lux (Kristensen et al. 2002). When exposed to sinusoidally modulated light flux (large flux or red light), the laying hen pupil responded approximately four times faster but with a smaller response amplitude compared to humans (response latency of 105 vs 434 ms in fowl and humans respectively) (Barbur et al. 2002). A comprehensive review of the effects of light on poultry vision and welfare exist (Prescott et al. 2003) and the reader is referred to this for details on the mechanisms involved in the visual perception of light by broilers, laying hens and turkeys.

Light intensity and eye morphology

Most studies on the influence of light on eye morphology on turkeys and chickens show that turkeys and chickens reared under continuous or near-continuous light (24 hours of light and no hours of darkness (24L:0D)) or under dim illuminances can develop morphological changes in the structure of the eye (e.g. Harrison et al. 1968; lauber et al. 1970; Siopes et al. 1983). Eye abnormalities have been found in response to continuous darkness (Jenkins et al. 1979; Oishi and Mirakami 1985) as well as continuous light (Lauber et al. 1970; Oishi and Murakami 1985). Ashton et al. (1973) found that 70% of turkey poults reared in continuous artificial light for the first 6 weeks developed eye abnormalities (vs. none of the turkey poults reared in the control group reared in natural daylight and darkness). The abnormalities could be detected when the birds were less than 1 week old, and included larger and heavier eyes, loss of corneal convexity, buphthalmos, and in some cases retinal detachment (Ashton et al. 1973). Interestingly, the turkey poults were able to recover from their eye pathologies developed during the first 6 weeks when subsequently reared under natural lighting conditions (Ashton et al. 1973). It is not known whether the eye abnormalities in this study were caused by the exposure to continuous light or the illuminance of the light, since both the photoperiod and illuminance varied between the experimental and control environments (Ashton et al. 1973). Broiler chicks reared in continuous light of 150 lux but not 5000 lux developed eye enlargements, whereas the continuous bright light (5000 lux) caused other morphological changes to the eye (Oishi and Mirakami 1985). Hens reared in blue light of low intensity (approximately 6 lux) for four weeks had heavier and larger eyes than controls reared in 269 lux of “clear” light, although both groups had been reared in 14L:10D (Harrison et al. 1968). Turkey poults reared in 1.1 lux of incandescent light (23L:1D) for 14 or 18 days post-hatch, developed significantly larger eyes (larger anterior-posterior diameter as well as transverse diameter and total eye weight) than birds reared under 11, 110 and 220 lux (Siopes et al. 1983). Siopes et al (1984) report very similar findings of increased eye weights and transverse diameter, but no significant changes in the anterior-posterior diameter of two-week old male turkey poults reared in 1.1 lux rather than 11, 110 or 220 lux. An increase in the anterior-posterior diameter of the eye could induce a myopic effect, whereas an increased transverse as well as anterior-posterior diameter could reduce the refractive power of the eye through corneal flattening (Harrison et al. 1968, Siopes et al. 1984). Ashton et al (1973) report striking histological and clinical similarities between light-induced buphthalmos, caused by continuous lighting, and the turkey-blindness syndrome, whereas others report low-intensity induced eye enlargements showing the characteristics of exopthalmos rather than bupthalmos as observed in continuous light (Harrison and McGinnis 1967; Harrison et al. 1968).

Overall, the studies reviewed here suggest that light of low intensity as well as continuous or near-continuous light can cause morphological ocular changes in broilers, hens and turkeys, which may in turn affect their behaviour and welfare. It thus appears that providing poultry with a sufficient illuminance and with a sufficient period of darkness may prevent the development of ocular abnormalities and thus possibly improve the welfare of the birds. Turkeys may have a threshold for eye abnormalities between 1.1 and 11 lux (Siopes et al. 1983; Siopes et al. 1984). However, the exact causal relationship between the light intensity, photoperiodic regime and spectral composition of the light environment needs detangling.

Transmission of social signals

Chickens recognise conspecifics via visual signals, which requires light (e.g. D'eath and Stone 1999). Hens were unable to discriminate between a familiar and an unfamiliar individual without the presence of visual cues and spent less time near any of the stimulus hens when these were behind a opaque black cloth (Hauser and Huber-Eicher 2004). Social recognition is predominantly controlled by the right hemisphere in chicken, i.e. mediated via the left eye, which is normally covered by the body in the chick embryo (Rogers 1995). Layer chicks incubated in the dark showed social discrimination in their pecking behaviour and mainly pecked at unfamiliar peers, whereas chicks exposed to light during incubation pecked indiscriminately at both familiar and unfamiliar chicks (Riedstra and Groothuis 2004). Two days old male broiler chicks required 11-14 hours of familiarisation (housed together) in order to discriminate between a familiar and an unfamiliar chick (Porter et al. 2005). However, when housed for the same period (11-14 hours) in a dark room (darkness lux level not defined) and subsequently tested in an illuminated room (lux not defined), the chicks were unable to discriminate between a familiar and an unfamiliar chick (Porter et al. 2005). This indicates a need for light during both social familiarisation and social discrimination between familiar and unfamiliar individuals.

Light intensity and fear during depopulation and shackling

Hughes and Black (1974) found that hens were generally more fearful when housed in 17-22 lux than in higher light intensities (55-80 lux). Bowlby (1957) report that broilers in his experience (not tested scientifically) were easier to catch when depopulating in dim blue light, rather than normal "white" light. Similarly, Perkins et al (2002) found that broilers showed lower fear responses under blue light than they did under iso-illuminant white or red light. In a human approach test, broilers appeared to be less fearful in 5 lux than in 20 lux (Perkins 2001). Depopulation studies on end-of-lay-hens show that changing the light intensity from that applied during the laying period eased the catching of the birds in cages, although the effects did not reflect any differences in the number of broken bones during catching (Gregory et al. 1993). A reduction in light intensity from 15 lux during lay to 12 lux during catching produced a stronger behavioural reaction to catching than increasing the intensity from 2 lux during lay and 12 lux during catching, although birds depopulated in 12 lux showed more wing-flapping behaviour than birds caught in lower light intensities (Gregory et al. 1993). A qualitative assessment of 30 slaughter plant facilities suggested that bright light increased wing flapping in shackled chickens (not specified whether broilers or layers), whereas dim light appeared to have a quieting effect on the birds. Loss of visual contact between neighbouring birds also appeared to increase wing-flapping in shackled chickens (Gregory and Bell 1987). 42 days old male broilers shackled individually revealed no significant difference between immobility in <2 lux, 5, 50 to 200 lux (Jones et al. 1998a), whereas broilers shackled in groups of three showed increased struggling response when shackled in high light intensity, with birds struggling sooner, for longer and in more bouts when light intensity was increased from <2 lux, 5, 50 to 200 lux incandescent light (Jones et al. 1998b). The results showed the lowest proportion of birds struggling in 5 lux (interestingly not in <2 lux), and the highest proportion of birds struggling in 200 lux (Jones et al. 1998b). The discrepancy between the two studies suggest that the social situation (whether shackled individually or in groups) may affect how the shackled broilers respond to the light environment (Jones et al. 1998a, 1998b).

The studies reviewed suggest that birds may be less fearful if depopulated in a lower illuminance than their normal light environment (Gregory et al. 1993; Perkins 2001), perhaps even in blue light (Perkins et al. 2002), and that shackling in 5 lux in groups where birds have visual contact with each other could reduce fear and struggling responses (Jones et al. 1998a, 1998b). In addition, one study suggests that the stunning area should be lit by lower illuminance than the shackling area in poultry processing plants, although this should be confirmed (Gregory and Bell 1987).

Light intensity and inspection of the flock

Morris (1994) recommends that light intensity levels for laying hens are selected on the basis of ensuring adequate inspection of the flock as well as staff working conditions, rather than the physiological needs of the chickens themselves. Martrenchar (1999) states that under very low light intensity (not defined), stockpersons may not be able to discriminate between blood and faeces on the plumage of the birds, which may result in them leaving birds in the flock, which should otherwise be culled. Appleby et al (1992) write that stock inspection is difficult at < 1 lux, although the threshold light level for the stockperson’s ability to identify welfare related problems in large flocks needs to be investigated. In the COE recommendation concerning turkeys (2001), it is specified in article 4: “Stockmanship and inspection”, article 5 that the husbandry system in use should allow the stockperson to recognise whether or not the birds are in good health (CoE 2001). Article 7 in the same document (CoE 2001) states that “…A source of light strong enough for each bird to be seen clearly shall be available for the purpose of this inspection”, suggesting that the normal light intensity in the turkey shed may not be adequate for inspecting the birds. Flock inspection may to some extent be influenced by the fear responses of the birds, so the issues relevant to fear at depopulation (above), may also apply to flock inspection.

1.2. Broilers

The light environment is known to have profound effects on broiler chickens. Particularly, the photoperiodic regime has been the focus of numerous investigations, and it is well known now that broiler chickens benefit from a period of darkness in each 24-hour cycle, which increases their activity and reduce leg problems (e.g. Wilson et al. 1984; Kristensen 1999). The review of light programmes is beyond the scope of this report, but reference can be made to several overviews on the subject (Manser 1996; Kristensen 1999; Lewis and Morris 2006).

The effects of light intensity on leg health and activity

Light onset was a positive sensory reinforcer for activity in young chicks (24-36 hrs. old, white leghorn males) at 4, 8 and 16 foot-candle (1fc = 10.76 lux according to Lewis and Morris 2006), with 4 and 8 foot-candle stimulating activity the most (Meyer and Auguston 1969). Newberry et al (1988) found that male and female broiler chickens responded similarly to light intensity, both sexes showed higher activity in bright (180 lux) vs dim (6 lux) light, but there was no difference in feed conversion or other performance measures between 6 and 180 lux, suggesting that the increased activity in the brighter environments did not increase the birds’ energy requirements significantly (Newberry et al. 1988). However, Newberry et al (1988) did find higher frequencies of leg disorders in broilers housed in 6 lux than in 180 lux at 6 but not 3 or 8 weeks of age, although a similar experiment failed to reproduce this effect (Newberry et al. 1986a, 1988). In an earlier study, Newberry et al (1985) found that broilers actively moved towards in brighter lit (6-12 lux) than in dim lit (0.5 lux) areas and were more active in the bright areas, although there was no significant difference between constant and alternating light on leg disorders at 7 or 10 weeks of age (Newberry et al. 1985). Krisensen et al (2007) found no significant difference between the activity of broiler chickens in 5 and 100 lux when these light intensities were provided evenly over the whole photoperiod. However, when the light intensity was alternated on a 2-hour basis between 5 and 100 lux over a 16 hour photoperiod, the broilers were significantly more active during the bright (100 lux) phases and less active during the dim (5 lux) phases. This suggests that the temporal as well as spatial variations in light intensity may be important for stimulating activity in broiler chickens. There was no difference between the leg health of broiler chickens reared in 5 and 100 lux from day-old to 42 days of age (Kristensen et al. 2006). In contrast, male Cobb broilers reared at 200 lux from day 5-49 of age showed higher tibial plateau angle (indicating higher degree of tibial bowing) than when reared at 2 lux (Gordon and Thorp 1994). The broilers were also heavier at 49 days of age when reared in 2 lux than 200 lux (Gordon and Thorp 1994). The authors suggest that increased activity during some crucial stage of bone development may be the cause of the increased tibial plateau angle and weight differences (Gordon and Thorp 1994). Prayitno et al. (1997) assessed the effects of red vs. blue light of three different illuminances (adjusted to iso-illuminance) at different ages in broiler chickens. Bright red light (30×10^{20} photons) early in the growing period (before day 16) increased active behaviour and reduced later locomotion disorders, whereas blue light reduced activity and increased gait abnormalities (Prayitno et al. 1997). Several studies have shown younger broilers to be more active than older broilers (Newberry et al. 1985; 1986b; Blokhuis and van der Haar 1990), but it remains to be confirmed whether there is also a difference in their activity in response to lighting.

