INTRODUCTION

Manipulation of lighting is a critical management tool for rearing broilers. Although the effects of lighting on the health and performance of broilers have been well researched, relatively little attention has been given to the effects on behavior \( \text{(Manser, 1996; Prescott et al., 2003)} \). A long photoperiod combined with a low light intensity (generally below 10 lx) is typically used in commercial broiler houses, as this lighting regimen reduces energy costs and is also thought to increase BW gain and G:F \( \text{(Appleby et al., 1992; Prescott et al., 2003)} \). However, poultry have large eyes and excellent color vision \( \text{(Nuboer, 1993)} \) which suggests that they will have better quality vision in more brightly lit environments. Therefore, light management may have important consequences for broiler behavior and health \( \text{(Prescott et al., 2004)} \).

Research on light management of poultry focuses on one of 4 light characteristics: intensity, photoperiod, color or wavelength, and source \( \text{(Manser, 1996; Prescott et al., 2004)} \). Although each of these characteristics may have an effect on behavior and health, all are intrinsic aspects of light and thus potentially have interactive effects. For example, photoperiod can be considered as a ratio of light to dark \( \text{(light:dark)} \) over a set period of time \( \text{(Gordon, 1994; Prescott et al., 2004)} \) or as a change, or contrast, in light intensity over that period of time. The photoperiod is the dominant entrainer of the circadian system, but changes in intensity between light and dark appear to affect the strength of that entrainer, with higher contrasts entraining more distinct rhythms \( \text{(Daan and Aschoff, 2001)} \). Although there are published studies on the effects of lighting on broiler behavior, performance, and health, few of these have either directly compared light:dark to light intensity contrast or evaluated the synergistic effects of these 2 aspects of lighting.
Activity rhythms are affected by contrasts in intensity. When given a choice, broilers prefer to be in higher intensity light (12 lx) when they are performing active behaviors but in dimmer areas (0.5 lx) when resting (Newberry et al., 1985). Broilers are also more active when reared with high intensity (180–200 lx) rather than low intensity (5–6 lx) light (Newberry et al., 1988; Blatchford et al., 2009).

In contrast, feeding behavior appears more affected by light:dark than by light intensity. When reared with moderate day lengths (12–14 h), broilers consume most of their feed during the photophase, with little feeding during the scotophase (Savory, 1976; Sykes, 1983; Buyse et al., 1996). Rhythms of feeding behavior can be affected by changing light:dark (Weaver and Siegel, 1968; Savory, 1976; May and Lott, 1992), but broilers consume the same total amount of feed regardless of light intensity within a range from 5 to 200 lx (Charles et al., 1992; Downs et al., 2006; Kristensen et al., 2006b; Blatchford et al., 2009).

Performance may also be more affected by light:dark than light intensity, although studies are conflicting. Broilers reared with continuous or near-continuous day lengths were found to have greater BW than those reared with moderate day lengths (Squibb and Collier, 1979; Renden et al., 1992; Lien, 2007). However, Perry (1981) and Rozenboim et al. (1999) found no differences in BW between broilers reared in either continuous or moderate day lengths. Lewis et al. (2009) found no effect of photoperiod when more than 6 h of light were provided, but less than that resulted in reduced BW. Although transitory effects on BW gain are sometimes observed when broilers are reared with higher (>10 lx) light intensities (Charles et al., 1992; Downs et al., 2006); light intensity has little effect on final BW (Newberry et al., 1988; Charles et al., 1992; Downs et al., 2006; Kristensen et al., 2006b). The above studies finding performance differences often attribute these to a higher level of activity by the broilers reared with higher contrast light intensities or moderate day length ratios, although none of these studies actually quantified activity.

If particular lighting regimens have the potential to increase activity, they could also have an effect on leg health and lameness. Several studies (Kestin et al., 1992; Weeks et al., 1994; Mench et al., 2001) suggest that when broilers are offered an opportunity to increase activity they show less lameness, but none of these studies actually measured activity. In studies that did examine the effect of light on activity, no differences in lameness were observed (Newberry et al., 1985; Kristensen et al., 2006a; Blatchford et al., 2009). However, these studies only evaluated light intensity contrast and not light:dark.

Lighting programs have also been shown to affect eye health. Near-continuous lighting regimens and low intensity light can both disrupt the functionality of the avian eye (Oishi and Murakami, 1985; Li et al., 1995) by inducing problems such as buphthalmia and possibly blindness (Whitley et al., 1984; Blatchford et al., 2009; Lewis and Gous, 2009). Corneal thickness is decreased when chickens are reared with extended periods of dim light or darkness (Harrison et al., 1968; Jenkins et al., 1979). Again, it is unclear whether light:dark or the contrast in light intensity is most important to normal eye development.

