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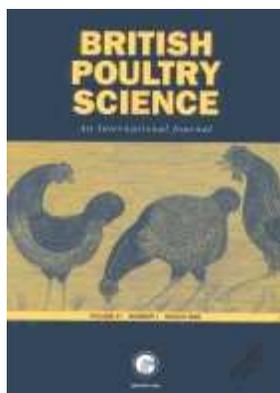
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The relationship between physical activity and leg health in the broiler chicken

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12 **5 The relationship between physical activity and leg health in the broiler chicken**
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Abstract 1. The relationship between the physical activity and leg health of broiler chickens was assessed on a semi-commercial scale.

2. Three batches of birds (2128 per batch) were raised under two lighting regimes during the photoperiod; either a step-wise change of light intensity alternating between
5 an illuminance of 200 and 10 lx or a constant illuminance of 10 lx. The activity of focal individuals (24 per batch) was observed at 2, 4 and 6 weeks of age, and leg health assessed weekly, based on gait score, the prevalence of burns on the hock and foot pad, and angulation and rotation of the leg at the intertarsal joint. Cortical bone density and thickness and area moments of inertia of the mid-physis tibiotarsus were measured *post*
10 *mortem* at 6 weeks of age.

3. The step-wise change in light intensity did not affect overall performance, activity or leg health.

4. An individual bird's activity did not affect its gait score, the prevalence of hock burn or foot pad burn, cortical density or thickness or shape of the tibiotarsus. Sex of the bird
15 was the only factor to affect significantly the area moment of inertia in the horizontal and vertical planes of the tibiotarsus, with females showing a lower moment of inertia for both. No variable had a significant effect on cortical density or thickness. Mean cortical density was low across all birds and may indicate that, when allowed to move freely as much or as little as they choose, broiler chickens do not exercise enough or do
20 not perform the higher impact activities required to affect bone quality.

5. These findings imply that the activity of broiler chickens raised on a semi-commercial scale is unaffected by step-wise changes in light intensity and that other husbandry measures are needed to raise activity and hence improve leg health.

INTRODUCTION

25 **Background**

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In the UK, over 800 million chickens are produced annually (Defra, 2007), reaching a slaughter weight of over 2 kg within 6 weeks, well before sexual maturity

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3 (approximately 18 weeks) and skeletal maturity (approximately 23-27 weeks) (Latimer,
4 1927; Rath *et al.*, 2000). This fast growth rate is associated with poor leg health that can
5 lead to lameness (Kestin *et al.*, 2001; Sanotra *et al.*, 2001), which has been
6 demonstrated to be detrimental to the bird's welfare (McGeown *et al.*, 1999) and likely
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12 5 to infringe FAWC's Five Freedoms (www.fawc.org.uk). Large-scale surveys of
13 lameness using gait scoring techniques in commercial broiler flocks have estimated that
14 about 27% of birds have an abnormal gait of sufficient severity for the birds' welfare to
15 be compromised (Kestin *et al.*, 1992; Knowles *et al.*, 2008).
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20 **Causes of poor leg health and lameness**

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23 10 There may be many causes of lameness in a broiler chicken, with the aetiology
24 generally classified as developmental, degenerative or infectious (Bradshaw *et al.*,
25 2002). Developmental abnormalities include varus-valgus deformation (VVD) at the
26 intertarsal joint, one of the most common leg distortions in broilers (EC, 2000), and
27 abnormal rotation within the tibiotarsus or femur. The most widespread degenerative
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34 15 disorder in commercial broilers is contact dermatitis, while infectious disorders are
35 suggested to cause the most severe cases of lameness (Kestin *et al.*, 1994).
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Developmental deformities may cause walking difficulties in the birds and increase the risk of injury during catching, causing downgrading or even rejection by the processor (Aviagen, 2001). The underlying cause of these conditions is poorly understood but high growth rate leading to altered load bearing, lack of activity and genetic factors are possible candidates (Duff and Thorp, 1985; Bradshaw *et al.*, 2002).

Contact dermatitis is a widespread problem in European broiler production (EC, 2000), with lesions occurring on areas of the body in prolonged contact with the litter, most commonly on the feet (foot pad or podo-dermatitis) but also on the hocks, commonly described as hock burns, and breast muscle, particularly in heavier and lame birds (Kristensen *et al.*, 2006b). In a survey of 28 broiler flocks in Denmark (Sanotra *et al.*, 2001) the prevalence of podo-dermatitis was 42%, while others suggest it may be lower at 11.1% in the UK (Haslam *et al.*, 2007). Proper litter management and the

