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# Improving leg health in broiler chickens: a systematic review of the effect of environmental enrichment

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## Abstract

*Leg problems are highly prevalent in modern broiler production and provision of environmental enrichment could be a strategy to improve leg health. Different types of environmental enrichment have undergone evaluation. Our objective was to conduct a systematic review of the effect of environmental enrichment on leg health in broiler chickens. The evaluation of leg health included measures of the entire leg and foot, and behavioural, pathological and physical measures. Six types of environmental enrichment were selected for inclusion: light programme, intensity of light, stocking density, perches, straw bales and separation of resources. For each type, a systematic literature search was performed. The review included 62 studies; 56 randomised trials and six cross-sectional studies. An assessment of the methodological quality of all 56 randomised trials was performed with some reporting deficits regarding occurrence of blinding, randomisation and reliability of measures. Provision of perches and increased intensity of light only displayed limited effectiveness in improving leg health and both mainly affected contact dermatitis. In contrast, there was evidence that a lowered stocking density and a dark/light schedule could improve leg health. Few studies have been carried out on the effect of straw bales and separation of resources. The few studies done have, however, shown that both types of enrichment can be effective in improving leg health. In conclusion, identifying and providing the optimal types of enrichment for broilers will reduce leg problems and increase mobility, thereby improving the welfare of the birds.*

**Keywords**: *animal welfare, broiler chicken, environmental enrichment, leg health, light, stocking density*

## Introduction

The demand for poultry meat worldwide is large, with the production rate rising by approximately three percent per year over the past decade (Food and Agriculture Organization of the United Nations 2015). To meet this high demand, modern broiler production has become more efficient by increasing growth rate and optimising feed conversion in chickens (*Gallus gallus domesticus*) (Robins & Phillips 2011). However, modern production presents several welfare issues with leg health one of the most prominent (Bessei 2006; Knowles *et al* 2008; Bassler *et al* 2013). Here, the leg is defined as the entire lower limb, including the upper leg, the knee, the lower leg, the hock and the foot. Factors affecting leg health in broilers have been addressed in a number of narrative reviews (Bradshaw *et al* 2002; Bessei 2006; Oviedo-Rondón *et al* 2006; Waldenstedt 2006); however, as yet, no systematic reviews are available.

### Environmental enrichment

Factors affecting broiler leg health can be roughly divided into two main categories: those directly related to the chicken, such as growth rate and nutrition, and those related to the external production environment, such as light conditions, perches and stocking density. While previous narrative reviews have focused mainly on nutritional factors (Oviedo-Rondón *et al* 2006; Waldenstedt 2006), the current review focuses on environmental enrichment. Here, we define the effect of environmental enrichment as "an improvement in the biological functioning of captive animals resulting from modifications to their environment" (Newberry 1995) with the improvement in biological functioning being an improvement in leg health. The causality behind the effect of environmental enrichment on leg health is likely multifactorial and not fully understood. One suggested mechanism behind the effect is that enrichment can increase activity levels. Studies where birds were more active also found positive effects on lameness (Reiter & Bessei 2009; Blatchford *et al* 2012) and foot-pad dermatitis (O'hara *et al* 2015). Another mechanism specifically relevant for contact dermatitis, is that enrichment types, such as perches and lowered stocking density, can result in reduced contact with the litter and improved litter quality which, in turn, can reduce contact dermatitis. Our objective is to conduct a systematic review to assess the effect of environmental enrichment on leg health in broilers.

**Table 1 Search terms, number of results and number of studies selected for inclusion in a systematic review of the effect of environmental enrichment on leg health in broilers.**

| Types of environmental enrichment | Stocking density | Light programme | Intensity of light | Perches | Straw bales | Separation of resources |
|---|---|---|---|---|---|---|
| Search terms† | 'stocking density' | 'light' | 'light' | 'perch' | 'straw' or 'hay' | 'distance' or 'barrier' |
| Number of results‡ | 98, 64, 19 | 271, 289, 67 | 271, 289, 67 | 31, 18, 5 | straw: 27, 3, 7<br>hay: 26, 0, 0 | distance: 26, 28, 8<br>barrier: 7, 8, 3 |
| Selected randomised studies (n) | 18 | 23 | 7 | 9 | 1 | 5 |
| Selected cross-sectional studies (n) | 6 | 1 | 0 | 0 | 0 | 0 |

† The search terms 'leg' and 'broiler' were used for all six types of environmental enrichment;
‡ In the databases Web of Science, Cab Abstract and PubMed, respectively.

## Materials and methods

### The review question

The selected types of enrichment are listed in Table 1. Following the recommendations of EFSA (2010), the review question was formulated as follows: "Is provision of environmental enrichment associated with an increase in leg health in broiler chickens, when compared to chickens that are kept without environmental enrichment?" The review question is based on the definition of four key elements: population, exposure, comparator and outcome (EFSA 2010). The population is conventional broiler chickens of all ages and both sexes from experimental and field trials (parent breeders are not included nor are organic broilers). The exposure is provision of environmental enrichment, while the comparator is lack of environmental enrichment. The outcome is leg health defined by three categories: pathological conditions, such as tibial dyschondroplasia (TD), behavioural conditions, such as changes in gait score, and physical properties of the bones of the leg, such as length and strength. Changes in the activity level of the chicken *per se* have not been included as an indicator of leg health. Outcome measures are further described in *Leg health measures.*

### Literature search and selection of studies

A systematic literature search was performed using three databases: Web of science, PubMed and Cab Abstracts. The search terms were ('leg') AND ('broiler') AND ('Search terms related to the enrichment type'; Table 1). The search was focused on whole texts and included primary research articles in English and German in a date range with no cut-off back in time and up until February 2016. Article selection was divided into two steps. Step one was an initial screening to identify potentially relevant articles. Step two was a detailed evaluation of articles selected in step one. Only publications in compliance with the previously mentioned key elements were selected. We estimated that the search term 'leg' would identify a broad range of conditions, including measures of the bones and foot, as articles including these measures are likely to mention 'leg' in the text and keywords. Furthermore, to avoid disregarding any articles, the strategy of Jones and Gosling (2005) was applied, ie we searched through the cited references of the included articles. If new relevant articles were identified, we searched through the cited references in the new articles. All references were saved and managed using the software Mendeley®.