The lower levels of activity of birds reared under low light intensity may result in the birds spending more time in contact with the litter, increasing the risk of developing contact dermatitis on the breasts, hocks and feet (Manser 1996). Cherry and Barwick (1962) found a higher occurrence of breast blisters in birds housed at 1.1 than 180 lux, whereas Newberry et al. (1988) found no significant difference in carcass downgrading due to breast blisters in broiler chickens reared in 6 and 180 lux. The discrepancy between results may empathise the importance of the interaction between the light environment and the litter quality in the experiments, rather than the effects of the light intensity alone.

Preferences for light intensity

Berk (1997) found that Ross broilers preferred to occupy a compartment lit by 20 lux rather than 0.05 lux, particularly during the first three weeks of life. After three weeks, the preference for 0.05 lux increased to approximately 39% at six weeks of age. Broilers were never observed to perch in the dark (0.05 lux) compartment, but perched in the light (20 lux) compartment (Berk 1997). Broiler chickens (Ross males) showed a preference for occupying light environments of 200 lux rather than 6, 20 or 60 lux at 2 weeks of age, whereas at 6 weeks of age, they preferred to occupy 6 lux rather than 20, 60 or 200 lux of incandescent light (Davis et al. 1999). The preferences for occupancy were made up by the most frequently observed behaviours, resting and perching (Davis et al. 1999). Berk (1997) found that Ross broilers preferred to feed in a compartment lit by 20 lux rather than in a compartment lit by 0.05 lux. However, the feeding behaviour followed the general preferences for occupancy of the broilers, and feeding in 0.05 lux increased with age (Berk 1997). Feed and water consumption (as well as feeding and drinking behaviour) increased significantly with light intensity (6, 20, 60 and 200 lux incandescent) at both 2 and 6 weeks of age (Davis et al.

1999). Newberry et al (1988) found no difference in feeding or drinking behaviour between broilers kept in 6 vs. 180 lux. Prayitno et al. (1997) found increased feeding behaviour with increasing light intensity in broilers reared in red and blue light.

Other effects of light intensity on broilers

Bowlby (1957) suggested that the light colour rather than intensity affected feather pecking in his broiler chickens, since he saw reduced pecking and increased feeding behaviour under red light in his own broiler sheds. Prayitno et al (1997) found increased aggressive behaviour with increasing light intensity in broiler chickens reared in red or blue light of one of three illuminances. Broiler breeder hens showed decreased mortality when reared in green light vs. white light (both 5 lux) up to 280 days (Cave 1990). Lien et al (2007) found no effect of light intensity (0.1 vs 1 FC) on the Heterophil:Lymphocyte ratio of 40-days old female broiler chickens (Ross x Ross 708).

1.2.1. Risk assessment on light intensity and the welfare of broiler chickens

There have been several reviews on lighting for broilers. Manser (1996) and Buyse et al. (1996) both review some of the literature available, but came up with different recommendations (20 lux and 5 lux respectively). The SCAHAW (2000) also reviews evidence for the effects of light intensity on broiler welfare. The studies reviewed here suggest that young broilers are more active and prefer brighter lit environments than older broilers, although the interaction between age, light and activity needs further confirmation. Broilers appear less fearful in 5 lux both during a human approach test and during shackling in groups, which may be due to reduced spatial acuity. There is somewhat conflicting evidence as to the effects of the light intensity on the leg health of broilers, which may reflect the importance of interactions between different temporal and spatial variability of environmental factors in affecting leg health in broiler chickens. The rapidly changing genotype of broiler chickens has probably altered the disposition of different leg problems in broilers, which may further complicate the comparison between different research results. Most previous studies as well as official recommendations suggest 20 lux as a minimum light intensity for the welfare of broiler chickens, comprehensive studies on commercial scale should confirm this.

1.3. Layers (Pullets and adults)

Light intensity needs for egg laying

Lewis and Morris (1999) comprehensively review the evidence available on the light intensity required for the performance of pullets and laying hens. By applying meta-analyses based on available data, Lewis and Morris (1999) recommend that pullets require a minimum of 2 lux from 14 weeks of age, in order to reach sexual maturity (age at first egg (AFE)) as early as possible (approx. 105 days). For optimising the rate of lay, the light intensity should be no less than 5 lux. Lewis and Morris (1999) found no adverse effects on liveability above 5 lux, based on the available data from earlier studies, and recommend an economic optimum light intensity of 5 lux for pullets and hens, whilst recognising that other recommendations, not related to biological (i.e. laying and physical performance parameters) or economical optimum, may be made on welfare grounds. Morris (1994) states that a light intensity of about 5 lux is adequate for laying hens but recommend that light intensity for laying hens are selected on the basis of the working conditions of the staff as well as ensuring adequate inspection of the flock, rather than because of the physiological needs of the birds. Tucker and Charles (1993) found that layers did not respond differently to 0.75 lux and 12.4 lux in terms of egg production. Despite this, they recommend a light intensity of at least 10 lux on the grounds of welfare and staff working conditions (Tucker and Charles 1993). Morris (1994) suggests that the laying performance of hens is relative insensitive to light intensity.

Light intensity and choice of nest sites

Zupan et al (2007) showed that the light intensity during early exposure to differently coloured nests could affect the later choice of nest colour, since layers with early exposure to red coloured nests of high light intensity (133 lux) later preferred yellow coloured nests, whereas layers given early exposure red coloured nests of lower intensity (59 lux) showed no nest colour preference. Layers given early exposure to yellow nests of high or low intensity light (118 vs 20 lux, adjusted to the spectral sensitivity of chickens), did not show any colour preference for nest boxes later on (Zupan et al. 2007). Appleby et al. (1983/1984) found that some hens preferred brightly lit nest boxes (20 lux), whilst others preferred dimly lit nest boxes (5 lux), when given a free choice. The choice of box lighting appeared to depend upon the strain of birds as well as the previous experience of nest sites with birds used to laying in open pens preferring illuminated nest boxes, whereas naive White Leghorn-derived strain (not Rhode Island Red hybrid) preferred to lay in unlit nest boxes (Appleby et al. 1983/1984).

Preferences for light intensity

Laying pullets (ISA Brown) showed a preference for occupying light environments of 200 lux rather than 6, 20 or 60 lux at 2 weeks of age, whereas at 6 weeks of age, they preferred to occupy 6 lux rather than 20, 60 or 200 lux of incandescent light (Davis et al. 1999). The preferences for occupancy were made up by the most frequently observed behaviours, resting and perching (Davis et al. 1999). Prescott and Wathes (2002) found that hens (ISA brown) showed a strong and active preference for feeding under bright illuminances (200 lux) rather than very dim light (<1 lux) with illuminances of 20 lux and 6 lux intermediate between the bright and dim light. Hens also consumed significantly less feed, pecked less and with less force at the feed in <1 lux compared with 6, 20 and 200 lux of incandescent light (Prescott and Wathes 2002). From an experiment using operant conditioning, it was estimated that hens were prepared to work 2.3 times harder (in terms of number of pecks) to gain access to feed in 200 rather than <1 lux (Prescott and Wathes 2002). Several studies have observed hens aggregating in bright patches of a poultry house and a partly covered yard (Gibson et al. 1985, Huber and Fölsch 1985, *both cited in* Manser 1996). This behaviour, believed to be related to "sun-bathing", may lead to suffocation of some birds within large aggregations, and subsequently it is recommended to keep illuminance fairly uniform and avoid very bright spots in a poultry house (Manser 1996).

Light intensity and feather pecking

Light intensity (3-5 vs 10-15 lux) during rearing did not significantly affect the rate of feather pecking behaviour or plumage condition at 35 weeks of age (Kjaer and Sørensen 2002). There was a significant interaction between light intensity and genotype, in that LSL showed higher rate of feather pecking than ISA hens at 3-5 lux, whereas there was no difference between the feather pecking behaviour of LSL and ISA hens at 10-15 lux (Kjaer and Sørensen 2002). However, Martin (1989) found increased feather pecking of hens in 50 lux than in 500 lux from 8 weeks of age, particularly when the hens were kept on wire floor (compared to deep-litter).

Johnsen et al (1998) found that the environmental conditions during the first 4 weeks of life affected the subsequent development of feather pecking in laying hens. Light conditions were not assessed in this study, which assessed the effects of different substrates during the first four weeks, after which all groups were kept under similar conditions (Johnsen et al. 1998). A light intensity of 30 lux during the rearing as well as the laying period caused higher mortality, mainly due to cloacal cannibalism, during the laying period than 3 lux (Kjaer and Vestergaard 1999). Plumage condition at 11 weeks was significantly better in 3 lux at neck and breast (ns on back, wings or tail); at 28 weeks, the light intensity during the laying, but not the rearing period, affected plumage condition (better at 3 lux than 30 lux) and there was no effect of light intensity during the rearing or the laying period on plumage condition at 46 weeks of age (Kjaer and Vestergaard 1999). Gentle feather pecking was higher in 3 lux than in 30 lux at 10 weeks, which the authors explain by increased exploratory pecking due to reduced ability to identify environmental cues (Kjaer and Vestergaard 1999). It should be noted that Kjaer and Vestergaard (1999) applied dimmable incandescent light sources, so the effects observed in this experiment may be due to intensity or to the difference in spectral composition of the dim and bright light, or an interaction between the two. Although the exact lux levels of high and low intensities changed over time between 0 and 21 weeks, caged hens housed in the higher levels always had higher levels of feather damage than hens housed in lower light intensitites (Hughes and Duncan 1972). However, Hughes and Black (1974) found no consistent effect of light intensity (17-22 vs 55-80 lux) on feather pecking, assessed by plumage scoring at 27 weeks of age.

In an epidemiological study of risk factors contributing to feather pecking in commercial pullet housing in Switzerland, light intensity (high or low, low defined as 6 lux or below) was not found to significantly affect the likelihood of feather pecking occurring in a commercial flock (Huber-Eicher and Audigé 1999). Rather, Huber-Eicher and Audigé (1999) identified two significant risk factors for feather pecking in commercial pullet flocks as stocking density and access to elevated perches, although the cut-off value of the light intensity (definition of “high” and “low”) may have affected this result. The provision of even light intensity of 5 lux in the whole house resulted in lower levels of cannibalism than uneven distribution of 10 and <1 lux, although this may be due to the light intensity or the even distribution of the light (Kathle 1999). White Leghorn chicks, incubated in the dark showed less feather pecking than chicks incubated in the light and dark-incubated also showed social discrimination in feather pecking mostly on unfamiliar peers, whereas light incubated pecked equally at familiar and unfamiliar peers (Riedstra and Groothuis 2004).