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3 absence of pre-existing leg conditions that cause birds to sit for long periods can reduce
4 the incidence and severity of contact dermatitis.
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8 One possible reason for poor leg health in broilers is reduced bone quality.
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10 Although the dimensions of the tibiotarsus in selected (modern) strains of broilers fed
11
12 5 *ad libitum* are correct for load support, the bone itself is weak. The cortical bone shows
13 high porosity and low mineral content (Thorp and Waddington, 1997; Williams *et al.*,
14 2000; Corr *et al.*, 2003a; Williams *et al.*, 2004), which may be due to rapid bone
15 deposition in the outer layers to increase width to support the increasing mass of the
16 bird but with insufficient time to allow infilling by osteoblasts due to the birds' rapid
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23 10 growth rate (Williams *et al.*, 2004), although others found that reducing growth rate did
24 not improve bone quality (Leterrier *et al.*, 1998).
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27 **Welfare concerns**

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29 Broilers from selected strains and fed *ad libitum* often show a number of morphological
30 changes compared with those of relaxed (*i.e.* randomly bred) strains (Corr *et al.*,
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33 15 2003a). The result of this altered morphology is a change in walking in an attempt to
34 increase stability (Corr *et al.*, 2003b). This altered gait is considered inefficient and
35 would rapidly tire birds, giving an explanation for the low levels of activity seen in all
36 broilers.
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43 Sound broilers spend, on average, 76% of their time lying down, but in lame
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45 20 birds this increases significantly to 86% (Weeks *et al.*, 2000). Time spent walking at
46 slaughter-weight is significantly shortened from 3.3% to 1.5% in the worst cases of
47 lameness. Sound birds also spend more time standing idle, standing preening and
48 standing eating (Weeks *et al.*, 2000).
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54 Poor leg health may affect the bird in several ways, with particular concern
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56 25 given to the possibility of pain. McGeown and colleagues (1999) showed that
57 moderately lame birds would complete an obstacle course faster when given an
58 analgesic, suggesting that in this case birds' walking speed was affected by pain from
59 their gait abnormality, rather than the abnormality itself. Lame birds will also self-select
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3 an analgesic (Danbury *et al.*, 2000). However, others have found that administration of
4 an analgesic does not change the walking behaviour of broilers (Corr *et al.*, 2007); thus,
5 the presence of pain arising from poor leg health and its role in walking ability remains
6 contentious. Nevertheless, the differences in behaviour exhibited between sound and
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12 5 lame birds may indicate poor welfare caused in ways other than pain.

13 **Alleviation of poor leg health through husbandry**

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15 Changes in husbandry such as stocking density or feeding regime can alleviate some
16 causes of poor leg health (Su *et al.*, 1999; Sorensen *et al.*, 2000), as can selective
17 breeding.
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23 10 Increasing the activity of a broiler chicken has been shown to improve walking
24 ability and influence bone development (Reiter and Bessei, 1995) and could be
25 achieved by increasing the distance between feeders and drinkers (Reiter and Bessei,
26 1996) or by the addition of barriers (Bizeray *et al.*, 2002). These practices increase the
27 thickness and density of the cortical bone and the diameter of the tibiotarsus diaphysis
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34 15 through the deposition of bone in response to the imposed stresses, as explained by
35 Wolff's Law (1892). Increased exercise also reduces the prevalence of abnormalities in
36 the physis and physeal vasculature of bone extremities from 40 to 18% (Thorp and
37 Duff, 1988).
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43 Another method found to be effective in encouraging activity in broiler
44 20 chickens is providing step changes in light intensity (Kristensen *et al.*, 2006a). The
45 colour and source of artificial light can also affect activity; low-frequency fluorescent
46 lighting lowers activity compared with high-frequency (Boshouwers and Nicaise, 1992)
47 and activity is higher in red than in blue light both at the same intensity, and at higher
48 intensities (Prayitno *et al.*, 1997). Gait abnormalities were also reduced with red light.
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55 25 The aim of this experiment was to investigate the relationship between physical
56 activity and leg health of broiler chickens on a semi-commercial scale, while also
57 exploring the effect of step changes in light intensity on individual activity within a
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3 large flock. Our hypothesis was that step-wise changes in light intensity would increase
4 individual activity thereby improving leg health.
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7 MATERIALS AND METHODS