### Data collection and interpretation

Tables were constructed to collect data from the included studies. Three of the studies had incomplete data and, in each case, the corresponding author was contacted by e-mail to try to obtain the missing results. None replied and these results were excluded from the review. To ensure methodological quality, all randomised studies were checked in order to ascertain explicit descriptions of the following: randomisation; blinding; missing outcome data; and reliability of measures. For randomisation and blinding it was also noted whether the method of randomisation/blinding was included and, if so, if the method was considered appropriate. If a study did not include any of the four elements it was excluded from the review. Cross-sectional studies were assessed narratively, as these were not fit for the methodological quality assessment One study included two types of enrichment (straw bales and perches) in the same treatment group (O'hara *et al* 2015). This study was excluded from the selected studies but included in the *Discussion*. Data from the selected studies were analysed and interpreted narratively. After taking advice from a statistician, the data were deemed unsuitable for a meta-analysis due to the large variation between the studies, both in the intervention, eg different formats of stoking density, and in the outcome, eg different scoring systems used for gait scoring.

### Leg health measures

#### *Gait score*

Table 2 lists all the leg health measures that were assessed in the current review. Here, it is shown that gait score was the most assessed measure as well as one susceptible to improvement by enrichment (14 out of 34 studies found an effect). The gait analysis method most commonly used was that of Kestin *et al* (1992), while a few studies utilised the scale developed by Garner *et al* (2002). The walking ability of birds is evaluated and given a score from 0 to 5 with 0 being a sound gait and 5 being an inability to walk (Kestin *et al* 1992).



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**Table 2 A list of leg health measures assessed in 65 studies included in a systematic review on the effect of environmental enrichment on leg health in broilers.**

| Leg health measure | Number of studies assessing the measure | Number of studies finding an effect of environmental enrichment* on the measure |
|---|---|---|
| Gait score | 34 | 14 |
| Foot-pad dermatitis | 29 | 17 |
| Hock dermatitis | 23 | 10 |
| Tibial dyschondroplasia | 17 | 3 |
| Bone measurements | 9 | 5 |
| Leg abnormalities/legs disorders | 8 | 8 |
| Culled due to leg disorders | 6 | 4 |
| Valgus/varus | 5 | 2 |
| Latency to lie | 4 | 2 |
| Bone ash | 3 | 1 |
| Presence of crooked toes | 1 | 1 |
| Leg condemnations | 1 | 1 |
| Jumping ability | 1 | 1 |
| Femoral head/neck necrosis | 1 | 0 |
| Occurence of leg weakness | 1 | 0 |
| Leg bruises at processing | 1 | 0 |
| Leg breakage at processing | 1 | 0 |
| Bone histology | 1 | 0 |

* Included types of environmental enrichment are light programme, intensity of light, stocking density, perches, straw bales and separation of resources.

### *Foot-pad and hock dermatitis*

Contact dermatitis of the foot-pad and hock is another indicator of leg health and has been assessed in a large proportion of the studies (Table 2). Contact dermatitis is a degenerative disorder that affects skin areas that have been in contact with the litter. Litter quality is the biggest determining factor regarding contact dermatitis (Bradshaw *et al* 2002). The terms 'burns', 'pododermatitis' or just 'dermatitis' have also been used to describe contact dermatitis (Bradshaw *et al* 2002; Shepherd & Fairchild 2010). Contact dermatitis has been assessed on a scale or simply described as present or absent. When contact dermatitis was measured on a scale, 0 usually signified that there was no lesion, and increasing numbers indicated increasing severity of the lesion (Haslam *et al* 2006; Allain *et al* 2009; Ventura *et al* 2010).

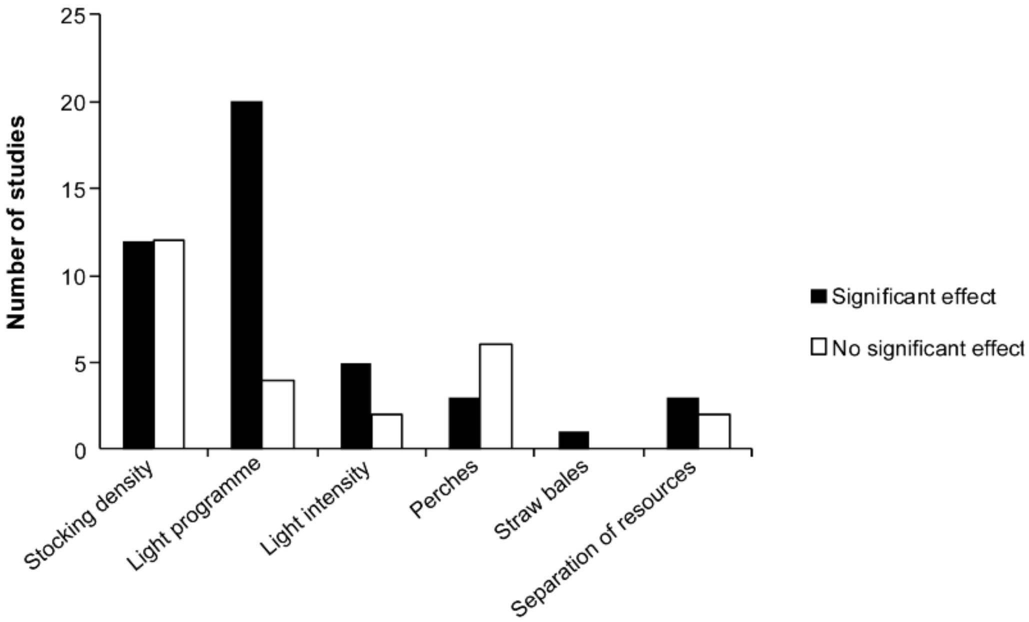
### *Tibial dyschondroplasia*

Tibial dyschondroplasia (TD) is a developmental leg disorder that occurs when there is a defect in cartilage formation within the tibia and may result in bone deformation or fractures (Bradshaw *et al* 2002). It was assessed in 17 studies (Table 2) and different methods applied as regards assessment. The disorder has been detected at post mortem (Blatchford *et al* 2009) and with x-ray fluorescence (Sørensen *et al* 1999). Both methods used abnormal cartilage development (also termed cartilage plugs: Sørensen *et al* 1999; Tablante *et al* 2003), as an indicator of TD. When TD severity was registered on a scale, higher scores signified larger amounts of abnormal cartilage formation.