Although the studies above illustrate the complexity of the development feather pecking in laying hens, it appears from some experimental studies that higher and/or perhaps unevenly distributed light intensities would increase feather pecking and cannibalism, although a commercial survey in Switzerland does not confirm this. Commercial conditions may vary from experimental conditions in many respects, for example in terms of the light sources, evenness of the light distribution and several other environmental factors, which may or may not interact with light to affect feather pecking. This illustrates the importance of validating experimental studies on commercial scale before making recommendations.

Light intensity and activity in laying hens

Young layer and broiler chickens showed higher patterned levels of activity when exposed to a light cycle which simulated that of a brooding hen (40min light 60 lux: 40 min dark 0 lux during the light phase) than when reared under an uninterrupted light period of 19h 20 min, followed by 3h 40min darkness) (Malleau et al. 2007). Layer chicks showed a higher degree of social synchronisation during the active phase when brooded under a dark brooder or a broody hen than when brooded under a heat lamp emitting light (Riber et al. 2007). Eacker and Meyer (1967) found that illumination change was an effective reinforcer in young male layer chicks, given the opportunity to change the light environment by breaking a photoelectric beam.

Hughes and Black (1974) found higher levels of activity (standing and pacing) in laying hens housed in high (55-80 lux) than in low (17-22 lux) light intensity. Kjaer and Vestergaard (1999) found that hens spent significantly more time walking and running (increased activity) and a tendency to spend more time foraging in 30 lux than in 3 lux at 10 weeks, but not at 28 or 45 weeks old laying hens. Laying hens showed significantly increased physical activity and energy expenditure in response to a range of increasing light intensities between 0.5 and 120 lux incandescent light (Boshouwers and Nicaise 1987). Laying hens were more active in 500 lux than in 50 lux (Martin 1989). Amount of activity as well as brain temperature were positively correlated with light intensity between 0.5 and 100 lux, even in constant illumination, in adult male White Rock and New Hampshire chickens (Aschoff and von Saint Paul 1973). The accuracy of laying hens to jump between perches did not differ consistently between 5, 10 and 20 lux (Moinard et al. 2004), although lower light intensities had significant effects on the ability to jump between perches in another experiment (Taylor et al. 2003). In this experiment, fewer hens jumped between perches in very low light intensities (0.8 lux) and the birds also vocalised more and increased their latency to jump, particularly when perches were further apart (1m vs 0.5m) (Taylor et al. 2003). In contrast to this finding, a practical study during depopulation showed that battery caged hens had a higher prevalence of old breaks when maintained at 15 lux than when kept at 2 or 0.5 lux during lay (Gregory et al. 1993).

1.3.1. Risk assessment on light intensity and welfare of pullets and laying hens

Light intensity may affect the production, nest choice, activity and feather pecking in pullets and laying hens. Hens appear to be able to sustain production in light intensity above 5 lux, and although increasing light intensity has been shown to increase general activity in hens, this does not appear to affect production. Pullets prefer higher light intensities at 2 than at 6 weeks of age. Light intensities at or above 5 lux appear to allow hens to jump between perches, thus indicating that this level is at least required for environmental perception. Young pullets also respond to increased light intensity with increased activity, although they may require periods of darkness or a dark brooder for resting and social synchronisation. Feather pecking appears to be influenced by different environmental factors; some experiments suggest that feather pecking increases with increasing light intensity in hens, although this was not confirmed in a commercial survey in Switzerland. The interactive effects of light intensity and light source appear to be confounded in several experiments and should be disentangled before making any firm conclusions.

1.4. Turkeys

In turkeys, light intensity adjustments may be necessary in order to prevent feather pecking and cannibalism (Nixey 1994). A survey of the light environment at 16 UK turkey poult houses showed that most producers used incandescent rather than fluorescent light sources, with a mean intensity of 5.3+/-2.43 lux (Barber et al. 2004).

Preferences for light intensity in turkeys

Sherwin (1998) assessed the preferences of male turkeys (6-19 weeks old) for incandescent light of either <1, 5, 10, or 25 lux. Turkeys reared in 4 lux spent significantly more time in 5 lux than the other illuminances, whereas turkeys reared in 12 lux showed a preference for brighter illuminances (Sherwin 1998). Both groups avoided the environment lit by <1 lux (never entered this light environment themselves). Feeding and preening whilst sitting and whilst standing was affected by the light intensity but differed between turkeys reared in 4 lux and 12 lux (Sherwin 1998). Turkeys reared in 4 lux did not differentiate between light of 10 and 25 lux, whereas turkeys reared in 12 lux significantly preferred 25 lux to 10 lux when tested (Sherwin 1998).

When given a free choice of <1, 6, 20 or 200 lux incandescent light, female turkey poults showed a clear preference for occupying 200 lux at 2 weeks of age, whilst they preferred illuminances of 20 or 200 lux at 6 weeks of age (Barber et al. 2004). The turkeys had equal experience of all available intensities, but preferred to rest and perch in the brightest illuminances at both 2 and 6 weeks of age, spending the least time in the dimmest environment at both 2 and 6 weeks of age (Barber et al. 2004).

Turkey hens showed a preference for laying in nest-boxes lit by low (0.5 lux) or medium (50-150 lux) rather than high light intensity (650-1000 lux), particularly if this nesting illuminance was familiar to them (Millam 1987), although the ranges of illuminances are quite wide within each light treatment. This indicates that either the turkey hens use the illuminance of the nest box as a cue to locate a particular nest-box in which they have previously laid (as suggested by the Millam 1987) or alternatively, turkey hens may simply show a preference for nesting in a particular light environment, possibly due to their ancestral environment which may have maximised fitness for individuals choosing particular nest-site characteristics.

Overall, turkeys have been shown to prefer familiar light intensities, both for occupying and for nesting. If they have equal experience of the light environments, they prefer brighter rather than dimmer light environments and avoid very dim environments (<1 lux) except for nesting.

Light intensity and feather pecking in turkeys

Light intensity has been well investigated with respect to feather pecking in turkeys. Both male and female (15-20 weeks old) turkeys show higher incidence of non-aggressive pecking and pulling of feathers when exposed to 86.1 lux than exposed to 10.8 lux continuous illumination, although this could not be confirmed in identical experiments conducted at another time of the year (although the experiment was conducted in light-controlled pens) (Leighton et al. 1989; Denbow et al. 1990). Other social pecking was unaffected by the light intensity in male and female turkeys (Leighton et al. 1989; Denbow et al. 1990). It should be noted that the experiments by Denbow et al (1990) and Leighton et al (1989) simultaneously assessed different light sources, but did not assess whether light source and light intensity had an interactive effect on the behaviour of the turkeys. The results from these two papers indicate that high illuminance may affect pecking and pulling behaviour but that the effect of illuminance may interact with other environmental factors. Moinard et al (2001) found that the number of pecking injuries on tail and wings of male turkeys up to 5 weeks of age increased with increasing light intensity. Under compact fluorescent light, the frequency of wing injuries was similar for birds housed at 5 and 10 lux light, but increased significantly at 36 and 70 lux light (Moinard et al. 2001). The frequency of tail injuries increased after 3 weeks of age, and was then positively correlated with light intensity (5 < 10 < 36 < 70 lux compact fluorescent). In another experiment, tail and wing injuries were significantly more frequent in birds housed in incandescent light than compact fluorescent light irrespective of the light intensity (fluorescent light of both 5 and 10 lux produced lower frequency of injuries than incandescent light of 5 and 10 lux) (Moinard et al. 2001). These results indicate that light intensity as well as light source affects feather pecking in male turkey poults (Moinard et al. 2001). Environmental enrichment significantly reduced aggression in male, but not female turkey poults, and generally reduced injurious pecking in both male and female turkey poults (Martrenchar et al. 2001). Likewise, injurious pecking was higher in male turkey poults housed in traditional 12L:12D incandescent light than the same conditions but supplemented with UV-light, straw and visual barriers (Sherwin et al. 1999), suggesting that environmental enrichment can prevent the development of injurious pecking in turkeys. Lewis et al (1998) found greater incidence of injurious pecking (particularly wing pecking) and higher losses in male turkeys maintained from 20 days of age at 10 lux vs 1 lux incandescent light, particularly under light regimes with more than 12 hours of continuous light, (particularly in 23L:1D). Hester et al (1987) report a higher number of birds which died with signs of cannibalism in 20 than in 2.5 lux, but it is not known if this was statistically significant. Bacon and Touchburn (1976) observed increased feather pecking in turkey poults housed at 11 or 33 lux compared to 0.11 lux between 3-12 weeks of age, although no statistical tests were performed.

From the studies above, light intensity appears to affect feather pecking in turkeys with higher illuminances increasing feather pecking in most studies. Environmental enrichment may reduce feather pecking and aggression in turkeys, and allow the use of higher illuminances. However, the results of the studies suggest that the light intensity, photoperiod and light source can all affect feather pecking and the interactions between these need to be investigated before any firm conclusions can be drawn.

Light intensity and leg health in turkeys

Light intensity did not affect performance, carcass components or the proportion of birds with leg imperfection, although leg problem culling was numerically, but not significantly higher in groups housed at 1 lux than 10 lux (Lewis et al. 1998). Hester et al (1987) found no significant difference between the incidence of leg abnormalities or mortality in 17 weeks-old male turkeys reared in either 2.5 or 20 lux. Similarly, the leg health of 17-weeks old male turkeys was not affected by light intensites of 86.1 and 10.8 lux (Leighton et al. 1989). Male turkey chicks were distinctly less active (not quantified) when exposed to 1.1 lux rather than to 11 lux or above for the first two weeks of life (Siopes et al. 1984) although leg health was not assessed in this study (Siopes et al. 1984). In contrast to Siopes et al (1984), male turkeys were found to be more active during observation periods in 2.5 than in 20 lux (Hester et al. 1987). Classen et al (1994) found that turkeys given an increasing or decreasing photoperiodic regime (light programme) had superior walking activity and were more active than control groups given constant light of the same illuminance, illustrating the importance of photoperiods.

The few studies addressing leg health above did not find any significant effects of light intensity on leg health in turkeys. There is somewhat conflicting evidence on the effects of light intensity on activity.