8 **Animals, housing and husbandry**

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11 5 Three batches of Ross 308 broilers (approximately 2128 chicks 'as hatched' per batch)
12 were obtained at d-old from a commercial hatchery (P D Hooks, Bampton) and used in
13 a large scale multi-factorial experiment. On arrival, the chicks were distributed
14 randomly between eight identical rooms, each holding 266 birds. Within each batch 40
15 sexed chicks – 20 of each sex – were marked for later identification then evenly
16 distributed between two of the rooms. At 9 d old, 6 birds of each sex from these marked
17 birds in both rooms were assigned one of 12 symbols. These were sprayed with black
18 stock marker for identification by overhead cameras. The marks were refreshed once or
19 twice weekly as required. These individuals became the 'focal' birds for further detailed
20 studies of behaviour.
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34 15 The eight 19.6 m² rooms were filled with wood shavings to a depth of at least
35 7.5 cm and warmed to a temperature of 30 °C at a relative humidity of about 70% prior
36 to the chicks' arrival. The birds were kept under normal commercial husbandry
37 conditions until 49 d old when they weighed approximately 2.5 kg, equivalent to a
38 stocking density of 34 kg m⁻². For the first 7 d, fluorescent lighting was provided on a
39 20:23:1h cycle of light: dark with lights on at 01.00 and a dawn and dusk period each of 30
40 minutes. From day 7 onwards, this cycle changed to 18:6h of light: dark, with lights on
41 at 03.00 and the same dawn and dusk period. Illuminance was dependent upon the
42 experimental treatment.
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54 Birds were provided with *ad libitum* access to water and were fed on a
55 25 standard, 4-stage commercial diet (ABN, Peterborough), provided in 4 meals per d at
56 03:00, 09:00, 15:00 and 20:00. Chicks were first provided with a starter crumb until dy
57 11, a starter pellet from d 12 to 23, grower pellets from dy 24 to 44 and a withdrawal
58 pellet ration between d 45 and 49. The diet was formulated to provide 90% of the
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3 normal crude protein content and the feed quantity was 5% below the normal allowance
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5 to encourage slower growth and extend the experimental period.
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8 Room temperature was reduced according to recommended guidelines
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10 (Aviagen, 2002). Humidity was maintained at approximately 70% relative humidity or
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12 5 higher using a misting system. Animal health was monitored twice daily by a skilled
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14 stockman and severely lame birds were culled humanely. Excluding the focal birds, the
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16 overall mortalities to 49 d were as follows; Batch 1: 3.7%, Batch 2: 5.5% and Batch 3:
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18 2.3%. The higher mortality of the second batch was due to a yolk sac infection.
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22 23 10 **Experimental design**

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25 The experiment started on d 14 and finished on d 44 when the focal birds were killed by
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27 cervical dislocation.
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29 The main experiment, the results of which will be reported separately,
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31 comprised a 2³ multi-factorial design with three replicates (batches) of each treatment.
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33 15 This investigated the response of broilers to step-wise changes in humidity, illuminance
34
35 and feed quantity. In our study, however, the only treatment under consideration was
36
37 the step-wise change in light intensity. In each batch this treatment was applied in one
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39 room, to which the focal birds were assigned in addition to the control room.
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42 *Step-wise changes in light intensity*

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44 20 The illuminance of the control room was kept at 10 lx throughout the photoperiod. The
45
46 light intensity treatment comprised step-wise changes in light intensity alternating
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48 between an illuminance of 10 lx and 200 lx throughout the photoperiod, as used in our
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50 previous research (Kristensen *et al.*, 2006a). There were 4 step changes each day (*i.e.*
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52 dim to bright and *vice versa*, twice) as illustrated in Figure 1. The illuminance
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55 25 immediately following dawn alternated each day, to balance the experimental design.
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57 **Experimental procedures**

58 *Activity of the focal birds*

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Figure 1 near here

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3 Video recordings were made of the focal birds when they were 2, 4 and 6 weeks of age.
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5 Recording took place between 04:00 and 05:00, 09:00 and 10:00 and 14:00 and 15:00,
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7 covering a steady light state, one feed and 20 minutes after a step change in light
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9 intensity. This schedule also allowed time for inspection by the stockman without
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11 influencing the observed birds' activity. The activity was quantified by counting the
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13 number of gridlines crossed by an individual every 5 minutes over an hour using a grid
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15 of 36 squares placed over the video image on a VDU. After initial analysis, more
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17 detailed investigation was required, so the bird's activity during a period of 5 minutes
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19 immediately following a step up in illuminance (at 10.18 am) was also examined by the
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21 same method when the birds were 4, 5 and 6 weeks of age.
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25 *Leg health*

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27 Measurements of leg health were taken while the birds were alive and *post mortem*.
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29 During the experimental period the focal birds were assessed weekly using gait scoring
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31 (Kestin *et al.*, 1992; Garner *et al.*, 2002), the prevalence and severity of any hock and
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33 foot pad burns, and the presence or absence of leg deformity (rotation and varus-valgus
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35 deformation). To measure gait score (GS), the selected bird was herded, its movement
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37 observed and scored on a 6-point scale (0 - completely sound bird; 5 – unable to stand).
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39 However, in this study any birds of gait scores 4 and 5 were culled on ethical grounds.
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41 Hock burns were scored 0 - no mark, 1 - reddening, 2 – mild scabbing (<10% hock with
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43 lesion) and 3 – severe scabbing (>10% hock with lesion). Foot pad burns were scored 0
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45 – no mark, 1 – mild lesion (<5mm) and 2 – severe lesion (>5mm) (Dawkins *et al.*,
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47 2004).
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52 Leg deformities were assessed by both varus-valgus deformation and abnormal
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54 rotation of the legs at the intertarsal joint. The bird was inverted, ventral side towards
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56 handler, and held by the legs below the intertarsal joint. Varus-valgus deformation and
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58 rotation were assessed subjectively with scores assigned as follows: 0 for straight, 1 for
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60 not straight (varus - angle of >22° where legs meet; valgus - angle of >= 30° between
legs; rotation – pads face each other >15°) (Dawkins *et al.*, 2004). The presence or