### *Bone measurements*

Nine studies included some form of bone measurement of tibia, femur or both, and five found all or some bone measures to be affected by the enrichment. Specific examples of bone measures included: length (Reiter 2004; Petek *et al* 2005; Brickett *et al* 2007; Yildiz *et al* 2009; Buijs *et al* 2012), thickness/width (Reiter 2004; Petek *et al* 2005; Brickett *et al* 2007) and curvature/angulation (Reiter 2004; Brickett *et al* 2007; Reiter & Bessei 2009; Birgul *et al* 2012; Buijs *et al* 2012). Tibial measures were obtained using computed tomography, a protractor (Reiter 2004; Reiter & Bessei 2009) and dedicated equipment for measuring breaking strength and bone ash (Reiter 2004; Reiter & Bessei 2009; Ruiz-Feria *et al* 2014). Although specific bone measures are not necessarily an indicator of leg problems, several tibial properties have been shown to correlate with lameness (Toscano *et al* 2013).

**Figure 1**




The effect of six different types of environmental enrichment on leg health in broiler chickens. The number of studies (horizontal axis) in a systematic literature search investigating the effect of environmental enrichment (vertical axis) on leg health. The black and white bars represent the number of studies finding and not finding an effect of the enrichment on leg health, respectively. A study is presented as having found an effect if at least one of the included leg health measures from the study was affected.

### *Leg abnormalities*

Leg abnormalities/disorders are very general terms that require a clear definition in order to be included as measures of leg health in a study. Eight studies included leg abnormalities as a measure of leg health (Table 2), and all measured the proportion of birds with leg disorders. In addition to measuring the proportion, two studies included a measure of the severity of leg disorders (Wilson *et al* 1984; Classen *et al* 1991). In general, leg abnormalities were defined as a list of specific leg disorders that differed between studies, but the majority of the lists included long bone distortions, such as twisted tibia or valgus/varus deformities (Robbins *et al* 1984; Ketelaars *et al* 1986; Classen & Riddell 1989; Classen *et al* 1991; Renden *et al* 1991, 1992, 1996). Other included disorders were swollen hocks (Robbins *et al* 1984; Renden *et al* 1991, 1992, 1996), perosis (Robbins *et al* 1984), TD (Robbins *et al* 1984), curled toes (Robbins *et al* 1984) and arthritis, enlarged stifle joint and spondylolisthesis (Classen *et al* 1991). Wilson *et al* (1984) defined leg abnormalities as birds having difficulty moving due to hip, leg or foot defects.

### *Culled due to leg disorders*

Six studies included the number of birds culled due to leg problems (Renden *et al* 1992; Hall 2001; Bailie & O'Connell 2015) or the mortality due to leg problems (Siddiqui *et al* 2003; Reiter 2004; Reiter & Bessei 2009). Certain leg problems are possible to observe on a carcase as has been done for valgus-varus deformities (Blatchford *et al* 2009) and contact dermatitis (Kyvsgaard *et al* 2013). None of the studies offered any explanation of the criteria for culling a bird or whether the bird died as a result of leg problems.

### *Valgus-varus deformities*

Valgus-varus deformation is a developmental disorder that gives rise to an inwards (varus) or outwards (valgus) angulation of the distal tibia. Five studies included valgus-varus deformities and two found an effect (Table 2). In all cases, the condition was measured as present or absent. Two studies used live birds (Blair *et al* 1993; Leterrier & Constantin 1996) and three assessed birds post mortem, looking at the intact carcase (Sørensen *et al* 1999, 2000; Blatchford *et al* 2009). Broilers with valgus-varus deformities have been shown to have a compromised gait (Julian 1984).

### *Latency to lie*

The latency to lie down test (LTL) is an alternative to gait-scoring (Weeks *et al* 2002). The test was performed in four studies (Buijs *et al* 2009; Bailie *et al* 2013; Ruiz-Feria *et al* 2014; Bailie & O'Connell 2015; Table 2). A broiler is placed into shallow water and the time taken to lie down is measured; the assumption being that the healthier the legs are, the longer it takes for the bird to lie down (Weeks *et al* 2002).

### *Other*

The remaining leg health measures were assessed in only one, two or three studies (Table 2). These included measures of mobility which were not expressed as gait scores, such as leg weakness or jumping ability (Seet & Azizah 1990; Blair *et al* 1993), presence of crooked toes and femoral head/neck necrosis (Leterrier & Constantin 1996; Blatchford *et al* 2009), bone ash and bone histology (Tablante *et al* 2003; Brickett *et al* 2007), and leg problems registered at slaughter, ie leg condemnations and leg bruises and leg breakage at processing (Rozenboim *et al* 1999; Hall 2001).



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## Results

The number of studies for each type of enrichment are shown in Figure 1. The studies are divided into those that detected an effect on leg health and those that did not. In the following sections, we present the results for each type of enrichment. First, we give an overview of the randomised and cross-sectional studies (if any) for the enrichment type. Secondly, we describe the implementation of the enrichment in the selected studies. Third, we present the effects on leg health. Finally, we provide a conclusion.

### Stocking density

#### *Randomised studies*

The impact of stocking density on broiler welfare is a well-studied area with 24 papers included. Here, a low stocking density is considered a type of enrichment as it results in more space per bird and thereby greater freedom of movement. Data from the 18 included randomised studies are presented in Table 3 (see supplementary material to papers published in *Animal Welfare* on the UFAW website: https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). The remaining six studies were cross-sectional; these are described separately below. In total, 12 out of 24 studies found an effect.

#### *Cross-sectional studies*

Six cross-sectional studies were selected for inclusion (Martrenchar *et al* 2002; Haslam *et al* 2006; Knowles *et al* 2008; Allain *et al* 2009; Bassler *et al* 2013; Kyvsgaard *et al* 2013). Each of these included several commercial broiler flocks. In each study, management factors including stocking density were obtained from the flocks. The management factors were set up against a list of health measures, including hock and foot-pad dermatitis, to identify any correlations between management and health. None of the studies found any significant effect of stocking density on hock or foot-pad dermatitis.

#### *Stocking densities*

Stocking densities are divided into low and high densities in Table 3 (https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). Due to great variation in stocking density between the studies, we did not set a cut-off value between low and high for all studies, instead the cut-off was chosen for each study within the range of stocking densities applied in the study. Four formats were used to describe stocking density in the 24 included studies: $m^2$ per bird, $cm^2$ per per bird, kg per $m^2$ and birds per $m^2$. Birds per $m^2$ was the most frequent format (13 out of 24). However, the actual density of birds housed at *x* birds per $m^2$ depends on the size of each bird. In contrast, kg per $m^2$, which was used in nine out of 24 studies, is a more precise measure.