Other effects of light intensity on turkeys

Sherwin (1998) calls for alternatives, such as environmental enrichment, to replace the current practice of dimming the light intensity for turkeys to reduce aggression. Martrenchar et al (2001) tested various types of environmental enrichment on male and female turkey poults, all reared at 5 lux. Siopes et al (1984) found significantly increased adrenal weight of male turkey poults reared in the first two weeks of life in 1.1 lux compared in 11, 110 and 220 lux incandescent light. Mortality during the first two weeks of life in turkey poults was increased in 1.1 lux but did not differ between 11, 110 and 220 lux incandescent (23L:1D) (Siopes et al. 1984). Mortality was significantly higher under 86.1 than 10.8 lux in one experiment, but unaffected in the other experimental replicate, conducted at a different time of the year (Leighton et al. 1989). Mortality was not affected by light intensity (86.1 vs 10.8 lux) in female turkeys (Denbow et al. 1990). Siopes (2007) found that light intensity (22 vs 567 lux) did not affect the rate of egg production in turkey breeders. Egg weight was higher in 22 than in 567 lux, although Siopes (2007) is critical of this result, since it contradicts earlier studies by the same author (Siopes 2007). Gill and Leighton (1984) found that 5.4 lux improved body weight gain of male turkeys at 8-16 weeks, whilst higher intensity illumination (86.1 lux) improved body weight gain later in the growing period. A comprehensive review of the effects of light intensity on turkey performance is given in Lewis and Morris (2006). Davis and Siopes (1985) found no significant effects of different photoperiods on turkey poult performance during the first 8 weeks, although the adrenal function (measured by corticosterone) was lowest during the first two weeks of age in all light treatments. Bacon and Touchburn (1976) found the turkeys reared in very low light intensities of 0.11 lux (12L:12D) during week 3-12 grew faster than turkeys reared in 1.1, 11 and 33 lux during the same period. After 12 weeks, this effect was reduced. The findings of Bacon and Touchburn (1976) are somewhat opposite to the general preferences of turkeys for brighter light early in the growing period but may be due to all groups reared under the same light intensity during the first 3 weeks of age or changes in the turkey genotype over the years. Martrenchar (1999) suggests that apart from the morphological eye damage of low light intensities, turkeys reared under very low illuminances may have difficulties performing exploratory behaviour.

1.4.1. Risk assessment on light intensity and the welfare of turkeys

Light intensity has been investigated in relation to preferences, feather pecking, production, leg health, eye morphology and mortality, amongst others. Siopes et al (1984) suggests that the threshold level of light intensity for turkey poults is between 1.1 and 11 lux (incandescent), based on evidence of altered performance, adrenal and eye morphology and mortality in turkeys housed in 1.1 but not 11 lux or above for the first two weeks of life (Siopes et al. 1984). When given a free choice, turkeys prefer to occupy familiar or bright light environments (20-200 lux), with younger individuals preferring the brighter environments. Higher illuminance may increase the risk of feather pecking in turkeys, although the interactions with photoperiods and light source need confirming. In addition, the effects of higher light intensity on feather pecking may be influenced by the level of environmental complexity. Environmental enrichment may thus allow the use of brighter light environments than barren environments. The few studies found on leg health revealed no effect of light intensity, and the evidence on activity and mortality is conflicting and needs verifying.

1.5. Conclusions on the effects of light intensity for poultry welfare

Light intensity is synonymous with illuminance and has been investigated in relation to many aspects of poultry welfare. This chapter reviewed the scientific evidence for the effects of light intensity on different aspects of welfare in broilers, layers and turkeys. In terms of eye morphology, dim continuous lighting may cause abnormal development of the eyes of broilers, laying hens and turkeys. Illuminances below 6 lux of blue light for laying hens and below 11 lux (between 1.1 and 11 lux) for turkeys caused eye abnormalities, although these values are based upon studies, confounding illuminance with light colour and light programme. Broilers and layers appear less fearful in lower illuminances (5 lux appear to reduce fear in a human approach test and at shackling in triads), although it needs to be confirmed whether this is due to the inherent light intensity level or to the relative change in light intensity to 5 lux. Regarding flock inspections, there is a trade-off between providing enough light for the stockperson to identify birds with welfare problems without inducing fear responses in the birds. Familiarisation with the stockperson as well as variations in light intensity may overcome this dilemma, although this has not been confirmed experimentally. Feather pecking is influenced by the light environment in laying hens and turkeys, although most studies have confounded the effects of light intensity, light colour and light programme. Whilst several studies on laying hens and turkeys suggest that high levels of light intensity may be associated with increased feather pecking, other studies have failed to find any effect of light intensity, and a commercial survey in Switzerland did not find light intensity to be a significantly contributing factor to feather pecking in laying hens. There is conflicting evidence on the effects of light intensity on leg health in broilers and turkeys. Light intensity level and dynamic properties may influence activity in broilers and laying hens, where young individuals generally show higher levels of activity than older birds. When given a free choice, turkey poults, laying pullets and broiler chickens all prefer to occupy brightly lit environments (200 lux) at two weeks of age. At six weeks of age, layer and broiler chickens preferred the dimmer environments (6 lux), whereas turkey poults still preferred brighter environments (20-200 lux) at this age. Several preference experiments agree that broilers and turkeys avoid environments <1 lux.

The evidence reviewed here suggests that light intensity should be higher for juvenile than for adult poultry, although the particular illuminance will depend upon the type of fowl as well as other environmental factors. Commercial applicability of research results as well a dynamic properties of the light environment should be a focus for future attention in order to define the optimal light environment allowing poultry to express a full behavioural repertoire.

2. Gradual changes in light intensity at dawn and dusk

The light:dark cycle is important for the circadian rhythm in chickens as well as other animals (Navara and Nelson 2007), and the absence of a light:dark cycle results in an apparently absent circadian rhythm in hens according to body temperature recordings (Cain and Wilson 1974). Providing animals with a dawn and dusk period provides individuals who cannot anticipate sudden light changes with a cue for this, which may prevent stress to these animals (Bryant 1987). A gradual transition between light and dark (dusk) may serve several adaptive functions, such as stimulating the attainment of food, thus avoiding depletion during the dark period, as well as avoidance of predators, by for example finding a suitable perching site for night roosting (Wood-Gush et al. 1978; Bryant 1987). Bryant (1987) argues for the importance of dawn and dusk for housed livestock and points out that the behavioural effects of dawn and dusk has been overlooked in the literature.

This chapter will focus upon the effects of gradual vs. sudden changes between light and dark, as well as the optimal dimming time between light and dark on the welfare of poultry.

2.1. Perching and settling behaviour

Under natural or semi-natural conditions, birds would usually roost at night and a gradual change between light and darkness would inform the birds to anticipate the oncoming dark-period, allowing them to settle in their preferred resting location before the night (e.g. Tanaka and Hurnik 1991; Martrenchar et al. 2000).

The EU directive on laying hens (CEU 1999) states that “a period of twilight of sufficient duration ought to be provided when the light is dimmed so that the hens may settle down without disturbance or injury”. DEFRA (2002a) also recommends provision of a period of dusk to facilitate roosting in laying hens, particularly in alternative systems with perches. Indeed, laying hens are motivated to perch during the night and show signs of frustration when access to perches is thwarted (e.g. Olsson and Keeling 2000). Yeates (1963) found that pullets kept in natural light started settling for the night on their perches approx 30 minutes before dark, when the light intensity was still approximately 15 lux. Hens in the wild would adjust their night roosting behaviour to the sunset and sunrise throughout the year (Wood-Gush et al. 1978). Medium hybrid laying hens as well as Jungle Fowl, kept under natural light in outdoor runs with access to perches, started perching for the night about 1 hour before sunset (Blokhuis 1984). It took 30-60 minutes for a group of 10 birds to settle on the perches, which involved a lot of flying on and off the perches during this period (Blokhuis 1984). Laying hens started to perch immediately upon a sudden change from 3 to 1 lux and more than 90% of the birds had settled on the perch within 10 minutes of the reduction in light intensity (Olsson and Keeling 2000). At dusk, groups of adult laying hens rapidly prepared for night, activity was replaced by passive behaviour, and half the hens were either resting or sleeping within 15 minutes of dusk (March et al. 1990). Even a 5-minute twilight period allowed laying hens to settle down more quietly than when the lights were switched off abruptly (Tanaka and Hurnik 1991). Martrenchar et al. (2000) found no difference on the number of birds perching during the dark period between groups of 3-6 weeks old Ross broilers given a 10 min artificial dusk period vs. instantaneous switching from light to darkness. Hughes and Elson (1977) found no diurnal variation in perching behaviour of broilers housed under 23L:1D over 6 observation times per day, although the exact times of these observations are not reported. Laying hens were more accurate when jumping upwards than downwards between perches and the accuracy did not differ consistently between 5, 10 and 20 lux (Moinard et al. 2004), although another experiment revealed that hens were more reluctant to jump between horizontal perches in lower light intensities (below 1.8 lux), particularly when the distance of the perches was increased from 0.5 to 1.0 m (Taylor et al. 2003). Perch colour had a significant effect on the hens' ability to jump in 0.6 lux but not in 1.8 or 32 lux, suggesting that the contrast of the perch to the background is important at low light intensities (Taylor et al. 2003). With regards to the transition from dark to light (dawn), perching under natural conditions was found to decrease drastically approximately 30 minutes before sunrise (Yeates 1963; Blokhuis 1984), when the illuminance was about 0.03 lux (Yeates 1963).

2.2. Anticipation of darkness and light

The circadian rhythm, caused by variations in the daily light cycle, results in an adaptive temporal response, which allows individuals to anticipate and adapt to the daily light-dark cycles in their environment, to optimally time metabolism, physiology and behaviour each day (Navara and Nelson 2007). Broilers were able to anticipate a period of feed unavailability only when it coincided with darkness and not when kept under continuous light (May and Lott 1992). Light deprivation in young chicks (24-36 hours old) affected the sensory reinforcement of light onset, but only if the chickens had been deprived of light for 24 hours, deprivation periods for less than 24 hours did not affect the sensory reinforcement of light onset (Meyer and Collins 1971). Eacker and Meyer (1967) found that the onset, offset increment and decrement of the light environment in a test box were similarly reinforced by young layer chicks, who could alter the light environment by breaking a photoelectric beam. Coenen et al (1988) found indications that individually caged adult laying hens were able to anticipate the oncoming darkperiod (14L:10D bio-intermittent during the light period of 15min L:45min D), since the birds showed behaviour comparable to the undisturbed dark-period rather than the 15 min bio-intermittent dark period during the last two hourly dark-periods (each of 45 min) of the day. In this experiment, light was defined as 200-600 lux, and darkness was defined as 1-4 lux (for observation purposes). Yeates (1963) did not observe the birds responding to bright moonlight during the night, which could be of higher light intensity than their anticipated dawn, but observed the birds flying to and from their perches at approximately similar illuminance levels each evening and morning (15 lux for settling on their perches and 0.3 lux for jumping down off the perches) rather than the exact times during the day. March et al (1990) report that laying hens anticipated the beginning of the day and increased their activity during the last 30 minutes of the night, starting by preening, looking around and drinking. The hens did not start feeding until the lights came on (March 1990). Broilers were able to anticipate the oncoming darkness, and fed more at the end of the light period than at the onset of the light period (May and Lott 1992).