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3 absence of crooked toes was also noted. Body weight was also measured after leg
4 assessment prior to returning the individual to the flock.
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8 At the end of the experimental period, the focal birds were killed by cervical
9 dislocation and both legs removed at the coxofemoral joint. They were then stored at
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11 minus 20°C until analysis. The mid-physis of the tibiotarsus in both legs was scanned
12 5 using a pQCT (peripheral quantitative computed tomography) scanner (StraTec XCT
13 using a pQCT (peripheral quantitative computed tomography) scanner (StraTec XCT
14 2000; Pforzheim, Germany) and a loop function performed for a measure of cortical
15 bone density and thickness and area moments of inertia. Five slices, each 1 mm apart,
16 were taken and the mean calculated.
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22 10 **Data analysis**

23 While the majority of analysis involved data from all weeks from all batches, the more
24 detailed investigation of activity and leg health was undertaken only on the final batch
25 of birds at 2, 4 and 6 weeks of age due to the time taken to collect and analyse this data.
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27 Minitab version 15 was used for all analysis.
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33 15 The relationship between gait score and weight was determined using a non-
34 parametric correlation coefficient (Spearman's). The differences in weight between
35 sexes and treatments were examined in a General Linear Model (GLM). Chi squared
36 analysis was used to compare the distribution of gait score and other leg health
37 measurements between treatments. Where expected frequencies of cells were less than
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44 20 5, Fisher's exact test was used.
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46 Hourly activity data were transformed by square root to conform to the
47 assumptions of a parametric test. A GLM was then used to analyse the activity data
48 against age, time of day and light treatment and the interactions therein.
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53 25 The activity data obtained over the 5 minutes immediately following a step up
54 in light intensity could not be transformed fully so were analysed using the non-
55 parametric Kruskal Wallis test for activity against treatment and activity against age. A
56 two-way ANOVA was then used with logged activity data to check interactions
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3 between treatment and age, although attention was paid to statistical significance (P) to
4 ensure agreement with the results of the non-parametric tests.
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8 A GLM was used to analyse transformed daily activity data against weight,
9 age, sex, gait score and hock burn score. PQCT data from both legs were then analysed
10 using paired t-tests to determine whether the density and thickness of the cortical bone
11 or the moments of inertia of the tibiotarsus differed significantly between the right and
12 left. A multivariate GLM was then performed of cortical density and thickness and both
13 horizontal and vertical moments of inertia against gait score, sex, mean activity and
14 final weight.
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22 RESULTS

23 **Light treatment effects on leg health and production**

24
25 Figure 2 shows the relationship found between gait score and mean weight across the
26 growing period for all batches and ages (2 to 6 weeks). Gait score and weight were
27 significantly correlated (Spearman's $r = 0.7$, $P = 0.01$); heavier birds had a poorer gait.
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33 Mean weights differed between sexes ($F = 45.8$, $P < 0.005$) at slaughter at 6 weeks;
34 males - 2.28 ± 0.38 kg and females - 2.04 ± 0.22 kg. Batch also affected weight ($F =$
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 19.9 , $P < 0.005$).

Figure 2 near here

Light treatment did not affect mean weekly weight ($P = 0.736$) and had no
significant effect on the overall numbers of sound (GS 0) or lame (GS 1-3) birds neither
across individual gait scores ($\chi^2 = 0.668$, $P = 0.881$) nor when grouped into sound vs.
lame categories ($\chi^2 = 0.445$, $P = 0.505$). The majority (68.6%, $n = 70$) of birds displayed
only slight gait impairment (GS 0 or 1) in both light treatments at week 6.

Data from the final week of study from all batches ($n = 70$) showed that neither
the prevalence nor severity of any leg health measure was affected by light treatment.
Table 1 shows two examples: rotation of the tibiotarsus (Fisher's exact test: $P = 0.149$)
and hock burns ($\chi^2 = 5.5$, $P = 0.064$), where the latter could be considered a trend for the
step change treatment to reduce the prevalence of the highest severity of hock burns.

Table 1 near here

Light treatment effects on activity

The GLM analysis showed that light treatment did not affect the mean activity of focal birds at any age ($n = 24$, $F = 12.3$, $P = 0.069$), although this could be considered a trend with the control light treatment producing higher activities than the step change. There was no interaction between light treatment and age or time. Activity decreased with age in both light treatments (Figure 3). Time and age interacted significantly to affect activity levels in both light treatments (Figure 4; $F = 25.5$, $P = 0.004$); as age increased, the difference in activity between times decreased. Table 2 shows the average hourly activity (represented by grid lines crossed) at each age across the focal birds. **Figures 3, 4 near here**

Given the trend for activity of the focal birds to be higher in the control room than with a step change in light intensity, the period (5 minutes) immediately following a step up in illuminance was examined to test the hypothesis that step change birds were more active during this period then became less active than the control birds at other times (*i.e.* those used in the original study). Treatment did not affect activity ($P = 0.572$), while age remained highly significant ($F = 10.71$, $P < 0.001$) and there was again no significant interaction between the two factors. **Table 2 near here**

Individual activity and leg health

The GLM analysis showed that none of sex, gait score, hock burn score or weight affected daily activity of focal birds. The only significant result was found with age ($F = 5.97$, $P = 0.004$); *i.e.* younger birds were more active than older birds.