The study presented here was designed to determine the effects of both light:dark and contrasts in light intensity on behavior, performance, and health parameters in broilers. To test this, 2 ratios (20L:4D and 16L:8D) at both a high contrast (200 lx:0.5 lx) and low contrast (1 lx:0.5 lx) light intensity were evaluated. These 2 ratios were chosen as they represent commonly used photoperiods both in commercial production as well as in experimental studies. The intensities were chosen to represent a stark difference in contrast. The 200 lx was chosen based on Blatchford et al. (2009) and the 1 lx was chosen to represent commercial conditions.

**MATERIALS AND METHODS**

**Birds and Husbandry**

Cobb 500 broilers (n = 1,004) were obtained from a commercial hatchery as 1-d-old straight-run chicks, from 4 separate hatches. The hatches were used as in-time trials. All chicks were vaccinated against Marek's disease at the hatchery. Upon arrival, approximately the same number of chicks (range of 40–42 chicks) was randomly allocated to each of 6 pens. They were given access to feed and water ad libitum throughout the study. The chicks were fed a prestarter mash (23.21% crude protein, 3.10 kcal/g of ME) for the first 3 wk, and then Purina Mills Flock Raiser Sunfresh Crumble (20% protein, 3.00 kcal/g of ME) for the remainder of the 6-wk growout period.

The broilers were housed in 6 environmental chambers and managed according to the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, 1999). Each chamber contained a 5.0-m² pen bedded with wood shavings (approximately 10 cm deep). The stocking density was 8.4 birds/m². Temperature was set at 29°C for the first week and decreased by 2°C each week until reaching 21°C. Relative humidity was set at 50% throughout the study.

During the first 3 d, all broilers were housed under a 23L:1D regimen (provided by incandescent lights) with intensities of 200 lx and 0.5 lx during the photophase and scotophase, respectively. Light intensity was measured in 3 areas along a horizontal plane at 25 cm above the litter with the photoreceptor sensor of a light meter (LT Lutron, model LX-100; Das Distribution Inc., East Granby, CT) pointed toward the light sources. Light intensity was equalized across the pens. There were no dawn-dusk transitions between the photophase and the scotophase. On d 4, each chamber was assigned a lighting regimen of either 16L:8D or 20L:4D and one of 2
photophase light intensities: 1 lx or 200 lx (as measured at broiler head height). Scotophase intensity remained at 0.5 lx. Light spectra in the chambers (Project Star Spectrometer, Learning Technologies Inc., Somerville, MA) ranged from 400 to 660 nm, with all colors represented in all treatments. These treatments continued for the remainder of the growout period. Assignments of photoperiod and intensity treatments were rotated through the different chambers, so that each chamber received each treatment an equal number of times.

**Behavioral, Health, and Performance Measures**

General activity patterns were measured using passive infrared detection (PID) devices (Brinks, model 7295b, Foothill Ranch, CA) as described in Pedersen and Pedersen (1995) and Nielsen et al. (2003). Starting at 3 wk of age, activity was recorded over a 48-h period once a week. The PID were placed 0.3 m from the front of each pen and at a height of approximately 20 cm from the floor. The infrared beam of the device was horizontal and spanned the entire width and depth of the pen. If at least one broiler was moving, the beam was broken and the device was turned on. If no movement was occurring in the pen, the device remained off. Every 10 s a Dickson Pro Series data logger (Dickson, Addison, IL) recorded whether the device was on or off. These values were then averaged (adjusting for the number of broilers in each pen) for each hour of the 24-h period. Each hourly mean was then divided by the overall mean activity of the broilers in all pens over that 24-h period to correct for any differences in individual PID devices. The resulting value represented the general activity for that pen during that hour on a scale from 0 to 1 (although the maximum value was actually higher than 1 due to correction for the number of birds in the pen). Thus, a relative activity value of 0 indicated no activity and of 1.27 indicated constant activity. This technique has been validated (Nielsen et al., 2003; Blatchford et al., 2009). Feeding activity was automatically recorded continuously using a digital scale (Ohaus, Pinebrook, NJ) for 24 h each week, as described in Blatchford et al. (2009).

At 41 d of age, all chickens were assessed for lameness using the 0–5 modified gait scoring system of Garner et al. (2002). Broilers were also informally assessed for lameness throughout the study, and any chickens scoring 4 or 5 were euthanized for ethical reasons.