#### *Leg health measures*

In 12 out of 24 studies, stocking density had a significant effect on a leg health measure (Table 3; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). The most commonly investigated measures were gait score, TD and foot-pad and hock dermatitis. Gait score was only affected by stocking density in four out of eleven studies, but lower stocking density always resulted in lower gait scores. TD was not affected by stocking density in any of the four studies that included the measure. Foot-pad and hock dermatitis is a condition seemingly highly influenced by stocking density. Although none of the cross-sectional studies found an effect on contact dermatitis, eleven out of 14 randomised trails found an effect on either one or both measures. The observed effect on contact dermatitis is in accordance with the finding that a high stocking density can lead to a poor litter quality, which is an important risk factor for contact dermatitis (Bradshaw *et al* 2002).

#### *Conclusion*

Half of the studies found lowered stocking density to have a positive effect on leg health with contact dermatitis being especially influenced. Thus, lowering stocking density might be one way to improve leg health in broiler chickens.

### Light programme

#### *Randomised studies*

Applying a dark/light schedule, as opposed to having continuous lighting, has been shown to increase the activity of broilers during light periods which, it has been hypothesised, promotes bone development and leg health (Bradshaw *et al* 2002; Bessei 2006). The effect of light programmes has also been well-studied, with 23 randomised studies (Table 4; see supplementary material to papers published in *Animal Welfare* on the UFAW website: https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material) and one cross-sectional study included.

#### *Cross-sectional studies*

One cross-sectional study from Bassler *et al* (2013) was included. The study included 89 commercial broiler flocks. The length of the dark period at three weeks of age (DARK3) was measured as a possible risk factor for lameness (gait score $\geq$ 3), foot-pad dermatitis and hock burns. The study found that when DARK3 increased, the prevalence of lameness decreased. Foot-pad dermatitis and hock burns were not significantly affected by DARK3.

#### *Light schedules*

Considerable variation in the lighting regime was observed among the 24 included studies. The definition of a continuous light schedule varied slightly, although a programme of 23 h of light and 1 h of darkness was most commonly used. A light schedule with only 1 h of darkness is currently illegal in the EU where the minimum requirement is 6 h of darkness during any 24 h with an uninterrupted period of at least 4 h darkness (Council Directive 2007/43/EC). Even taking into account EU requirements for dark periods, dark/light schedules vary considerably in the included studies. The schedules differed between studies both in the number and length of dark periods over the course of 24 h as well as in the type of transition between light and darkness; abrupt versus gradual. An overall effect of


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**Table 5 Summary of research on the effect of intensity of light on leg health in broiler chickens.**

| Study | Population (age, sex, breed) | Group (n)/ replications per treatment | Low intensity of light in lux (comparator) | High intensity of light in lux (exposure) | Outcome and the effect of exposure indicated as (↓)† or (0)‡ |
|---|---|---|---|---|---|
| Newberry *et al* (1998) | 1 day to 6/9 weeks<br>Mixed<br>Peterson × Arbor Acre | Experiment 1: 35/4<br>Experiment 2: 65/8 | 6 lux | 180 lux | Ability to walk, experiment 1 (↓)<br>Ability to walk, experiment 2 (0) |
| Kristensen *et al* (2006) | 1 day to 42 days<br>Females<br>Ross 308 | 275/2 | 5 lux | 100 lux | Gait score (0)<br>Contact dermatitis, foot-pad (0)<br>Contact dermatitis, hock (0) |
| Olanrewaju *et al* (2007) | 1 day to 36 days<br>Mixed<br>Ross × Ross 708 | 88/2 | 0.2 lux | 1) 2 lux<br>2) 20 lux | Gait score (0) |
| Blatchford *et al* (2009) | 1 day to 40 days<br>Mixed<br>Cobb 500 | Total of 753/not stated | 5 lux | 1) 50 lux<br>2) 200 lux | Gait score (0)<br>Incidence of hock and foot-pad lesions (↓)<br>Valgus-varus (0)<br>TD score (0)<br>Femoral head-neck necrosis (0) |
| Deep *et al* (2010) | 1 day to 35 days<br>Mixed<br>Ross × Ross 308 | 950/2 | 1 lux | 1) 10 lux<br>2) 20 lux<br>3) 40 lux | Foot-pad health score (↓)<br>Gait score (0) |
| Blatchford *et al* (2012) | 1 day to 42 days<br>Mixed<br>Cobb 500 | 40 to 42/4 | 1 lux | 200 lux | Gait score (↓) |
| Deep *et al* (2013) | 1 day to 35 days<br>Mixed<br>Ross × Ross 308, 708 | 62 and 68/24 | 0.5 lux | 1) 1 lux<br>2) 5 lux<br>3) 10 lux | Foot-pad score (↓)<br>Gait score (0) |

† (↓) High intensity of light resulted in a significant decrease in the outcome. For all outcomes a decrease in the outcome signifies a positive effect of a high intensity of light on leg health. ‡ (0) High intensity of light had no significant effect on the outcome.

lighting regime was found. In 20 out of 24 studies the inclusion of a dark period, ie an intermitted light schedule, resulted in a positive effect on leg health when compared to continuous lighting (Table 4; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). The positive effect was observed both for simple and complex light programmes.

*Leg health measures*

The leg health measures investigated were mainly leg disorders, walking ability and TD (Table 4; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). Leg disorders seem to be especially affected by light programme. All eight studies that included 'leg disorders' or 'leg abnormalities' as a measure of leg health found a significant effect of light programme (Table 4; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material), not including studies that included 'leg abnormalities' as a measure of walking ability. Gait score was also affected by light programme with six out of seven randomised trials finding greater walking ability with the use of an intermitted light schedule (Table 4; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). In addition, the cross-sectional trial also found a positive effect on lameness. A condition influenced less by light programme was TD. Only three out of ten studies found a significantly lower severity or prevalence of TD with a dark/light schedule (Table 4; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). In fact, Renden *et al* (1996) found that the TD score was higher in birds subjected to a dark/light schedule. A possible explanation for the overall limited effect on TD is that it tends to mainly be influenced by nutrition, particularly vitamin D, and genetics (Bradshaw *et al* 2002).



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*Conclusion*

Based on the included studies, there is evidence that the application of a dark/light schedule can improve leg health in broilers (20 out of 24 studies); gait score and prevalence of leg disorders showed the greatest tendency for improvement.

## Intensity of light

*Randomised studies*

Providing a high intensity of light measured in lux is another type of enrichment. The hypothesis posits that enhanced light intensity will increase birds' activity thereby increasing leg health (Blatchford *et al* 2012; Deep *et al* 2013). Seven randomised studies were selected for inclusion and data from these are presented in Table 5.