Data from bird 11 were removed as this individual had a large influence, being an anomaly outwith the rest of the data due to the bird's low weight. Table 3 shows the descriptive data for cortical density and area moments of inertia in each leg as well as the final weight of the birds. The statistical analysis demonstrated that there was no difference between the right and left legs of the birds for any value; cortical bone density ($P = 0.461$), thickness ($P = 0.232$) horizontal plane area moment of inertia ($P = 0.319$), vertical plane area moment of inertia ($P = 0.977$). Therefore, for subsequent analysis only data from the right legs were used. Females showed lower moments of

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3 inertia (lower resistance to bending) for both horizontal ($F = 5.0$, $P = 0.04$) and vertical
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5 ($F = 13.8$, $P = 0.002$) planes of the tibiotarsus; females: 142.1 ± 24.7 and 163.1 ± 26.2
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7 mm^4 and males: 198.3 ± 46.4 and $233.0 \pm 35.2 \text{ mm}^4$. Final weight also increased the
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9 horizontal plane moment of inertia ($F = 15.7$, $P = 0.001$), but this is likely to be
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11
12 5 somewhat confounded by sex (females weighed less than males at slaughter age, 6
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14 weeks). No variable had a significant effect on cortical density or thickness. The R^2
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16 value was high at 0.98. Table 3 near here

DISCUSSION

Effects of step-wise changes in light intensity on leg health and production

10 The correlation seen between gait score and weight was expected. Other studies have
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12 reported a strong positive correlation between gait score and body weight (Kestin *et al.*,
13
14 1992; Sorensen *et al.*, 1999; Vestergaard and Sanotra, 1999; Kestin *et al.*, 2001;
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16 Kristensen *et al.*, 2006a), although this is sometimes confounded when severely lame
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18 birds (scores 4 and 5) are included since an inability to feed causes a loss in body
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20 weight. At a slaughter age of 6 weeks, a broiler chicken's skeleton is not mature, so
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22 heavier birds put more strain on soft bones and less fully formed joints. Complete
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24 ossification does not occur in the chicken until around 25 weeks (Latimer, 1927; Rath *et*
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26 *al.*, 2000). The rapid growth rate of modern strains of broilers leads to less dense and
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28 poorly mineralised cortical bone (Williams *et al.*, 2000; Williams *et al.*, 2004), which
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30 could increase the risk of fractures and leg deformations (varus-valgus or rotation).
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33 15 Heavier birds may also tire faster, either from their sheer weight or from an altered
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35 morphology, so are reluctant to walk.

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The light treatment had no significant effect on overall gait score although there
was a trend for the number of birds with the highest severity of hock burn to be reduced
with the step-wise changes in light intensity. This may have been due to a reduction in
time spent sitting or a drier litter with reduced ammonia content. A study on turkeys
found that the incidence of leg abnormalities, as observed by gait and deformities at the
intertarsal joint, was significantly reduced in high intensity light regimes (Hester *et al.*,

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2
3 1983). However, Kristensen and colleagues showed that broiler leg health was
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5 unaffected by light intensity (Kristensen *et al.*, 2006b). Overall, our light treatment had
6
7 no significant effect on the leg health of broilers.
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10 **Activity and light treatment**

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12 5 There was insufficient evidence to support the original hypothesis that the step-wise
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14 changes in light intensity increases the activity of individual birds. On the basis of
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16 previous work (Kristensen *et al.*, 2006a), we had expected activity to be greater when
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18 the step-wise changes were implemented, but lighting treatment had no significant
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20 effect on the activity of individuals; indeed there was a trend for control birds to be
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23 10 more active than those in the step change lighting treatment. This is contrary to the
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25 results of Kristensen *et al.* who found that a similar step-wise change in light intensity
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27 resulted in greater activity of broilers during the periods of bright intensity (Kristensen
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29 *et al.*, 2006a), but is similar to a study in which male turkeys were less active during the
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31 period of higher light intensity (Hester *et al.*, 1987). There are several explanations for
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34 15 these conflicting findings. Firstly Kristensen *et al.* (2006) only used 4 broiler chickens
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36 in each group, compared to much larger flock of 266 birds (of which 12 were the focal
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38 birds). There is some evidence of greater jostling between individuals at higher stocking
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40 densities (Dawkins *et al.*, 2004), which may have affected the activity of the birds
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42 preventing similar results to be seen, and broilers have also been observed to walk
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45 20 longer distances at lower densities (Lewis and Hurnik, 1990). Secondly, it may be the
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47 case that birds response with a spurt of activity to the intensity change *per se* rather than
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49 the absolute intensity. This was tested by observing activity immediately after a step
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51 change in intensity, but there was no significant difference between treatments.
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53 **Individual activity and leg health**

