
Quantifying the welfare impacts of lameness in broiler chickens

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I. Background

Lameness, a clinical indicator of a collection of disorders that affect the ability of an individual to walk, is widely considered a major problem in the broiler industry and the primary welfare concern for broilers [1,2]. It is defined as an impairment in the ability to walk normally as a result of injury, infection or deformity in one or more weight-bearing structures (e.g., skeleton, muscle, tendons, skin or nervous system in the legs and feet), and conformation [3,4]. Given its potentially painful nature [5–8], and the impact it can have on behavior, accessing essential resources such as feed and water, morbidity and mortality, lameness is considered a major welfare concern [9,10].

As shown in Figure 1, lameness is a multifactorial condition heavily associated with fast growth rates [11–14]. The modern broiler is the result of decades of intensive genetic selection narrowly focused on a rapid rate of growth and muscle mass deposition. Growth rates have increased by over 400% between 1957 and 2005 [15], with broilers now being capable of reaching market weight with merely 5 to 6 weeks of age. Because bone development is not as rapid as the rate of muscle deposition [16], disproportionate stress is placed on relatively immature bones and joints [13,17].

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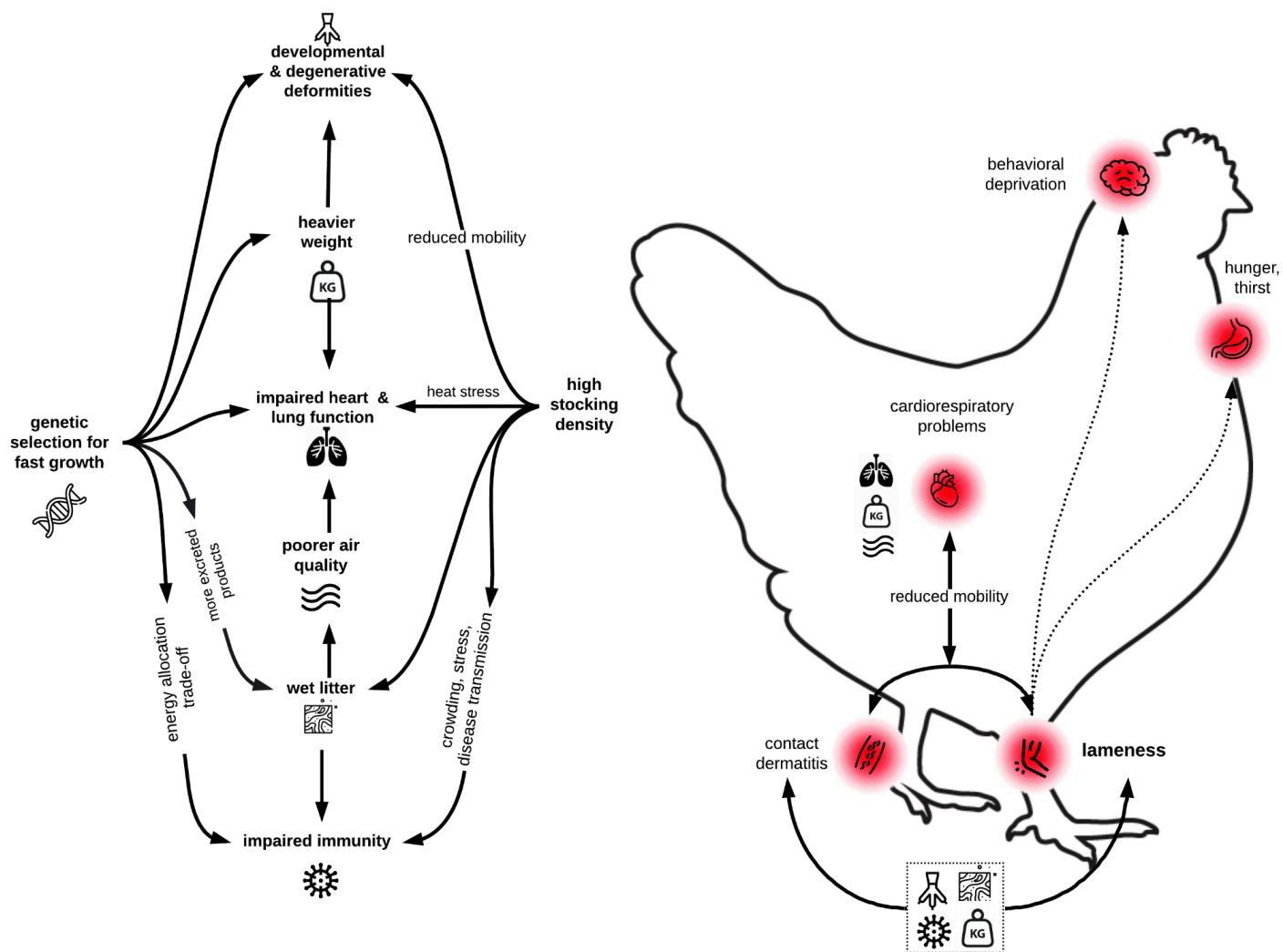