*Intensities of light*

Light intensities in the seven studies ranged from 0.2 (Olanrewaju *et al* 2007) to 200 lux (Blatchford *et al* 2009, 2012). Newberry *et al* (1988) and Kristensen *et al* (2006) applied the light treatments from day 0 while the remaining studies waited between three to eight days before initiating treatment. Until the light treatment was initiated, the majority of the studies stated that they kept intensity at a high level. Five of the studies used incandescent light bulbs as a source of light and one further study neglected to mention their source (Olanrewaju *et al* 2007). Meanwhile, Kristensen *et al* (2006) tested the effect of two different light sources; biolux and warm-white. In general, light intensity was measured with a light meter at the level of the chicken, apart from Olanrewaju *et al* (2007) who failed to mention how intensity was measured. Apart from the effects on leg health, intensity of light was shown to affect weight gain (Blatchford *et al* 2012; Deep *et al* 2013) and ocular dimensions (Blatchford *et al* 2009; Deep *et al* 2010, 2013).

*Leg health measures*

Light intensity had a significant effect on leg health in five out of seven studies; in all cases the groups with a high intensity of light showed superior leg health. Several different leg health measures were included in the five studies that found an effect. However, all five found only a single leg health measure to be affected (Table 5). The most common measures of leg health were gait score and contact dermatitis. Gait score was only affected in one out of six studies. In addition, Newberry *et al* (1988) found an effect on ability to walk by measuring the proportion of birds with impaired walking ability without giving a specific gait score. Contact dermatitis was affected by intensity of light in three out of four studies (Table 5). As previously mentioned, the theory behind a high light intensity improving leg health is an increase in activity. Three of the included studies assessed activity and found overall activity (Newberry *et al* 1988) or activity during the photo phase (Blatchford *et al* 2009, 2012) to be higher in chickens kept at high light intensity, supporting the above theory.

*Conclusion*

Five of the seven studies found that high light intensity could improve leg health. Intensity of light mainly affected contact dermatitis while gait score was only affected to a limited degree. Other effects of intensity were found, such as effects on activity level, weight gain and ocular dimensions. All in all, the evidence that intensity of light affected leg health was limited and dependent on the specific leg health measure assessed, ie contact dermatitis was the main outcome affected.

## Perches

*Randomised studies*

The provision of perches in broiler production systems can motivate chickens to jump in order to reach the perch as well as providing a resting place away from the litter. Nine studies presented in Table 6 were included in the review. Here, a perch is defined as either a simple, longitudinal perch or a constructed platform assembled from various materials and of various shapes.

*Perch designs*

Perches ranged from a simple, round, wooden pole (Su *et al* 2000) to a connected platform of PVC pipes, steel brackets, screws and rubber texturing tape (Tablante *et al* 2003). The main materials were wood and PVC pipes (Table 6). Two studies used water-cooled steel perches (Zhao *et al* 2012, 2013). Shape varied from platforms to round or square poles either hanging alone or connected to a system of poles (Table 6). Horizontal barriers with a width and height that enabled the birds to perch on them were also used (Hongchao *et al* 2013). Zhao *et al* (2012) found that chickens in a hot climate preferred water-cooled perches over normal perches and had lower foot-pad and hock burn scores with the use of water-cooled perches compared to normal perches. An important factor is ensuring perches are at a height enabling access. A common trait of those perches having an effect on leg health was that they tended not to be any higher than 10 cm off the ground, or were angled creating a ramp for access.

*Leg measures*

Provision of perches resulted in a significant improvement in leg health in only three out of nine studies. In the three studies where an improvement was found, the leg measures were foot-pad and hock dermatitis (Zhao *et al* 2012, 2013) and bone angle disorder score (Birgul *et al* 2012). A possible explanation for dermatitis being affected is that contact with the litter is a risk factor for foot-pad and hock dermatitis (Bradshaw *et al* 2002), and usage of perches results in reduced contact with the litter.

The locomotor ability of broilers was improved by increasing activity in a study where broilers were trained to walk on a treadmill (Reiter & Bessei 2009). Gait score and LTL, both measures of locomotor ability, were not affected


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**Table 6 Summary of research on the effect of perches on leg health in broiler chickens.**

| Study | Population (age, sex, breed) | Group (n)/ replications per treatment | No perches (comparator) | Perches (type, height) (exposure) | Outcome and the effect of exposure indicated as (↓)[†] or (0)[‡] |
|---|---|---|---|---|---|
| Seet & Azizah (1990) | 1 day to 8 weeks<br>Mixed<br>Ross 308 | 100 to 150/3 | No perches | Rectangular wood, 45 cm | Percentage leg weakness (0) |
| Su *et al* (2000) | 1 day to 42 days<br>Mixed<br>Ross 208 | Experiment 1: 30/48<br>Experiment 2: 30/24 | No perches | Experiment 1: rectangular wood, 10–25 cm<br>Experiment 2: round wood, 10–25 cm | TD score (0)<br>Gait score (0)<br>Foot-pad burn score (0)<br>Hock burn score (0) |
| Tablante *et al* (2003) | 1 day to 44 days<br>Mixed<br>Avian × Avian | 45 to 90/3 | No perches | 1) 0° angled PVC platform, 8.5 cm<br>2) 10° angled PVC platform, 17 cm<br>3) 20° angled PVC platform, 35.5 cm | Incidence of TD (0)<br>Bone ash of tibiotarsus (0) |
| Ventura *et al* (2010) | 1 day to 7 weeks<br>Mixed<br>Ross 308 | 36 to 80/4 | No perches | 1) Simple wood barrier, 10 cm<br>2) Complex wood barrier, 10 cm | Foot-pad dermatitis score (0)<br>Hock burn score (0) |
| Birgul *et al* (2012) | 1 day to 7 weeks<br>Mixed<br>Ross 308 | 30/4 | No perches | 1) 0° angled PVC, 0 cm<br>1) 0° angled PVC, 17 cm<br>1) 0° angled PVC, 33 cm<br>1) 0° angled PVC, 70 cm | Bone angle disorder score (↓)<br>Gait score (0)<br>TD prevalence (0) |
| Zhao *et al* (2012) | 1 day to 42 days<br>Male<br>Arbor Acres | 48/3 | No perches | 1) Water cooled steel, 10 cm<br>2) PVC, 10 cm | Foot-pad burn score (↓)[§]<br>Hock burn score (↓)[§] |
| Zhao *et al* (2013) | 1 day to 42 days<br>Male<br>Arbor Acres | 48 to 80/3 | No perches | 1) Water cooled steel, 10 cm | Foot-pad burn score (↓)<br>Hock burn score (↓) |
| Hongchao *et al* (2013) | 1 day to 35 days<br>Mixed<br>Arbor Acres | 48 to 80/3 | No perches | 1) Wood barrier, 10 cm<br>2) Horizontal PVC, 8.5 cm<br>3) Sloped PVC, 10.4 cm | Foot-pad burn score (0)<br>Hockburn score (0)<br>Gait score (0) |
| Bailie & O'Connell (2015) | 1 day to 42 days<br>Mixed<br>Ross 308 | 23,000/4 | No perches | Horizontal wood, 15 cm | LTL (0)<br>Gait score (0)<br>Culled for leg problems (0)<br>Incidence of pododermatitis (0)<br>Incidence of hock burn (0) |