At 42 d of age, all chickens were euthanized using argon gas with less than 2% residual oxygen. After euthanasia, 5 broilers from each pen (n = 120) were randomly selected (balanced for sex), and their left and right eyes were removed. Extra-ocular tissue was trimmed from the eyes and gross measures were made of eye weight, back-to-front and side-to-side diameters, and corneal radii using digital calipers. Chickens in each chamber were weighed at 7, 14, 21, 28, 35, and 41 d of age, and weekly feed consumption was recorded.

**Statistical Analysis**

A split-plot design (with pen as a blocking variable, to control for any variation across trials) was used, with treatment as the main plot and age as the subplot. To analyze behavioral differences (general and feeding activity) among the treatments, an unbalanced mixed GLM was used, with ratio, contrast, and age as fixed variables and pen as a random variable. When significant differences were found, Tukey post hoc tests were performed. The assumptions of the GLM were tested (Shapiro-Wilk test for normality, Levene’s test for homogeneity of variance) and data were transformed as necessary to meet those assumptions. Data for general activity over 24 h and the photophase, as well as feeding activity during the scotophase, were transformed using a power transformation ($10^4$); no other data required transformation.

Body weight and G:F were also analyzed using the unbalanced mixed GLM described above. Because gait score data were ordinal, they were analyzed using the Kruskal-Wallis test on the equality of the medians, adjusted for ties. When significant differences were found, the Dwass, Steele, Critchlow, and Fligner post hoc test was performed (Hollander and Wolfe, 1999). As eye measures were not independent from one another, differences were compared using a MANOVA, with Tukey post hoc tests performed when significant differences were found. The left and right eye values were averaged for each measure. All analyses were performed using SAS 9.1 for Windows (SAS Institute Inc., Cary, NC). We considered all results at $P < 0.05$ to be statistically significant and $P$-values between 0.05 and 0.09 to show trends in the data.

**RESULTS**

**Contrasts in Intensity**

Daily activity rhythms of the broilers over a 24-h period are shown in Figure 1. There was no effect of intensity on activity over the whole 24-h period ($F_{1,20} = 0.59; P = 0.45$), but there was an effect during the photophase ($F_{1,20} = 5.41; P = 0.03$) and the scotophase ($F_{1,20} = 6.59; P = 0.02$), with the 200 lx birds more active during the photophase ($P < 0.001$) and less active during the scotophase ($P < 0.001$) than the 1 lx birds (Figure 2). Likewise, intensity did not affect feeding activity over the 24-h period ($F_{1,20} = 0.34; P = 0.56$), although there was an effect during the photophase ($F_{1,20} = 16.98; P = 0.001$) and the scotophase ($F_{1,20} = 41.29; P < 0.001$), with 200 lx feeding more during the photophase ($P < 0.001$) but less during the scotophase ($P < 0.001$) than 1 lx (Figure 3).

There was an effect of light intensity on final BW ($F_{1,20} = 6.90; P = 0.02$); 1 lx (mean ± SEM, 2.79 ± 0.02 kg) were heavier ($P < 0.001$) than 200 lx (2.72 ± 0.03 kg). However, there was no effect of intensity on G:F ($F_{1,20} = 0.24, P = 0.63$), with broilers from all
treatments averaging an efficiency of 1.63 ± 0.02 kg of BW/kg of feed.

There was also a difference between treatments \( (H_3 = 19.65; P < 0.001) \) in gait score, with 200 lx having better \( (P < 0.05) \) mean gait scores than 1 lx. However, this difference was numerically slight, and the median gait score was 2 for all groups (Table 1). Eye measurements are shown in Figure 4. There was an effect of intensity on the side-to-side \( (F_{1,118} = 4.96; P = 0.03) \) and back-to-front \( (F_{1,118} = 15.06; P < 0.001) \) diameter of the eyes as well as eye weight \( (F_{1,118} = 78.65; P < 0.001) \) but not on the corneal radii \( (F_{1,118} = 0.02; P = 0.90) \).

**Light:Dark**

There was no effect of light:dark on activity patterns over the whole 24-h period \( (F_{1,20} = 0.90; P = 0.35) \) or during the photophase \( (F_{1,20} = 0.20; P = 0.66) \) or scotophase \( (F_{1,20} = 0.01; P = 0.94) \). Likewise, there was no effect on feeding activity over the whole 24-h period \( (F_{1,20} = 1.91; P = 0.18) \) or during the photophase \( (F_{1,20} = 0.38; P = 0.54) \) or scotophase \( (F_{1,20} = 3.35; P = 0.08) \). Nor was there an effect on weight gain \( (F_{1,20} = 0.03; P = 0.86) \) or G:F \( (F_{1,20} = 0.40; P = 0.54) \).