In general, domestic fowl appear to be stimulated to feed by a dusk period Savory (1980). The function of this feeding peak in response to simulated dusk would be that birds take the opportunity to fill their crop and prevent food deficit occurring during the night (Savory 1980; Bryant 1987). Providing immature as well as adult broilers with a simulated dusk period stimulated them to feed before the oncoming dark period and hence to anticipate the hours of darkness (Savory 1976a and 1976b, *cited in* Savory 1980). March et al (1990) found that laying hens concentrated their activity on feeding and drinking during two hours before dusk, Classen and Riddel (1989) found a higher feed intake when providing a two-hour dawn and dusk period for broiler chickens, but whether this is due to increased feeding during the dusk period is not clear. During the final 8-10 minutes of the light period, feeding and drinking behaviour was replaced by preening (March et al. 1990). Savory (1980) reviewed the evidence of a diurnal feeding pattern in domestic fowl (layers and broilers) and conclude that birds, who are able to anticipate the oncoming dark period adjust their feeding activity according to the expected length of this dark period (Savory 1980).

2.3. Risk assessment on poultry welfare and gradual changes between light and dark

Manser (1996) recommends a gradual onset and offset of light for poultry, on the bases that it appears less stressful for the birds than sudden changes in light intensity. Bryant (1987) advocates the importance of a dusk (and dawn) period but also state that the inclusion of a dawn and dusk may require a higher light intensity during the day, to allow a twilight period to be noticeable for the animals. Lewis and Morris (2006) argues that although lighting for poultry is usually turned on and off abruptly, there may be benefits to production and welfare by providing particularly dusk periods.

Overall, laying hens have been found to use a reduction in light intensity as a sign for night roosting, and a gradual dusk period would give the birds the opportunity to settle onto their perches whilst they can still do so without injuries. Laying hens in the wild jump onto their perches in approximately 15 lux, although the lower limit of when they can safely navigate between perches appear to be approximately 2 lux. The very few studies on broiler chickens suggest that they do not use dusk as a cue for perching, although dusk may still be a cue for the oncoming dark period for other behavioural purposes, such as filling their crop and settling down for the night. Under natural conditions, laying hens may fly to their roosting sites 30-60 minutes before dusk, although the minimum period required for perching under artificial dusk may be lower. Even a 5-10 minute period of dusk has been shown to be beneficial for the welfare of laying hens (Tanaka and Hurnik 1991). The period of dusk may be required to be longer than the dawn period, since the visual system takes longer to adapt to a decrease in light intensity than an increase in light intensity, the birds would be expected to adjust faster to increasing than decreasing light intensity. In addition, dusk rather than dawn has been shown to stimulate feeding behaviour, so giving the birds the opportunity to fill their crops for the night during a long dusk period, would probably increase bird welfare as well as production.

In conclusion, a gradual change from light to darkness appears important to poultry as a cue for the oncoming dark period. It may be more important to provide the birds with a gradual dusk period rather than a gradual dawn period. The length of the dusk period should allow the birds to fill their crop for the night and find an appropriate place (perch or ground) to settle for the night.

3. Definition of darkness for poultry

This chapter will focus on the scientific basis for a threshold which broilers, layers and turkeys perceives as darkness.

3.1. Definition of darkness in studies on light and poultry

Reviewing the literature on light and darkness for poultry, it is striking how few papers give detail of their definition of darkness in lux, these are given below. This is of some concern, since the papers citing the light intensity during the dark period (scotoperiod), reveals great variation in their definition of darkness. For example, Malleau et al (2007) report their light intensity during the dark period to be 0 lux, Berk (1997) report darkness in their experiment on broilers to be 0.5 lux, whereas Coenen et al (1988) report 1-4 lux during their dark period to allow observations of laying hens. Van Luijtelaar et al (1987) describe sleeping behaviour in domestic hens where the light during the scotoperiod is about 3 lux (blue bulbs) to facilitate observations. March et al (1990) studied sleep and activity in laying hens during a dark period, defined as <0.25 lux of blue light. Blokhuis (1984) investigated resting behaviour in laying hens and jungle fowl in an outdoor run with natural light and an indoor run with blue light on continuously (40W bulbs, lux not reported), to allow observations during the dark period. Rattenborg et al (2005) describe sleep induced by darkness in pigeons (darkness not defined in lux but described as a dark room with only infra-red light sources on to facilitate video recordings). Bacon and Touchburn (1976) assessed the performance of turkey poults during a 12-hour light period of very low illuminances (0.11 lux), whereas darkness was not defined in the paper, it must be assumed to be less than 0.11 lux (Bacon and Touchburn 1976). Even papers on the effects of light/dark cycles on specific pineal activity fail to define the light intensity applied during the scotoperiod, although the light environments during the photoperiods are well described in the papers (e.g. Zawilska et al. 2007; Faluhelyi and Csernus 2007; Nagy and Csernus 2007). From the large variation in the definitions of darkness in the few papers having reported the light level during the scotoperiods, it is not possible to assess the effects of the degree of darkness from this basis.

3.2. Physiological effects of the perception of light and darkness

The perception of light and dark enables the bird to identify a subjective day and also controls ovulation and oviposition (Perry and Lewis 1993). The absolute degree of darkness required during the long scotoperiods to effectively terminate photorefractoriness and induce photosensitivity in turkey breeder hens was less than 0.5 lux (incandescent) (Siopes 1991). Turkey breeder hens were also photostimulated by as little as 0.5 lux during the photoperiod (Siopes 1991). This suggests that the darkness threshold for photorefractoriness and photostimulation, at least for turkeys, is below 0.5 lux (Siopes 1991).

The light-dark cycle and circadian rhythms

A regular light-dark cycle (photoperiod) plays an important role in regulating melatonin production in turkeys and layers (Lewis et al. 1989; Zawilska et al. 2007). In turkeys, the pineal, retinal and plasma melatonin concentrations were found to oscillate with a robust diurnal rhythm, with high values during darkness (darkness lux not defined), which changed in response to the length of the dark period (Zawilska et al. 2007). Plasma prolactin levels were consistently higher at the end of the dark period (darkness not defined) than at the end of the light period in turkey hens during their reproductive cycle (Proudman 1998). Lewis et al (1987) showed that adult laying hens were inactive but did not rest as a flock during short cycles of light and dark (30 min light:30 min dark) and the melatonin production of hens during a two-hour dark period in the middle of a normal 14-hour light period was different from their normal longer dark period (Lewis et al. 1989). This suggests that the perception of darkness and thus melatonin production in hens is controlled by the hens' subjective day and night, and not only by light and dark *per se* (Lewis et al. 1989). A reversal of the light-dark cycle caused changes (rephrasing) in the deep-body temperature within 36 hours (Winget et al. 1968), indicating that the light-dark cycle, at least in part, controls the circadian oscillations of deep-body temperature. Hamm et al (1983) showed that the eyes as well as the pineal gland are involved in light perception for melatonin regulation during the circadian rhythm, since blinded chicks showed less activity of an enzyme involved in melatonin regulation in the pineal gland than non-blinded chicks (Hamm et al. 1983). The brain temperature and amount of activity showed clear circadian rhythm in adult male White rock and New Hampshire chickens (Aschoff and von Saint Paul (1973). Changing the light intensity caused simultaneously abrupt changes in brain temperature (Aschoff and von Saint Paul 1973). Perry and Lewis (1993) refer to an old study by Warren and Scott (1936), who reversed a 12L:12D regimen and found that birds took about 60 hours to adjust their oviposition time (Warren and Scott 1936, *cited in* Perry and Lewis 1993).

Photosensitivity and the colour of the light during the dark period

In humans, retinal ganglion cells, responsible for suppressing melatonin production, are most sensitive to blue/violet light (459nm), and exposure to very low (undefined) levels of blue spectrum light comparable in brightness to moonlight resulted in melatonin suppression (Navara and Nelson 2007). The chicken pineal gland is directly sensitive to dim light (<10 lux), even in the embryo (Faluhelyi and Csernus 2007) and contains a special photosensitive pigment with absorption maximum of blue light (Csernus et al. 1999). Since several of the reviewed studied have applied blue light during the "dark period", it would be interesting to confirm whether these pineal photosensitive pigment cells in poultry have the same effect on melatonin suppression as the retinal ganglion cells in humans.

Exposure to light during the dark period

Exposure to light at night is accompanied by a significant decrease in melatonin levels (Navara and Nelson 2007). Faluhelyi and Csernus (2007) assessed the effects of illumination (light intensity and hours of light) during normal darkness on the melatonin release from pinealocytes from adult chickens and 17d chick embryos *in vitro*. When exposed to 8 or 12 hours of light during a normal scotoperiod, the cells responded fast by reversing the melatonin release with little difference between 10 and 600 lux. However, when only exposed to 3 hours of light of 10 lux, the reversal was much slower, suggesting that either the exposure period or an interaction with light intensity affected the melatonin release (Faluhelyi and Csernus 2007). The enzyme (serotonin N-acetyltransferase), which is involved in the synthesis of melatonin in chicken pineal glands, has been shown to have a peak sensitivity of approximately 500nm in cultured chick pineals (Deguchi and Axelrod 1981, cited in Hamm et al. 1983). Exposure to light (1 hour of 1400-1500 lux) during the normal dark period (darkness not defined) caused a 5-fold decrease in serotonin N-acetyltransferase (Hamm et al. 1983).

3.3. Nocturnal behaviour of poultry

Scotopic/photopic vision

Porter et al. (2005) found that chicks housed in darkness (lux not defined) with a partner for 11-14 hours at two days of age were subsequently unable to discriminate between this partner and an unfamiliar individual. This confirms that vision appears to be the most important single sense for social discrimination in chicks, which is in agreement with findings in adult fowl (Houser and Huber-Eicher 2004).

Sleep and rest in poultry

Blokhuis (1984) defines rest as "a prolonged period of inactivity that can clearly be distinguished from other maintenance behaviours". Rest is important for the animal, since it allows energy conservation, tissue restoration and growth as well as learning and facilitation of adaptive behaviours during waking hours (Blokhuis 1984). Light is an important factor in the control of many biological processes, and also for rest and sleep in poultry (Yano et al. 1974, *cited in* Blokhuis 1983). Blokhuis (1983) describes both slow- and fast-wave sleep in poultry and refers to studies estimating that fast-wave sleep occurs more in young than in adult fowl (Blokhuis 1983; Mascetti and Vallortigara 2001). Paradoxical (fast-wave) sleep differ somewhat between mammals and domestic hens, since a complete tonic muscle inhibition is not a general characteristic in domestic hens, as it is in mammals (van Luijtelaar et al. 1987). Another difference between sleep in birds and mammals is the "unihemispheric sleep" in which birds during slow-wave sleep in one hemisphere keep the contralateral eye closed, whilst the hemisphere contralateral to the open eye is awake, unlike bihemispheric sleep or REM (fast-wave) sleep, where both eyes are closed (Mascetti and Vallortigara 2001). Light stimulation during incubation is asymmetric, and affects the right eye facing the shell more than the left eye facing the body of the embryo. There have been many studies of the effects of incubating chicks in light vs. darkness on visual lateralisation in chicks (e.g. Rogers 1990). However, it has only recently been confirmed that light incubation can also modulate the side of monocular sleep in the chicks after they hatch (Mascetti and Vallortigara 2001). Dark-incubated chicks preferred to sleep with their left eye open during unihemispheric sleep in the first 5 days post-hatch whereas light-incubated chicks preferred to sleep with their right eye open (Mascetti and Vallortigara 2001). Blokhuis (1984) defines two types of resting behaviour from an ethological point of view: Dozing and sleeping; Dozing defined as the neck more or less withdrawn and the hen being stationary either sitting or standing, whilst sleeping was defined as the head tucked into the feathers and the hen being stationary either sitting or standing (Blokhuis 1984). Both resting behaviours were most often observed in a sitting rather than standing position (Blokhuis 1984). During the night, the only other behaviour observed besides resting was preening behaviour whilst perching (Blokhuis 1984). Van Luijtelaar et al. (1987) describe sleep in domestic hens via electrophysiological and behavioural recordings during the third and sixth hour of a 10-hour continuous scotoperiod (3 lux in the scotoperiod). They found that hens spent more time sleeping (sleeping posture with head tucked into feathers or resting posture with both eyes closed) during the third than the sixth hour of the scotoperiod (van Luijtelaar et al. 1987). Pigeons responded to acute and unexpected changes from light to darkness during their normal photoperiod (from 200 lux to darkness, darkness lux not given but only an infrared light source present) by sleeping with either one or both eyes closed (Rattenborg et al. 2005). The authors conclude that sleep may be induced by darkness, which may be independent of melatonin in pigeons (Rattenborg et al. 2005).