[†] (↓) Provision of perches resulted in a significant decrease in the outcome. For all outcomes, except LTL, a decrease in the outcome signifies a positive effect of perches on leg health;
[‡] (0) Provision of perches had no significant effect on the outcome;
[§] Only 'cooled perches' decreased foot-pad and hock burn scores when compared to 'no perches.' When comparing 'PVC perches' to 'no perches,' PVC perches increased foot-pad and hock burn scores.



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**Table 7 Summary of research on the effect of straw bales on leg health in broiler chickens.**

| Study | Population (age, sex, breed) | Group size (n)/ replications per treatment | No straw bales (comparator) | Straw bales (exposure) | Outcome and the effect of exposure indicated as (↓)[†] or (0)[‡] |
|---|---|---|---|---|---|
| Bailie *et al* (2013) | 1 day to 42 days | 23,000/4 | No straw bales | 1 bale per 44 $m^2$ | LTL test (↓) |
| | Mixed | | | | Gait score (↓) |
| | Ross | | | | Incidence of hock burn and pododermatitis (0) |

[†] (↓) Provision of straw bale resulted in a significant decrease in the outcome. For all outcomes a decrease in the outcome signifies a positive effect of straw bales on leg health;
[‡] (0) Provision of straw bales had no significant effect on the outcome.

by perches in any of the studies (Table 6). The main function of a perch is an elevated resting place, and thus a perch does not stimulate locomotion and increased activity. This lack of activation might explain why gait score and LTL were not affected by perches. Furthermore, Bailie *et al* (2013) could not detect a difference in activity between birds provided with perches and those not.

*Conclusion*

Of the nine included studies, three found an effect, providing scant evidence that provision of perches can improve leg health in broilers apart from having an effect on foot-pad and hock dermatitis. Even though perches do not appear effective in improving leg health, there are other beneficial effects of perches that should be taken into account, such as inducing a broader behavioural repertoire and lowering aggression levels, as shown by Ventura *et al* (2012).

## Straw bales

*Randomised studies*

Provision of straw bales in broiler flocks may serve several functions through being an object to perch on or cluster around and by promoting foraging and pecking behaviour (Kells *et al* 2001; O'hara *et al* 2015). Only one publication on the effect of straw bales was selected for inclusion (Table 7).

*Straw bales*

Square straw bales of wheat measuring 40 × 40 × 80 cm (length × width × height) were provided. These were not replaced during the production cycle resulting in them becoming fully dismantled by the end of the cycle (Bailie *et al* 2013).

*Leg measures*

Bailie *et al* (2013) found an improvement in gait score and LTL, indicating that the interaction with the straw bales, eg jumping on and off, resulted in better mobility, although the overall activity was not affected by straw bale provision.

*Conclusion*

Limited information is available on the effect of straw bales on leg health specifically, yet the included study found a positive effect on leg health. Furthermore, the birds were observed gathering around the straw bales and pecking at them (Bailie *et al* 2013). Based on the above, the provision of bales merits further investigation as an enrichment material for broilers.

## Separation of resources

*Randomised studies*

In commercial broiler farms, drinkers and feeders are placed in close proximity. Separating the resources either by distance or physical barriers forces the birds to be active in their efforts to reach food and water. Five randomised studies regarding separation of resources were selected for inclusion (Table 8).

*Separation of resources*

The use of barriers between food and water prevents birds from walking in a straight line between the two resources (Bizeray *et al* 2002; Ventura *et al* 2010; Ruiz-Feria *et al* 2014). Bizeray *et al* (2002) placed two parallel rows of barriers forcing the birds to either jump over the perches or move in a slalom-like pattern around them. A similar set-up was used by Ventura *et al* (2010). A triangular ramp with a 38° inclination was used by Ruiz-Feria *et al* (2014) forcing the birds to walk up and down to cross the barrier. Adding distance between the food and water will, in the same way as barriers, force the birds to walk longer distances though without increasing the complexity of the environment. Distances applied are listed in Table 8. One crucial point when separating food and water is to make sure that the birds can still eat and drink enough to support growth, and a possible increase in activity that the separation of resources results in. The final bodyweight of the chickens was not affected by separation of resources in any of the included studies.

*Leg measures*

Investigation of leg health was performed mainly by obtaining gait scores (Bizeray *et al* 2002; Reiter 2004; Reiter & Bessei 2009; Ruiz-Feria *et al* 2014) and tibia measures (Reiter 2004; Reiter & Bessei 2009; Ruiz-Feria *et al* 2014). Gait scores were significantly affected by enrichment in two studies (Reiter 2004; Reiter & Bessei 2009). In Experiment 2 by Ruiz-Feria *et al* (2014), gait score was not affected (Table 8). However, in the same experiment LTL was affected, suggesting a discrepancy between gait score and LTL, contrary to the highly significant relationship between the measures found by Weeks