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55 25 Rath and colleagues have surmised that bone density can be used as an index of bone
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57 strength (Rath *et al.*, 2000), since tibiotarsus breaking strength and bone density are
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59 significantly correlated (Frost and Roland, 1991). Therefore in our study cortical
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density was used as a proxy measure for bone strength. There was insufficient evidence

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3 to support the original hypothesis that increased activity promotes good leg health, as
4 measured in terms of gait, the prevalence of hock burn, cortical bone density and
5 thickness and the moments of inertia of the tibiotarsus. This is contrary to the findings
6 of Reiter *et al.* (1995), who showed that active birds had thicker and denser cortical
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12 5 bone in the tibiotarsus compared with less active controls. However, the former had
13 been trained to run 100 m in 20 minutes daily on a treadmill, whereas the controls
14 moved freely around their home pen (a 1 x 1m enclosure with 8 birds per m²). The
15 distance travelled by these trained birds was mostly higher than the hourly average
16 activity of the focal birds in our experiment, which ranged from approximately 140.6 m
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23 10 at two weeks of age to 46.1 m at 6 weeks (estimated from the average distance between
24 grid lines and the number crossed). It is a strong possibility that the activity of our
25 broilers, even in those considered more active, was insufficient to affect cortical density
26 or shape of the tibiotarsus. An alternative explanation is that treadmill-based exercise
27 imposes a greater dynamic load than normal walking, enlarging the circumference of
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34 15 the tibiotarsus; however this would not explain the increased bone density. Reiter and
35 colleagues reported that by training the fast growing strain of birds, the reduction in
36 activity normally seen at three weeks of age was delayed until 6 weeks. While the final
37 liveweight was unaffected by exercise, perhaps the high growth rate typical of broilers
38 was delayed enough to allow sufficient infilling by osteoblasts, a process suggested by
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45 20 Williams *et al.* (2004). The mean cortical densities of the birds in this study are higher
46 than those reported by Reiter *et al.*, but this can be explained by the location of
47 scanning used in the latter study, namely at the proximal end of the tibiotarsus rather
48 than at the mid point used here. However, both measures of cortical density are much
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55 25 mg/cc at a liveweight of 0.99 kg at five weeks of age, and 1250 mg/cc at 2.5kg at 15
56 weeks of age (Rath *et al.*, 2000)). The cortical density of the tibiotarsus of adult layers
57 is also much higher at 1350mg/cc (Zhang and Coon, 1997). The significance of sex on
58 the shape of the tibiotarsus may be related to the change in width of the bone in
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3 response to increased loading, i.e. mass, in the males. Our results indicate that the fast
4 growing, young broiler chickens used in meat production have weak legs for their body
5 size that, despite an increased width to reduce bending, may nonetheless put them at a
6 greater risk of leg fractures and leg deformations.
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11 5 Conclusions

12 In this study, carried out in a semi-commercial setting in contrast to other studies of its
13 kind, a novel lighting regime of step-wise changes in light intensity did not affect
14 performance, leg health or activity of broiler chickens. There was no association
15 between an individual's activity and its leg health, measured in terms of gait, the
16 prevalence of hock burn, tibiotarsus cortical bone density and thickness and shape.
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18 Although this latter finding is counter intuitive, one plausible explanation is that
19 modern, fast growing strains of broiler chickens do not take sufficient exercise to
20 produce a difference in bone quality when given the choice.
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Table 1. Prevalence of two measures of leg health of focal birds from batches 1-3 (n=70) at 6 weeks of age against light treatments

		Light treatment	
		Control	Step change
Rotation of tibiotarsus <i>P</i> = 0.149	No	30 (43%)	32 (46%)
	Yes	6 (9%)	2 (3%)
Hock burns (Increasing severity) <i>P</i> = 0.064	0 (no discolouration or lesions)	12 (17%)	10 (14%)
	1 (reddening)	9 (13%)	17 (24%)
	2 (scabbing)	15 (21%)	7 (10%)

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Table 2. Mean hourly activity across focal birds at each age ($n = 24$)

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Age of birds (weeks)	Mean hourly activity (grids crossed) (+/- 95% CI)	Std. deviation
2	163.5 ± 16.77	39.72
4	77.0 ± 10.57	25.04
6	53.6 ± 7.55	17.89

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Table 3. Descriptive data from right (RL) and left (LL) legs of Batch 3 focal birds (n=23)

	Minimum	Maximum	Mean	Std. Deviation
RL cortical density (mg/cc)	938.92	1017.90	973.47	22.30
RL horizontal plane moment of inertia (mm ⁴)	97.74	294.24	168.99	45.89
RL vertical plane moment of inertia (mm ⁴)	126.17	288.51	196.55	46.70
LL cortical density (mg/cc)	895.52	1072.08	968.98	38.03
LL horizontal plane moment of inertia (mm ⁴)	68.47	295.56	172.91	46.95
LL vertical plane moment of inertia (mm ⁴)	101.28	314.81	196.44	47.94
Weight (g)	1055	2595	1980	317.0

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Figure 1. Step changes employed for illuminance.