There was no effect of light:dark on the side-to-side \( (F_{1,118} = 0.20; P = 0.66) \) diameter of the eyes, corneal radii \( (F_{1,118} = 1.09; P = 0.30) \), or eye weight \( (F_{1,118} = 1.34; P = 0.25) \). However, there was an effect on the back-to-front diameter of the eyes \( (F_{1,118} = 5.92; P = 0.02) \); 16L:8D had greater diameters \( (1.33 ± 0.01 \text{ cm}) \) than 20L:4D \( (1.30 ± 0.01 \text{ cm}) \).

### Interactions and Mortality

There was a trend for an interaction effect on the back-to-front diameter of the eye \( (F_{1,118} = 3.25; P = 0.07) \), with 200 lx-20L:4D \( (1.26 ± 0.01 \text{ cm}) \) having a smaller diameter than 200 lx-16L:8D \( (1.32 ± 0.01 \text{ cm}) \), 1 lx-20L:4D \( (1.33 ± 0.01 \text{ cm}) \), and 1 lx-16L:8D \( (1.34 ± 0.01 \text{ cm}) \). Although the multivariate model did show significant interaction effects for scotophase activity \( (P = 0.002) \), BW \( (P = 0.02) \), and side-to-side diameter

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**Table 1.** The mean and median gait scores of 41-d-old broilers reared with 4 lighting treatments

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Mean (±SEM) score(^1)</th>
<th>Median score(^1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20L:4D, 1 lx</td>
<td>2.11 ± 0.02(^a)</td>
<td>2</td>
</tr>
<tr>
<td>16L:8D, 1 lx</td>
<td>2.12 ± 0.03(^b)</td>
<td>2</td>
</tr>
<tr>
<td>20L:4D, 200 lx</td>
<td>2.00 ± 0.03(^b)</td>
<td>2</td>
</tr>
<tr>
<td>16L:8D, 200 lx</td>
<td>1.98 ± 0.03(^b)</td>
<td>2</td>
</tr>
</tbody>
</table>

\(^{a,b}\)Means in the same column without a common superscript differ at \( P < 0.05 \).

\(^1\)A score of 2 denotes an identifiable gait abnormality that does not impede the bird’s ability to walk (Garner et al., 2002).
of the eye ($P = 0.03$), subsequent analysis using post hoc comparisons revealed that these effects were due to the strong effect of intensity contrast and were not true interactions. Likewise, post hoc comparisons of a marginally significant interaction for corneal radius ($P = 0.05$) showed there were no differences between treatments. There were no interactions between treatment and age ($P > 0.05$).

Mortality was low throughout the study, with only 20 broilers found dead in the pens, but most of this mortality occurred before 10 d of age. Eleven broilers were euthanized because they had a gait score of 4 or 5. These birds were evenly distributed among the treatments.

**DISCUSSION**

Light:dark had no effect on the activity of the broilers, but there was a very strong effect of intensity contrast, with 200 lx birds showing a stronger rhythm of activity than 1 lx birds. These results are consistent with Blatchford et al. (2009), who found that broilers reared with 50 or 200 lx of light were more active during the photophase than those reared with 5 lx of light. However, they did not find an activity difference during the scotophase, whereas in the current study, 1 lx birds were more active during the scotophase than 200 lx birds. In fact, 1 lx showed almost no daily activity rhythm. Deep et al. (2012) observed a daily activity rhythm when broilers were reared with a 1 lx photophase and 0 lx scotophase. This suggests that the intensity contrast between 1 and 0.5 lx was not sufficient to provide a day/night cycle, unlike the contrast between 5 and 1 lx used in Blatchford et al. (2009). The greater level of photophase activity observed with bright light in the current study is consistent with Newberry et al. (1988), who found that broilers reared with 180 lx were more active than those reared with 6 lx.