**Table 8 Summary of research on the effect of separation of resources on leg health in broiler chickens.**

| Study | Population (age, sex, breed) | Group (n)/ replications per treatment | No separation of resources (comparator) | Separation of resources (exposure) | Outcome and the effect exposure indicated as (↓)† or (↑)‡ or (0)§ |
|---|---|---|---|---|---|
| Bizeray *et al* (2002) | 1 day to 42 days<br>Mixed<br>Ross 308 | 45/10 | No barrier between food and water | Wood barrier placed between food and water | Gait score (0)<br>TD score (0) |
| Reiter (2004) | 1 day to 37 days<br>Mixed<br>Cobb | 600/4 | 2 m between food and water | 12 m between food and water | Gait score (↓)<br>Tibial length, diameter, torsion and proximal angulation (0)<br>Tibial distal angulation (↓)<br>Mortality due to leg disorders (↓) |
| Reiter & Bessei (2009) | 1 day to 36 days<br>Mixed<br>Cobb | 600 per group/4 replications per treatment | 2 m between food and water | 12 m between food and water | Gait score (↓)<br>Mortality due to leg disorders (↓)<br>Tibia cortical thickness and torsion (↓)<br>Tibia cortical surface and proximal and distal angulation (0) |
| Ventura *et al* (2010) | 1 day to 42 days<br>Mixed<br>Ross 308 | 36 to 80/4 | No barrier between food and water | 1) Simple barrier between food and water<br>2) Complex barrier between food and water | Foot-pad dermatitis score (0)<br>Hock burn score (0) |
| Ruiz-Feria *et al* (2014) | Experiment 1: 1 day to 56 days<br>Mixed<br>Ross 708<br>Experiment 2: 1 day to 49 days<br>Males<br>Cobb 500 | Experiment 1: 72/6<br>Experiment 2: 54/4 | Experiment 1: 1 m between food and water<br>Experiment 2: no ramp between food and water | Experiment 1:<br>1) 3.3 m between food and water<br>2) 6.6 m between food and water<br>Experiment 2:<br>1) 3 m between food and water<br>2) 8 m between food and water<br>3) Ramp between food and water | Experiment 1:<br>LTL (0)<br>Foot-pad lesion scores (↓)<br>Tibia strength and ash content (0)<br>Experiment 2:<br>LTL (↑)<br>Foot-pad lesion scores (0)<br>Tibia strength and ash content (0)<br>Gait score (0)<br>Calcaneus breaking strength (0) |

† (↓) Separation of resources resulted in a significant decrease in the outcome. For all outcomes, except 'LTL', a decrease in the outcome signifies a positive effect of separation of resources on leg health;
‡ (↑) Separation of resources resulted in an increase in the outcome;
§ (0) Separation of resources had no significant effect on the outcome.

*et al* (2002). Tibial measures were affected by separation of resources in two out of three studies (Table 8).

*Conclusion*

Separation of food and water has been implemented by the use of simple or complex barriers or by increasing the distance between the resources. Separation of resources has been shown to have a positive effect on leg health, with three out of five studies finding an effect.

## Methodological quality

Data from the quality assessment are presented in Figure 2. The majority (45/56) of the studies mentioned that the allocation of animals was randomised. However, all but one study refrained from mentioning the method of randomisation. Only four out of 56 studies mentioned that the study was blinded. Of the four studies that mentioned blinding, two described the specific method. It is not known whether the remaining 52 studies were blinded or not but no mention



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was made either way. In 52 out 56 studies, there was no missing outcome data, or the reason for missing outcome data was clearly explained. Regarding reliability of measures, seven out of 56 studies reported some degree of quality assurance of obtained measurements (training of observer, intra- and/or inter-observer reliability etc).

## Discussion

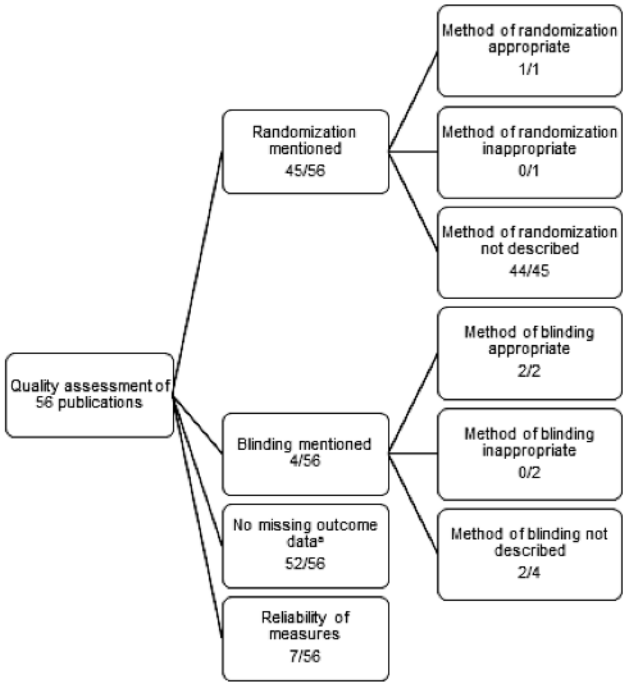
Efforts to improve leg health in broiler chickens are of great importance, as leg health issues are arguably the most important welfare problem facing broiler chickens. One suggested cause of leg problems is low activity levels in birds often kept in a barren environment (Weeks *et al* 2000), coupled with the high growth rate (Williams *et al* 2000; Shim *et al* 2012) and high stocking density (Dawkins *et al* 2004). The hypothesis that leg health in broiler chickens can be improved through the provision of enrichment has been confirmed by a number of studies in this current review; however, the strength of the association between the enrichment and leg health is dependent on the type of enrichment.

For the enrichment factors, light programme and intensity of light, more than half of the studies found an effect. The effect of light programme is well-documented with 20 out of 24 studies finding an effect. The results clearly indicate that a dark/light schedule is associated with an increase in leg health; especially improved gait scores. When designing a dark/light schedule, one should take into account the risk of a decrease in growth rate as observed by Classen *et al* (1991). The effect of intensity of light on leg health was investigated in seven studies with five finding an effect on only one of the included leg health measures. Based on the paucity of literature and the low proportion of affected leg health measures, the evidence that increased light intensity can affect leg health is unconvincing. However, we included studies that compared fixed light intensities, as opposed to varying light intensities within a treatment, ie as occurs with access to natural light.

For the factors inclusion of straw bales (one out of one finding effect) and separation of resources (three out of five finding effect), a clear limiting factor is the sparsity of available literature. However, the existing results are promising, showing that provision of straw bales and separation of resources can increase leg health. One study by O'hara *et al* (2015) used straw bales in combination with perches and found a positive effect on foot-pad dermatitis. This study was excluded from the selected studies here, since it was impossible to determine whether the given effect on leg health was due to the straw bales, the perches or a combination of both. However, the results do indicate a positive effect of either or both types of enrichment. O'hara *et al* (2015) also found an increase in activity with the provision of straw bales and perches.

Perches were the type of enrichment that had the least influence on leg health with three out of ten studies finding an effect. However, there was a great variation in perch design in the included studies, and it is possible that there are benefits to be gained, especially regarding contact dermatitis, from finding the ideal perch design.

**Figure 2**




Assessment of the methodological quality of 56 randomised trials included in a systematic review on the effect of environmental enrichment on leg health in broiler chickens. [a] Publications were recorded as having no missing outcome data when there was no missing outcome or if the reason for missing outcome data was clearly explained.

Finally, for stocking density, half of the studies found an effect (12 out of 24). Discovering that contact dermatitis was particularly susceptible to improvement supports the theory that stocking density can improve leg health; perhaps via an increase in litter quality in addition to any improvement resulting from increased activity levels. Thus, there is convincing evidence for a lowered stocking density to be able to improve leg health.