Malleau et al (2007) investigated if layer and broiler chicks would rest if they were provided with light/dark cycle lengths, which mimicked the brooding cycle of a hen with chicks in a warm environment. Both layer and broiler chicks rested more when provided with 40min light:40 min dark during the light period (19 hours and 20 minutes) than when provided with an uninterrupted light period of 19 hours and 20 minutes, followed by an uninterrupted dark period of 3 hours and 40 minutes. All chicks spent all of the 3h 40 min “night” resting, irrespective of their light cycle treatment during the “day”. The performance (growth rate, feed conversion, body composition and shank length) was not affected by the light cycles, although the chicks on the simulated brooding light cycles showed more patterned levels of activity (Malleau et al. 2007).

Nocturnal feeding behaviour

Broiler (and layer) chicks were very rarely recorded at the feeder or drinker during the lights-off period (Malleau et al. 2007), but spent the dark hours resting as a group. Kristensen (2007) found no broilers feeding or drinking during an 8-hour uninterrupted scotoperiod (0 lux) at 2 or 6 weeks of age. Several reviews agree that chickens do not feed or drink during a long period of darkness (8-12 hours) (Savory 1980; Kuhles and Petersen 2005) although they may feed during short 4-hour darkperiods when provided during their normal light period, which the authors suggest is because the chicks perceive the short and the long dark period differently. Savory (1980) state that fowl did not feed during 8-hour periods of darkness, whereas they did feed during 6-hour dark-periods, suggesting that they perceive even these two periods of darkness differently.

Preferences for light and darkness

In a behavioural experiment, Savory and Duncan (1982/83) assessed the motivation for light and darkness in broilers and layers, by training them to peck on a panel to switch light on or off. When the room was lit, the birds only worked for being in darkness for less than 1% of the time, whereas in a dark room, the birds worked for having the lights on for about 20% of the time. Although this study is often referred to as suggesting that birds are adverse to darkness, it may simply reflect the birds’ general aversion to the sudden loss of visual input when switching the light off. Rather, it would be more appropriate to apply the same methods to allow the birds to adjust the light intensity up or down gradually in smaller steps, although the longer dark-adaptation time of the visual system may still complicate the interpretation of the results.

3.4. Risk assessment on the effects of darkness on poultry welfare

Light has several effects on avian pineal physiology, synchronising pineal circadian rhythm, inhibiting melatonin release (Hamm 1983). It is uncertain whether one single exact darkness threshold for poultry exists. Such a darkness threshold is likely to depend on the processes in question, be this i) visual abilities, where the change from photopic to scotopic vision (cone to rod dominated vision) occurs at retinal level; ii) circadian rhythm, which may be dependent upon melatonin synthesis and rely on input from the retina and the pineal gland; iii) nocturnal behaviour, which may depend upon the bird's perception of the relative difference between the relative light during the "day" and "night", which may change with experience; iv) physiological or production responses, such as photorefractoriness and photosensitivity for stimulating egg production.

Several papers (e.g. Savory 1980; Tucker and Charles 1993) refer to a Morris (1968) for a believed darkness threshold for laying hens to be 0.4 lux, although the basis for this threshold would need further confirmation. Tucker and Charles (1993) found that layers did not respond differently to 0.75 lux and 12.4 lux in terms of egg production and thus speculated whether the current darkness threshold of modern layers may be lower than 0.4 lux. In constrast, turkeys have been shown to respond to 0.5 lux both in terms of photorefractoriness and photostimulation (Siopes 1991), which suggests that the darkness threshold in turkeys is below 0.5 lux. Whether turkeys, broilers and laying hens have the same threshold for darkness perception is not possible to say from the reviewed papers. The perception of darkness in poultry is indeed an area, which needs further research since this may affect several aspects of poultry behaviour, production, physiology and overall welfare.

Acknowledgements

I would like to thank The Norwegian Scientific Committee for Food Safety for the opportunity to write this report and Professor Knut E. Bøe for constructive comments on an earlier version of this report.

References

1. Appleby MC, Hughes BO and Elson HA. 1992. Poultry Production Systems: Behaviour, Management and Welfare. CAB International: Wallingford, UK.
2. Appleby MC, McRae HE and Pietz BE. 1983/1984. The effect of light on the choice of nests by domestic hens. Applied Animal Ethology 11: 249-254.
3. Aschoff J and von Saint Paul U. 1973. Circadian rhythms of brain temperature in the chicken, measured at different levels of constant illumination. Japanese Journal of Physiology 23: 69-80.
4. Asmundson VS, Lorenz FW and Moses BD. 1946. Influence of light intensity on ovulation in turkeys. Poultry Science 25: 346-354.
5. Aston WLG, Pattison M and Barnette KC. 1973. Light-induced eye abnormalities in turkeys and the turkey blindness syndrome. Research in Veterinary Science 14: 42-46.
6. Bacon WL and Touchburn SP. 1976. Effect of light intensity on confinement rearing of male turkeys. Poultry Science 55: 999-1007.
7. Barber CL, Prescott NB, Jarvis JR, Le Seuer C, Perry GC and Wathes DM. 2006. Comparative study of the photopic spectral sensitivity of domestic ducks (*Anas platyrhynchos domesticus*), turkeys (*Meleagris gallopavo gallopavo*) and humans. British Poultry Science 47: 365-374.
8. Barber CL, Prescott NB, Wathes CM, Le Sueur C and Perry GC. 2004. Preferences of growing ducklings and turkey poults for illuminance. Animal Welfare 13: 211-224.
9. Barbur JL, Prescott NB, Douglas RH, Jarvis JR and Wathes CM. 2002. A comparative study of stimulus-specific pupil responses in the domestic fowl (Gallus gallus domesticus) and the human. Vision Research 2002: 249-255.
10. Berk J. 1997. Light-choice by broilers. In Rutter SM, Rushen J, Randle HD and Eddison JC (Eds) Proceedings of the 29th International Congress of the International Society for Applied Ethology. Universities Federation for Animal Welfare: Wheathampsted, UK.
11. Bizeray D, Estevez I, Leterrier C and Faure JM. 2002d. Effects of increasing environmental complexity on the physical activity of broiler chickens. Applied Animal Behaviour Science 79: 27-41.
12. Blokhuis HJ and van der Haar JW. 1990. The effect of stocking density on the behaviour of broilers. Archiv für Geflügelkunde 54: 74-77.
13. Blokhuis HJ. 1983. The relevance of sleep in poultry. World’s Poultry Science Journal 39: 33-37.
14. Blokhuis HJ. 1984. Rest in Poultry. Applied Animal Behaviour Science 12: 289-303.
15. Boshouwers FMG and Nicaise E. 1987. Physical activity and the energy expenditure of laying hens as affected by light intensity. British Poultry Science 33: 711-717.
16. Bowlby GMS. 1957. Some preliminary investigations into the effects of light on broilers. World’s Poultry Science Journal 13: 214-216.
17. Bryant SL. 1987. A case for dawn and dusk for housed lifestock. Applied Animal Behaviour Science 18: 379-382.
18. Buyse J, Simons PSM, Boshouwers FMG and Decuypere E. 1996. Effect of intermittent lighting, light intensity and source on the performance and welfare of broilers. World’s Poultry Science Journal 52: 121-130.
19. Cain JR and Wilson WO. 1974. The influence of specific environmental parameters on circadian rhythms of chickens. Poultry Science 53: 1438-1447.
20. Cave NA. 1990. Effects of feeding level during pullets-layer transition and pretransition lighting on performance of broiler breeders. Poultry Science 69: 1141-1146.
21. CEU 1999. Council Directive 1999/74/EC of 19 July 1999. Laying down minimum standards for the protection of laying hens. Official journal of the European Communities. Available

from: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:1999:203:0053:0057:EN:PDF.

22. CEU 2007. Council of the European Union. 2007. Council Directive 2007/43/EC. Laying down minimum rules for the protection of chickens kept for meat production. Official Journal of the European Union (L182/19) 28 June. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2007:182:0019:0028:EN:PDF.
23. Cherry P and Barwick MW. 1962. The effect of light on broiler growth. 1. Light intensity and colour. British Poultry Science 3: 31-39.
24. Classen HL and Riddell C. 1989. Photoperiodic effects on performance and leg abnormalities in broiler chickens. Poultry Science 68: 873-879.
25. Classen HL, Riddell C, Robinson FE, Shand PJ and McCurdy AR. 1994. Effect of lighting treatment on the productivity, health, behaviour and sexual maturity of heavy male turkeys. British Poultry Science 35: 215-225.
26. CoE 1995. Council of Europe 1995. Standing Committee of the European Convention for the Protection of Animals Kept for Farming Purposes. Recommendations Concerning Domestic Fowl. Council of Europe.
27. CoE 2001. Council of Europe 2001. Standing Committee of the European Convention for the Protection of Animals Kept for Farming Purposes. Recommendations Concerning Turkeys. Council of Europe.
28. Coenen AML, Wolters EMTJ, Vanluijtelaar ELJM and Blokhuis JH. 1988. Effects of intermittent lighting on sleep and activity in the domestic hen. Applied Animal Behaviour Science 20: 309-318.
29. Csernus V, Becher P and Mess B. 1999. Wavelength dependency of light-induced changes in rhythmic melatonin secretion from chicken pineal gland in vitro. Neuroendocrinology Letters 20: 299-304.
30. D’eath RB and Stone RJ. 1999. Chickens use visual cues in social discrimination: An experiment with coloured lighting. Applied Animal Behaviour Science 62: 233-242.
31. Davis GS and Siopes TD. 1985. The effect of light duration on turkey poult performance and adrenal function. Poultry Science 64: 995-1001.
32. Davis NJ, Prescott NB, Savory CJ and Wathes CM. 1999. Preferences of growing fowls for different light intensities in relation to age strain and behaviour. Animal Welfare 8: 193-203.
33. Deaton JW, Reece FN, McNaughton JL and Lott BD. 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.
34. DEFRA 2002. Laying hens: Code of recommendations for the welfare of livestock. Department of the Environment, Food and Rural Affairs: London, UK.
35. Deguchi T. 1981. Rhodopsin-like photosensitivity of isolated chicken pineal gland. Nature (Lond.) 290: 706-707.
36. Denbow DM, Leighton AT and Hulet RM 1990. Effect of light source and light intensity on growth, performance and behavior of female turkeys. British Poultry Science 31: 439-445.
37. Eacker JN and Meyer ME. 1967. Behaviourally produced illumination change by the chick. Journal of Comparative and Physiological Psychology 63: 539-541.
38. Faluhelyi N and Csernus V. 2007. The effects of environmental illumination on the *in vitro* melatonin secretion from the embryonic and adult chicken pineal gland. General and Comparative Endocrinology 152: 154-158.
39. Farm Animal Welfare Council 1992. Report on the Welfare of Broiler chickens. Ministry for Agriculture, Fisheries and Food: London, UK.
40. Farm Animal Welfare Council 1995. Report on the Welfare of Turkeys. Ministry for Agriculture, Fisheries and Food: London, UK.
41. Farm Animal Welfare Council 1997. Report on the Welfare of Laying Hens. Ministry for Agriculture, Fisheries and Food: London, UK.