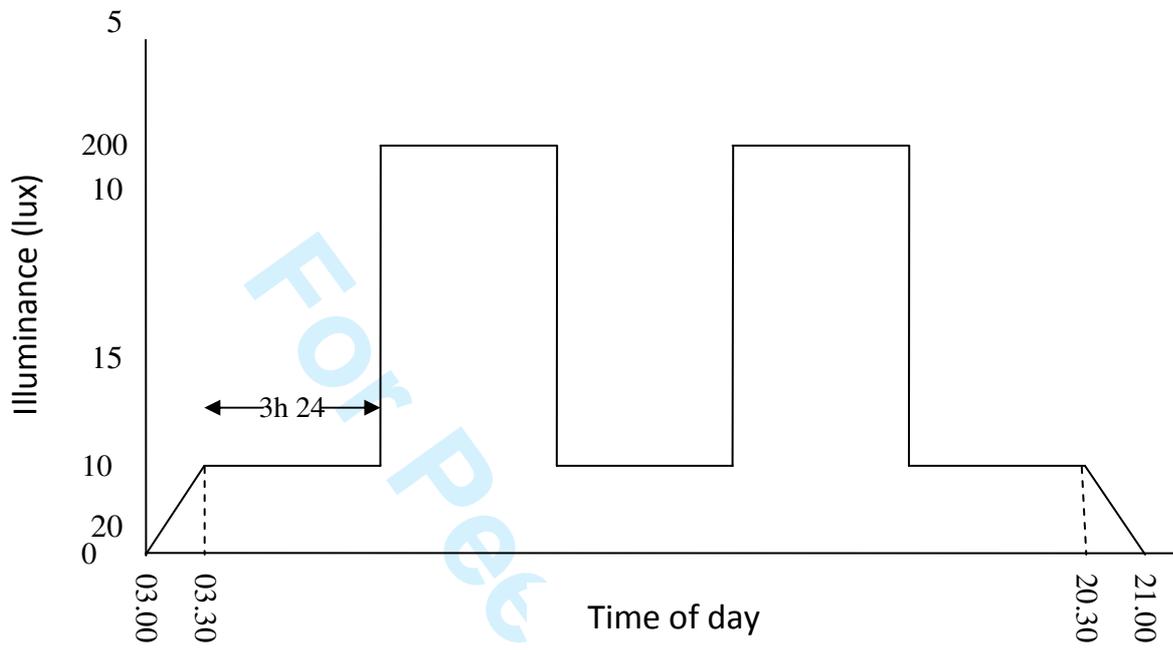


Figure 2. Relationship between mean weight and gait score at all ages (weeks 2 to 6).