A logical consequence of higher activity levels, as occurs with the provision of enrichment, is a higher energy requirement, ie an increase in feed intake. Several studies included feed intake as a variable, but results varied between studies. Some studies found an increase in feed intake with enrichment (Meluzzi *et al* 2008; Hongchao *et al* 2013; Ruiz-Feria *et al* 2014), others a decrease (Zuowei *et al* 2011) and some could not detect any difference (Thomas *et al* 2004; Ravindran *et al* 2006). Another possible consequence of a higher activity level is a change in bodyweight; either a decrease since the bird is expending more energy or an increase due to increased muscle mass. As for feed intake, bodyweight was found to increase in some studies (Meluzzi *et al* 2008; Deep *et al* 2013), decrease in others (Ventura *et al* 2010; Das & Lacin 2014) or not to be affected (Kristensen *et al* 2006; Buijs *et al* 2009; Bailie & O'Connell 2015). Stocking density was the type of enrichment where most studies included feed intake or bodyweight as a parameter (eight studies) but, likewise, no clear effect was seen when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stocking density was viewed in isolation. However, a change in feed intake or bodyweight is an important economic consequence of enrichment for broiler producers, and a better understanding of the effect on these parameters is needed. Finally, it should be noted that a higher level of activity could have an adverse effect on leg health, and that leg health and activity are closely interlinked as birds with leg pain are less likely to be active. However, we suggest that too high an activity level, as regards leg health, is unlikely to be a problem in broilers, unless activity results in injuries, such as when jumping on and off platforms.

The results of this review are divided into those studies that detected an effect and those that did not. However, another crucial factor to consider is the magnitude of the detected effect, ie the effect size. Using stocking density and mean foot-pad scores as an example, some variation was found in effect size. Sørensen *et al* (2000) found a limited effect size; mean scores increased from 0.920 to 0.687 with a change from 16 to 22 birds per $m^2$. On the other hand, Buijs *et al* (2009) found mean scores of 1.0, 1.3 and 3.1 at stocking densities of 6, 33 and 56 kg per $m^2$, respectively. Here, the increase in mean scores with a change from 6 to 33 kg per $m^2$ was limited, while there was an almost three-fold increase in mean scores from 33 to 56 kg per $m^2$, indicating that foot-pad dermatitis is particularly responsive to changes in stocking density at high densities. It is beyond the scope of this review to analyse effect size for all leg measures. Yet, it is evident, as previously stated, that enrichment can improve leg health to a large extent, and we would hypothesise that this is especially applicable for measures in which the underlying mechanism explaining the effect is clear; lowered stocking density can improve litter quality thereby reducing foot-pad scores. However, it is unlikely that environmental enrichment alone can eradicate leg problems. Thus, to effectively minimise these, the provision of enrichment should probably be combined with other factors, such as growth rate and breeding.

In the quality assessment of the 56 included randomised trials, three issues were present in the majority of studies. First, although 45 out of 56 studies mentioned randomisation, all but one neglected to mention the method of randomisation. The method is important, and inappropriate techniques include assigning the first half of the population to one treatment or assigning based on seemingly irrelevant farm characteristics, such as order of entry into the trial. Inappropriate methods of randomisation will influence the credibility of the observed results, as they can result in unwanted bias. Secondly, blinding was mentioned in only four out of 56 studies. Blinding is important in helping prevent unwanted bias but can be complicated or impossible to achieve with live observations or video observation where enrichment can be seen. Finally, reliability of measures, such as inter-observer agreement (Ruiz-Feria *et al* 2014) and repeatability of measures (Buijs *et al* 2012), was mentioned in only seven out of 56 studies. For future studies within the assessed field of research, the focus needs to be on transparency as regards to blinding and method of randomisation and on reporting the reliability of the measures included in a study.

When interpreting the result of the 62 included studies it is important to take into account the variation in study design, choice of breed, year of publication and type of leg health measures. The review included 56 experimental randomised trials which are ideal for detecting an effect of enrichment, as variation between the control group and treatment group is limited. A possible disadvantage of experimental studies is that the conditions within which birds are kept, might not be representative of commercial broiler production. An example would be the work of Buijs *et al* (2012) in which birds were kept in groups as small as eight per pen. The remaining six cross-sectional studies, on the other hand, were carried out on a sample of commercial broiler flocks and were therefore representative of commercial conditions. The disadvantage of cross-sectional studies is that they are not ideal for detecting an effect of enrichment, as flocks with and without enrichment can differ in many aspects other than simply enrichment. The types of variation mentioned above, together with the difference between experimental and commercial conditions, may be contributing factors to the difference in findings seen here.

There has been a rapid increase in the growth rate of the broiler with 56-day-old broilers reaching a bodyweight of 905 g in 1957 and increasing this by more than 400% to 4,202 g in 2005 (Zuidhof *et al* 2014). Publication years, here, range from 1984 to 2015, and it seems likely that genetic as well as management factors associated with leg problems have changed during this period. A study of gait scores in Danish broilers showed that 84.34% had a gait score 2 in 2011, while gait scores were more evenly distributed across the scale (24.3% had gait score 2) in 1998/1999 (Videncentret for Landbrug 2012). Such a difference in distribution can affect the likelihood of identifying an effect of environmental enrichment on gait scores, and a similar trend is likely to apply to the other included leg health measures. Care should therefore be taken when interpreting the results of older studies.

In the current review we chose to maintain a broad definition of leg health measures and include all the measures listed in Table 2. By including many different measures, it was possible to assess which were investigated most often and which were most affected by enrichment (Table 2). Furthermore, since the scope of this review was to evaluate the effect of enrichment on leg health, selecting only a few leg health measures would not have been representative.

## Animal welfare implications and conclusion

Provision of some types of environmental enrichment can improve leg health. A lowered stocking density and a dark/light schedule are both well-studied strategies that have been effective in improving contact dermatitis and gait scores, respectively. High light intensity and provision of perches do not seem to be effective in improving leg health, except for perhaps having an effect on contact dermatitis. Provision of straw bales and separation of resources have only been studied to a limited extent, but both appear effective in improving leg health and merit further investigation. It is not only leg health that is affected by enrichment, other factors, such as diminished aggression, activity levels and behavioural repertoire have all been shown to be positively influenced by environmental enrichment. Thus, we believe there to be positive effects to be gained on leg health and welfare from identifying and implementing the correct types of environmental enrichment in broiler production.

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