42. Forskrift for Hold af Høns og Kalkun 2001. Vedtatt av Norges Landbruksdepartementet 12/12-2001, med hjemmel i lov om dyrevern av 20. desember 1974 nr. 73 §30. Available at: http://www.lovdata.no/cgi-wift/ldles?doc=/sf/sf/sf-20011212-1494.html.
43. Gibson SW, Innes J and Hughes BO. 1985. Aggregation behaviour of laying fowls in a covered strawyard. In: Wegner R-M (Ed) Second European symposium on poultry welfare, pp 196-298. German branch of the World's Poultry Science Association, Celle.
44. Gill DJ and Leighton AT Jnr. 1984. Effect of light environment and population density on growth performance of male turkeys. Poultry Science 63: 1314-1321.
45. Gordon SH and Thorp BH. 1994. Effect of light intensity on broiler liveweight and tibial plateau angle. Volume 1, Proceedings of the 9th European Poultry Conference, Glasgow, UK: 286-287.
46. Gottlieb G. 1968. Prenatal behavior in birds. Quarterly Reveiw of Biology 43:148-174.
47. Gregory NG and Bell JC. 1987. Duration of wing flapping in chickens shackled before slaughter. Veterinary Record 121: 567-579.
48. Gregory NG, Wilkins LJ, Alvey DM and Tucker SA. 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.
49. Guilford T. 1990. The secrets of aposematism – unlearned responses to specific colours and patterns. Trends in Ecology and Evolution 5: 323.
50. Güntürkün O. 2000. Sensory Physiology: Vision. Chapter 1 in Whittow GC (ed): Sturkie's Avian Physiology, Fifth Edition. Academic Press, San Diego. pp 1-19.
51. Gwinner E and Hau M. 2000. The pineal gland, circadian rhythms and photoperiodism. Chapter 21 in Whittow GC (ed): Sturkie's Avian Physiology, Fifth Edition. Academic Press, San Diego. pp 557-568.
52. Hamm HE, Takahashi JS and Menaker M. 1983. Light-induced decrease of serotonin N-Acetyltransferase activity and melatonin in the chicken pineal gland and retina. Brain Research 266: 287-293.
53. Harrison PC and McGinnis J. 1967. Light induced exopthalmus in the domestic fowl. Proceedings of the Society for Experimental Biology 1, 126: 308-312.
54. Harrison PC, Bercovitz AB and Leary GA. 1968. Development of eye enlargement of domestic fowl subjected to low intensity light. International Journal of Biometeorology 12: 351-358.
55. Hester PY, Sutton AL and Elkin RG. 1987. Effect of light intensity, litter source and litter management on the incidence of leg abnormalities and performance of turkey toms. Poultry Science 66:666-675.
56. Houser J and Huber-Eicher B. 2004. Do domestic hens discriminate between familiar and unfamiliar conspecifics in the absence of visual cues? Applied Animal Behaviour Science 85: 65-76.
57. Huber H-U and Fölsch DW. 1985. The hen's need for light. In: Wegner RM (ed) Second European Symposium on Poultry Welfare 292-293. WPSA: Celle, Germany.
58. Huber-Eicher B and Audige L. 1999. Analysis of risk factors for the occurrence of feather pecking in laying hen growers. British Poultry Science 40: 599-604.
59. Hughes BO and Black AJ. 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.
60. Hughes BO and Duncan IJH. 1972. The influence of strain and environmental factors upon feather pecking and cannibalism in fowls. British Poultry Science 13: 525-547.
61. Hughes BO and Elson HA. 1977. The use of perches by broilers in floor pens. British Poultry Science 18: 715-722.
62. Jenkins RL, Ivey WD, McDaniel GR and Albert RA. 1979. A darkness induced eye abnormality in the domestic chicken. Poultry Science 58: 55-59.

63. Johnsen PF, Nørgaard-Nielsen G and Vestergaard KS. 1998. Influence of early rearing conditions on the development of feather pecking and cannibalism in domestic fowl. Applied Animal Behaviour Science 60: 25-41.
64. Jones RB, Hagedorn TK and Satterlee DG. 1998a. Adoption of immobility by shackled broiler chickens: Effects of light intensity and diverse hooding devices. Applied animal Behaviour Science 55: 327-335.
65. Jones RB, Satterlee DG and Cadd GG. 1998b. Struggling responses of broiler chickens shackled in groups on a moving ling: effects of light intensity, hoods and 'curtains'. Applied Animal Behaviour Science 58: 341-352.
66. Kathle J. 1999. Sluttrapport – Prosjekt F263 "Effekt av lysstyrke på hvitegghybrider i løsdrift. Institutt for Husdyrfag, NLH, Ås, Norge.
67. Kjær JB and Sørensen P. 2002. Feather pecking and cannibalism i free-range laying hens as affected by genotype, dietary level of methionine + cystine, light intensity during rearing and age at first access to the range area. Applied Animal Behaviour Science 76: 21-39.
68. Kjaer JB and Vestergaard KS. 1999. Development of feather pecking in relation to light intensity. Applied Animal Behaviour Science 62: 243-254.
69. Kristensen HH, Aerts JM, Leroy T, Wathes CM and Berckmans D. 2007. Modelling the dynamic activity of broiler chickens in response to step-wise changes in light intensity. Applied Animal Behaviour Science 101: 125-143.
70. Kristensen HH, Perry GC, Prescott NB, Ladewig J, Ersbøll AK and Wathes CM. 2006. Leg health and performance of broiler chickens reared in different light environments. British Poultry Science 10: 257-263.
71. Kristensen HH, Prescott NB, Ladewig J, Perry GC and Wathes CM. 2002. Light quality and the visual acuity in broiler chickens. Proceedings of the 36^{th} International Congress of the ISAE, Egmond aan Zee, The Netherlands, 6-10^{th} August 2002.
72. Kristensen HH. 1999. Photoperiods and the behaviour and welfare of broiler chickens: a review. Technical Report Published (in Danish) by the Danish Society for the Protection of Animals, September 1999.
73. Kuhles A and Petersen J. 2005. Influence of light and darkness on the process of adaptation in chicks – a review. Archiv fur Geflugelkunde 69: 2-10.
74. Lauber JK, Boyd JE and Boyd TAS. 1970. Intraocular pressure and aqueous outflow facility in light-induced avian bupthalmos. Experimental Eye Research 9: 181-187.
75. Leighton AT, Hulet RM and Denbow DM. 1989. Effect of light source and light intensity on growth, performance and behavior of male turkeys. British Poultry Science 30: 563-574.
76. Lewis PD and Morris TR. 2006. Poultry Lighting *the theory and practice*. Northcot, Andover, UK.
77. Lewis PD, Perry GC and Cockrem JF. 1989. Plasma concentrations of melatonin in layers under interrupted lighting. British Poultry Science 30: 968-969.
78. Lewis PD, Perry GC, and Tuddenham A. 1987. Noise output of hens subjected to interrupted lighting regimes. British Poultry Science 28: 535-540.
79. Lewis PS and Morris TR. 1999. Light intensity and performance of domestic pullets. World's Poultry Science Journal 55: 241-250.
80. Lewis PS, Perry GC and Sherwin CM. 1998. Effect of photoperiod and light intensity on the performance of intact male turkeys. Animal Science 66: 759-767.
81. Lien RJ, Hess JB, McKee SR, Bilgili SF and Townsend JC. 2007. Effect of light intensity and photoperiod on live performance, heterophil-to-lymphocyte ratio, and processing yields of broilers. Poultry Science 86: 1287-1293.
82. Lu J, Zoran MJ and Cassone VM. 1995. Daily and circadian variation in the electroretinogram of the domestic fowl: Effects of melatonin. Journal of Comparative Physiology A. 177: 299-306.