The effect of the lighting regimens on feeding behavior was similar to the effect on activity. Consistent with other studies (Weaver and Siegel, 1968; Charles et al., 1992; Downs et al., 2006; Kristensen et al., 2006b; Blatchford et al., 2009), overall feeding activity did not differ between treatments. However, 200 lx birds did show a more distinct pattern of feeding behavior, feeding more during the photophase and less during the scotophase than 1 lx birds. There was a surprisingly large amount of nocturnal feeding in all groups. The high rate of growth in modern broilers may account for this. Food can pass through a broiler’s digestive tract in as few as 2.2 h (Chee et al., 2010), so they may not be able to store enough feed in their crop to last through the entire scotophase, and therefore feed in the dark. However, Duve et al. (2011) found that broilers reared with an 8-h scotophase had greater crop contents than those on a split (4 + 4) scotophase regimen. This suggests that broilers should be able to compensate for a moderate scotophase and not show much feeding behavior during the scotophase. It could be that the 0.5 lx light intensity used in the current study’s scotophase was enough to permit feeding behavior, whereas complete dark may not.

Light intensity, but not light:dark, had an effect on final BW, with 1 lx being slightly heavier than 200 lx birds. Final BW for all treatments met the mean values expected for Cobb 500 broilers (Cobb 500 product profile). Previous studies (Newberry et al., 1988; Downs et al., 2006; Kristensen et al., 2006b; Blatchford et al., 2009) found no effect of intensity on final BW. However, Foshee et al. (1970) suggested that the primary factor affecting the growth rate of broilers is uniform activity periods. The relatively constant but low level of activity observed in the 1 lx broilers could therefore be the reason for the slightly higher BW. However, it is important to note that the current study was performed with a relatively small number of broilers and it is therefore difficult to generalize the production results to a commercial scale.

Although previous studies (Newberry et al., 1985; Kristensen et al., 2006a; Blatchford et al., 2009) found no effect of intensity on gait scores, 200 lx birds in the present study had better mean gait scores than 1 lx. However, this difference is probably not biologically significant, given that 89% of the broilers, regardless of treatment, scored either a 1 or 2, which signifies an identifiable gait abnormality but one that is associated with little to no impairment of overall function (Garner et al., 2002). The treatment difference likely arose from the small percentage (11% total) of broilers that had a score of 3 or greater, which signifies an impairment of overall function (Garner et al., 2002). None of the 200 lx broilers had scores greater than 3 but 5 of the 1 lx did.

The 1 lx broilers had larger and heavier eyes than 200 lx broilers. This finding is consistent with the results of Blatchford et al. (2009), who found that broilers reared in low light intensity (5 lx) had heavier eyes. Deep et al.
(2010) also that found broilers reared with 1 lx light intensity had larger, heavier eyes than those reared with 10 lx or more, suggesting that light dimmer than 5 lx has an even stronger effect on eye morphology, by enlarging the eye as well as increasing the weight. The lack of effect of light:dark on eye morphology may be because both of the photoperiods evaluated provided at least 4 h of darkness; Li et al. (1995) reported that 4 h of continuous dark was sufficient for proper eye development in chicks. In the current study, 16L:8D did have longer back-to-front eye diameters than 20L:4D, although the reason for this is unclear. Jenkins et al. (1979) found eye enlargement in birds that were reared with continuous darkness. The 8 h of 0.5 lx coupled with a 1 lx photophase may more closely emulate continuous dark than the 4-h treatment, as the activity patterns in the present study also suggest.

In this study, there was little effect of light:dark (20L:4D and 16L:8D) on the behavior and health of broilers, but there was a strong effect of intensity contrasts. High contrast in intensity was associated with strong daily rhythms of behavior, whereas low contrast in intensity suppressed those rhythms. Intensity also had an effect on health, with brighter light associated with slightly less lameness and dim light associated with larger, heavier eyes. This suggests that rearing broilers in very dim light, such as the 1 lx used in this study, has adverse effects on their welfare. Blatchford et al. (2009) showed dampened activity patterns and increased eye weights of broilers reared with 5 lx compared with 50 or 200 lx. However, the results of the current study show an even more pronounced effect on behavior and eye health. Deep et al. (2010) examined eye measures on 32-d-old broilers reared with 1, 10, 20, or 40 lx light intensity and found that only the 1 lx light intensity was associated with changes in eye morphology. However, they did not measure behavior. It may be that there is a linear effect of light intensity at low levels, and more work should be conducted to examine intensities between 5 and 50 lx to determine where the threshold is for the effects of light intensity on both behavior and physiology.

Finally, although broilers reared with 1 lx of light had greater final BW than those reared with 200 lx, it is difficult to generalize this effect to a commercial scale. Investigations using larger numbers of birds under conditions more similar to commercial conditions would help to elucidate the potential effects of low intensity light on production.

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