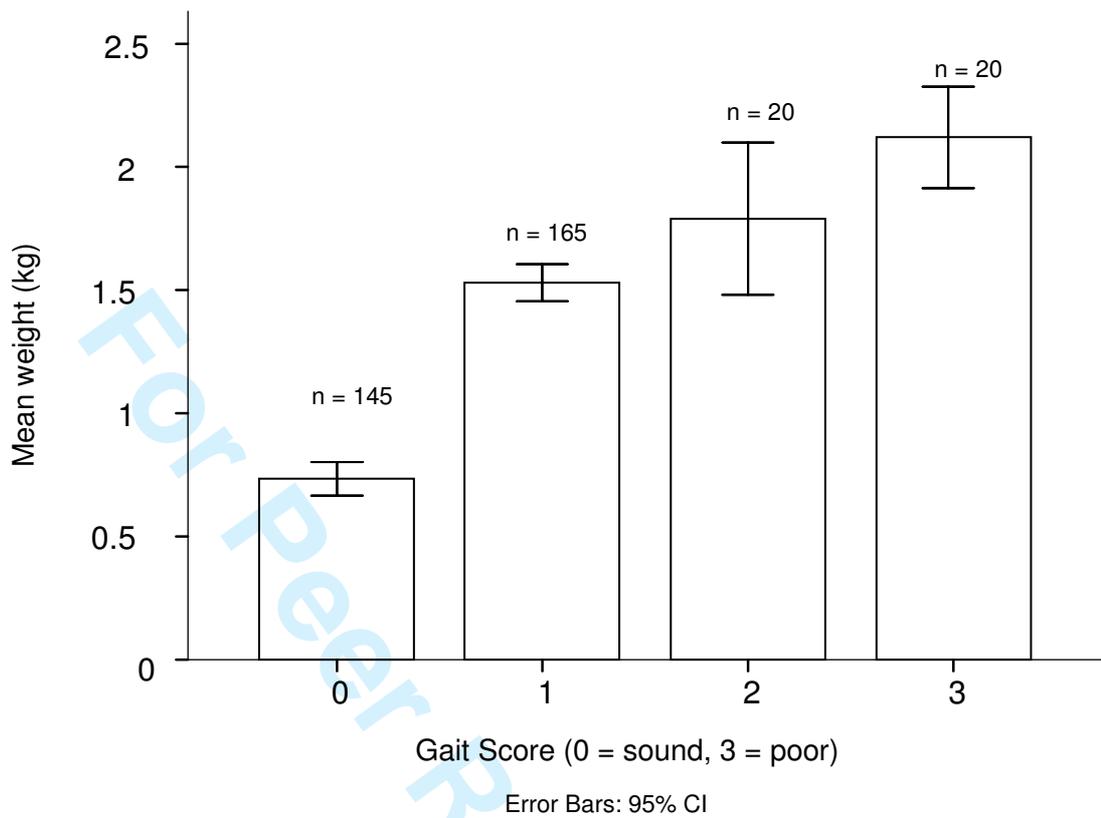
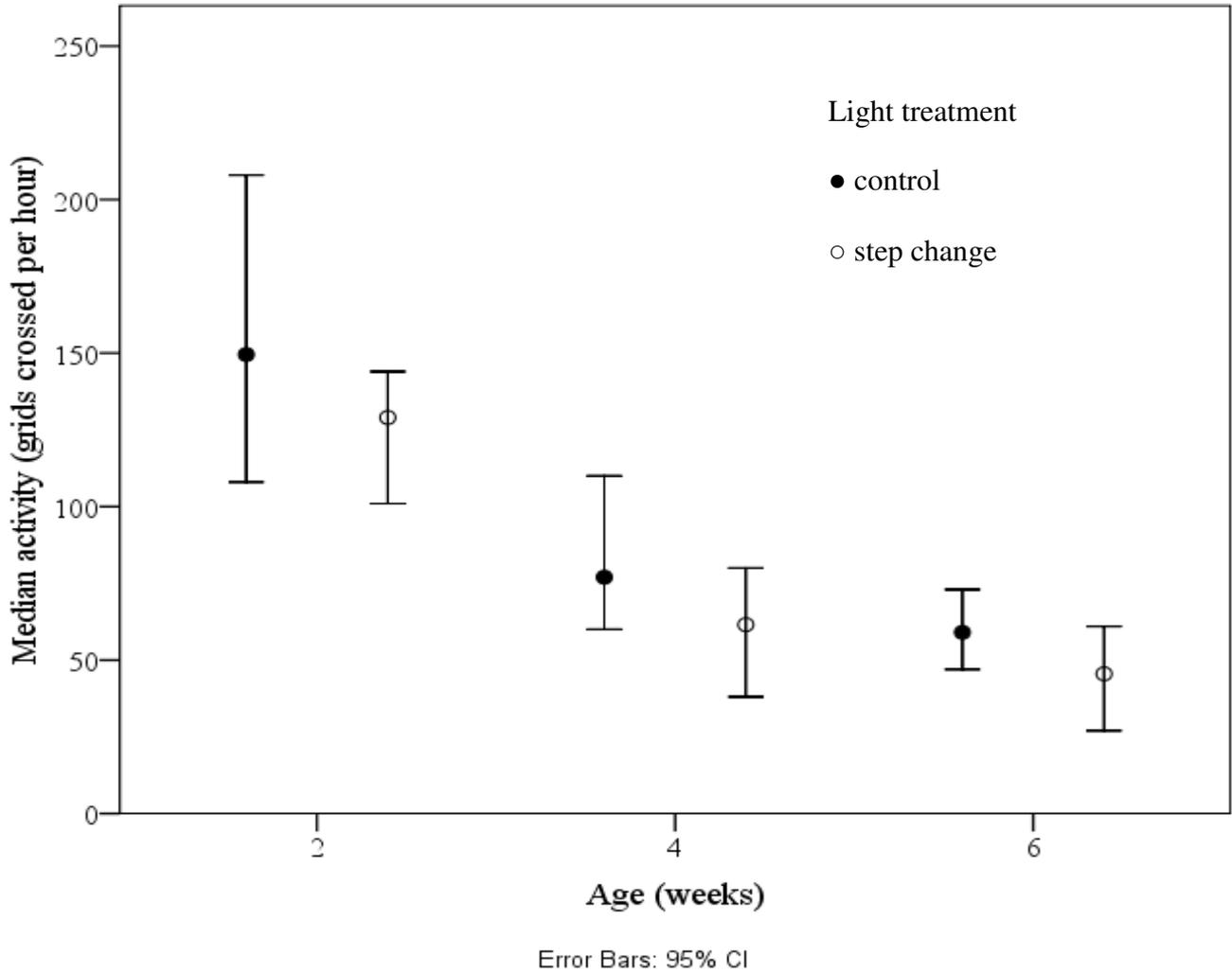


Figure 3. Decline in median activity of focal birds in Batch 3 (n=24) as age increases for each light treatment.



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Figure 4. *The interaction between age and time in relation to median activity of focal birds in Batch 3 (n=24).*