83. Maddocks SA, Cuthill IC, Goldsmith AR and Sherwin SM. 2001. Behavioural and physiological effects of absence of ultraviolet wavelengths for domestic chicks. Animal Behaviour 62: 1013-1019.
84. Malleau AE, Duncan IJH, Widowski TM and Atkinson JL. 2007. The importance of rest in young domestic fowl. Applied animal behaviour Science 106: 62-69.
85. Manser CE. 1996. Effects of light on the welfare of domestic poultry: A review. Animal Welfare 5: 341-360.
86. March TJ, Thompson LJ, Lewis PD and Perry GC. 1990. Sleep and activity behaviour of layers subjected to interrupted lighting schedules. British Poultry Science 31: 895-896.
87. Marchenchar A, Huonnic D and Cotte JP. 2001. Influence of environmental enrichment on injurious pecking and perching behaviour in young turkeys. British Poultry Science 42: 161-170.
88. Marchenchar A, Huonnic D, Cotte JP, Boilletot E and Morisse JP. 2000. Influence of stocking density, artificial dusk and group size on the perching behaviour of broilers. British Poultry Science 41: 125-130.
89. Marchenchar A. 1999. Animal Welfare and intensive production of turkey broilers. World's Poultry Science Journal 55:143-152.
90. Martin G. 1989. Federpickhäufigkeit in Abhängigkeit von draht- und einstreuboden sowie von der lichtintensität (Influence of light intensity on feather pecking of hens on deep litter or wire floor). KTBL Schrift 342: 108-133.
91. Mascetti GG and Vallortigara G. 2001. Why do birds sleep with one eye open? Light exposure of the chick embryo as a determinant of monocular sleep. Current Biology 11: 971-974.
92. May JD and Lott BD. 1994. Effects of light and temperature on anticipatory feeding by broilers. Poultry Science 73: 1398-1403.
93. Meyer DB and May HC. 1973. The topographical distribution of rods and cones in the adult chicken retina. Experimental Eye Research 17: 347-355.
94. Meyer ME and Collins MS. 1971. Light deprivation and sensory reinforced behaviour in chicks. Perceptual and Motor Skills 32: 602.
95. Meyer ML and Auguston ST. 1969. Reinforcement and activation of domestic chickens as a function of the intensity of light onset. Animal Behaviour 17: 177-180.
96. Millam JR. 1987. Preference of turkey hens for nest boxes of different levels of interior illumination. Applied Animal Behaviour Science 18: 341-348.
97. Moinard C, Lewis PD, Perry GC and Sherwin CM. 2001. The effects of light intensity and light source on injuries due to pecking of male domestic turkeys (*Meleagris gallopavo*). Animal Welfare 10: 131-139.
98. Moinard C, Statham P, Haskell MJ, McCorquodale C, Jones RB and Green PR. 2004. Accuracy of laying hens in jumping upwards and downwards between perches in different light environments. Applied Animal Behaviour Science 85: 77-92.
99. Morris TR. 1968. Light requirements of the fowl. In: Carter TC (Ed) Environmental Control in Poultry Production. Oliver and Boyd, Edinburgh.
100. Morris TR. 1994. Lighting for layers: What we know and what we need to know. World's Poultry Science Journal 50: 283-287.
101. Nagy AD and Csernus VJ. 2007. Cry1 expression in the chicken pineal gland: Effects of changes in the light/dark conditions. General and Comparative Endocrinology 152: 144-147.
102. Navara KJ and Nelson RJ. 2007. The dark side of light at night: Physiological, epidemiological and ecological consequences. Journal of Pineal Research 43: 215-224.
103. Newberry RC, Hunt JR and Gardiner EE. 1985. Effect of alternating lights and strain on behavior and leg disorders of roaster chickens. Poultry Science 64: 1863-1868.
104. Newberry RC, Hunt JR and Gardiner EE. 1986. Light intensity effects on performance, activity, leg disorders, and sudden death syndrome in roaster chickens. Poultry Science 65: 2232-2238.

105. Newberry RC, Hunt JR and Gardiner EE. 1986. The influence of light intensity on behavior, leg disorders and sudden death syndrome of chickens. Canadian Journal of Animal Science 66: 1159-1160.
106. Newberry RC, Hunt JR and Gardiner EE. 1988. Influence of light intensity on behavior and performance of broiler chickens. Poultry Science 67: 1020-1025.
107. Nixey C. 1994. Lighting for the production and welfare of turkeys. World's Poultry Science Journal 50: 292-294.
108. Nuboer JFW, Coemans MAJM and Vos JJ. 1992. Artificial lighting in poultry houses: Are photometric units appropriate for describing illumination intensities. British Poultry Science 33: 135-140.
109. Nuboer JFW, van Nuys WM and van Steenbergen JC. 1983. Colour changes in a light regimen as synchronizers of circadian activity. Journal of Comparative Physiology A, 151: 359-366.
110. Nyce J and Binkley S. 1977. Extraretinal photoreception in chickens: Entrainment of the circadian locomotor activity rhythm. Photochemistry and Photobiology 25: 529-531.
111. 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.
112. Olsson IAS and Keeling LJ. 2000. Night-time roosting in laying hens and the effect of thwarting access to perches. Applied Animal Behaviour Science 68: 243-256.
113. Osorio D, Jones CD and Vorobyev M. 1999a. Accurate memory for colour but not pattern contrast in chicks. Current Biology 9: 199-202.
114. Osorio D, Miklósi A and Gonda Zs. 2001. Visual ecology and perception of coloration patterns by domestic chicks. Evolutionary Ecology 13: 673-689.
115. Osorio D, Vorobyev M and Jones CD. 1999b. Colour vision of domestic chicks. The Journal of Experimental Biology 202: 2951-2959.
116. Perkins GY. 2001. The effects of light colour and illuminance on the behaviour and fear responses of broilers. MSc Thesis, University of Edinburgh, UK.
117. Perkins GY, Kristensen HH, Prescott NB and Wathes CM. 2002. The effects of light colour and illuminance on the behaviour and fear responses of broilers. Proceedings of the 36th International Congress of the ISAE, Egmond aan Zee, The Netherlands, 6-10th August 2002.
118. Perry G and Lewis P. 1993. Light perception and behaviour. In: Savory CJ and Hughes BO (eds). Fourth European Symposium on Poultry Welfare pp 27-38. Universities Federation for Animal Welfare: Wheathampstead, Hertfortshire, UK.
119. Porter RH, Roelofsen R, Picard M and Arnould C. 2005. The temporal development and sensory mediation of social discrimination in domestic chicks. Animal Behaviour 70: 359-364.
120. Prayitno DS, Phillips CJC and Stokes DK. 1997. The effects of colour and intensity of light on behaviour and leg disorders in broiler chickens. Poultry Science 76: 1674-1681.
121. Prescott NB and Wathes CM. 1999b. Spectral sensitivity of the domestic fowl (Gallus g. domesticus). British Poultry Science 40: 332-339.
122. Prescott NB and Wathes CM. 2002. Preferences and motivation of laying hens to eat under different illuminances and the effect of illuminance on eating behaviour. British Poultry Science 43: 190-195.
123. Prescott NB, Wathes CM and Jarvis JR. 2003. Light, vision and the welfare of poultry. Animal Welfare 12: 269-288.
124. Proudman JA. 1998. Circulating prolactin levels at the end of the photophase and the end of the scotophase throughout the reproductive cycle of the turkey hen. Poultry Science 77: 303-308.
125. Rattenborg NC, Obenmeyer WH, Vacha E and Benca RM. 2005. Acute effects of light and darkness on sleep in the pigeon (Columba livia). Physiology and Behaviour 84: 635-640.

126. Riber AB, Nielsen BL, Ritz C and Forkman B. 2007. Diurnal activity cycles and synchrony in layer hen chicks (Gallus gallus domesticus). Applied Animal Behaviour Science 108: 276-287.
127. Riedstra B and Groothuis TGG. 2004. Prenatal light exposure affects early feather-pecking behaviour in the domestic chick. Animal Behaviour 67: 1037-1042.
128. Robbins KR, Adekunmisi AA and Shirley HV. 1984. The effect of light regime on growth and pattern of body fat accretion of broiler chickens. Growth 48: 269-277.
129. Rogers LJ 1995. Development of brain and behaviour in the chicken. Wallingford: CABI.
130. Rogers LJ. 1990. Light and the reversal of functional lateralization in the chicken brain. Behavioural Brain Research 38: 211-221.
131. Savory CJ and Duncan IJH. 1982/1983. Voluntary regulation of lighting by domestic fowl in Skinner boxes. Applied Animal Ethology 9: 73-81.
132. Savory CJ. 1976a. Effects of different lighting regimes on dirunal feeding patterns of domestic fowl. British Poultry Science 17: 341-350.
133. Savory CJ. 1976b. Broiler growth and feeding behaviour in three different lighting regimes. British Poultry Science 17: 557-560.
134. Savory CJ. 1980. Diurnal feeding patterns in domestic fowl: A review. Applied Animal Ethology 6: 71-82.
135. SCAHAW 2000. The welfare of chickens kept for meat production (Broilers). Report of the European Commission Scientific Committee on Animal Health and Animal Welfare. SANCO.B.3/AH/R15/2000.
136. Sherwin CM. 1998. Light intensity preferences of domestic male turkeys. Applied Animal Behaviour Science 58: 121-130.
137. Sherwin CM; Lewis PS and Perry GC. 1999. Effects of environmental enrichment, fluorescent and intermittent lighting on injurious pecking amongst male turkey poults. British Poultry Science 40: 592-598
138. Siopes TD, Timmons MB, Baughman GS and Parkhurst CR. 1983. The effect of light-intensity on the turkey poult eye morphology. Poultry Science 62: 2486-2488.
139. Siopes TD, Timmons MB, Boughman GR and Parkhurst CR. 1984. The effects of light intensity on turkey poult performance, eye morphology and adrenal weight. Poultry Science 63: 904-909.
140. Siopes TD. 1991. Light-intensity for turkey breeder hens – degree of darkness required during short-day light restriction and intensity threshold during photostimulation. Poultry Science 70: 1333-1338.
141. Siopes TD. 2007. Lighting for summer egg production by turkeys: Day length and light intensity. Poultry Science 86: 2413-2419.
142. Tanaka T and Hurnik JF. 1991. Behavioural responses of hens to simulated dawn and dusk periods. Poultry Science 70: 483-488.
143. Taylor PE, Scott GB and Rose P. 2003. The ability of hens to jump between horizontal perches: Effects of light intensity and perch colour. Applied Animal Behaviour Science 83: 99-108.
144. Théry M. 2001. Forest light and its influence on habitat selection. Plant Ecology 153: 251-261
145. Thomason DM, Leighton Jr. AT and Mason Jr. JP. 1972. A study of certain environmental factors on reproductive performance of Large White turkeys. Poultry Science 51: 1438-1449.
146. Tucker SA and Charles DR. 1993. Light intensity, intermittent lighting and feeding regimen during rearing as affecting egg production and egg quality. British Poultry Science 34: 255-266.
147. Van Luijtelaar ELJM, Van der Grinten CPM, Blokhuis HJ and Coenen AML. 1987. Sleep in the domestic hen (Gallus domesticus). Physiology and Behaviour 41: 409-414.
148. Warren DC and Scott HM. 1936. Influence of light on ovulation in the fowl. Journal of Experimental Zoology 74: 137-156.

149. Warren DC and Scott HM. 1936. Influence of light on ovulation in the fowl. Journal of Experimental Zoology 74: 137-156.
150. Wilson JL, Weaver WD, Beane WL and Cherry JA. 1984. Effects of light and feeding space on leg abnormalities in broilers. Poultry Science 63: 565-567.
151. Winget CM, Card DH and Pope JM. 1968. Circadian oscillations of three parameters at defined light intensities and color. Journal of Applied Physiology 24: 401-406.
152. Wood-Gush DGM, Duncan IJH and Savory CJ. 1978. Observations on the social behaviour of domestic fowl in the wild. Biology and Behaviour 3: 193-205.
153. Wortel JF, Rugenbrink H and Nuboer JFW. 1987. The photopic spectral sensitivity of the dorsal and ventral retinae of the chickens. Journal of Comparative Physiology 160: 151-154.
154. Yano J, Oshima S and Gotoh J. 1974. Effects of various lighting regimes on diurnal rhythms of EEG components in the chicken. Poultry Science 53: 918.
155. Yeates NTM. 1963. The activity pattern in poultry in relation to photoperiod. Animal Behaviour 11: 287-289.
156. Zawilska JB, Lorenx A, Berezinska M, Vivien-Roels B, Pévet P and Skerne DJ. 2007. Photoperiod-dependent changes in melatonin synthesis in the turkey pineal gland and retina. Poultry Science 86: 1397-1405.
157. Zupan M, Krushwitz A and Huber-Eicher B. 2007. The influence of light intensity during early exposure to colours on the choice of nest colours by laying hens. Applied Animal Behaviour Science 105: 154-164.