Figure 1. Risk factors for lameness in commercial broiler chickens. Right: risk factors and consequences of lameness. Some risk factors are depicted by icons, described in the left panel. On the left, the relationship with secondary and indirect risk factors is also depicted. Illustration: C.Schuck-Paim & W.J. Alonso

In addition to the pressure on the leg bones and joints, rapid muscle growth has been accompanied by substantial changes in body conformation, including greater breast mass, causing an unbalanced distribution of weight. In today's broilers, pectoral mass accounts for approximately 20% of total body mass, compared with about 10% in ancestral varieties [17]. To achieve balance, modern broiler breeds compensate by modifying their gait. This creates a vicious cycle, in that gait modifications and reduced locomotion further predispose the birds to skeletal and muscle disorders [16,18–20]. For example, the reduced physical activity further impairs bone development [21].

As the birds become increasingly inactive with age, they spend more time in direct contact with the litter, causing an associated increase in the incidence and severity of lesions typically associated with contact dermatitis (hock burn and footpad dermatitis) [2]. In addition to pain, which further impairs locomotion,

these lesions can be a gateway for bacteria, which may spread through the bloodstream and cause joint inflammation. Additionally, compromised circulation from prolonged sitting times, and the greater stress on immature cartilage further increase joint susceptibility to bacterial infection [10,22,23].

As a result of diversion of energy for rapid growth, critical organ systems and biological functions have been concurrently compromised. Immune function is among them [24,25]. By limiting the energy available for other physiological demands, selection for faster growth has impaired the maturation of the immune system and the magnitude of the immune response [26,27]. For example, modern-day broilers have weakened acute phase inflammatory responses, releasing lower amounts of proinflammatory cytokines (signaling molecules of the immune system) when exposed to a pathological challenge [28,29]. In fact, a blunted immune response may have been indirectly selected for the very reason that a reduced inflammatory response can also favor growth and muscle deposition [28,30]. Genetic selection for rapid growth has also been shown to negatively affect the adaptive arm of the immune system, impairing antibody production [31,32]. Accordingly, heavier and faster growing genetic lines have shown lower resistance to multiple infectious diseases [26,29,31,33–37] as well as a higher likelihood of mortality from infection compared to slower growing strains [27,38,39].

While the risk of lameness is predominantly linked with genetics, other risk factors also affect the likelihood and severity of the condition in commercial flocks (Figure 1). Among these are high stocking densities (e.g., greater than 29 kg body weight/m²; [40]), poor litter quality [41] and minimal periods of darkness [2,8,12,19,42]. For example, by limiting the space available for movement and creating a greater volume of waste per area [10], high stocking densities lead to greater litter moisture and poorer air quality [12,19,43], which are important risk factors for lameness [44,45]. Accordingly, high stocking densities have been associated with greater severity of leg issues, such as hock burn [40,43], footpad dermatitis [43], tibial dyschondroplasia [19,40,46] and compromised walking ability [10,43]. Culling rates associated with leg-related problems have been shown to be higher with greater densities [10,41,43]. In general, factors that reduce the activity levels of birds and increase growth rate increase the likelihood and severity of leg health problems.

The welfare consequences of lameness are many, and depend on the severity of the condition, often measured using gait score. Gait scoring is the most common method to assess leg health and the severity of lameness and is based on visual appraisal of walking ability. Briefly, birds are observed as they walk and scored using either a three-point scale (0: completely normal, 1: walking impaired; 2: unable to walk) or the widely used Bristol six-point 'gait scoring' scale [47], whereby trained personnel assign a score between 0 and 5 based upon the criteria described in Table 1. This is typically conducted using a large group of randomly selected birds and a flock average is determined based on this sample. Inter-observer reliability tests can be used to better ensure that observers are scoring consistently [48]. Still, human error, bird velocity while walking and the technically subjective nature of this assessment can contribute to variability in lameness prevalence estimates in commercial flocks [18,19]. However, this non-invasive method of assessing leg health is widely used given its feasibility of implementation in a farm setting [18,41].

Table 1. Bristol Gait Scoring System [47].

Score	Normality	Agility	Preference
GS0	No detectable abnormalities	Dextrous and agile	No preference detected
GS1	Slight defect detected, but difficult to define	Agility not negatively impacted	No preference detected
GS2	Definite and identifiable defect in gait	Agility not negatively impacted	No preference detected
GS3	Obvious gait defect which negatively impacts movement and walking ability	Agility impacted and unsteady movements observed	Squat position preferred when not coerced to move
GS4	Severe gait defect, but still capable of walking when strongly motivated	Acceleration, maneuverability and speed severely and negatively impacted	Maintained squatting position at first available opportunity
GS5	Incapable of locomotion		

In this chapter we use the [Cumulative Pain Framework](#) [49] to provide a quantitative basis upon which to evaluate the welfare impacts of lameness in fast- and slower-growing broiler breeds. Many are the knowledge gaps and uncertainties in this exercise. The endpoint, therefore, is not yet a definitive conclusion about how much pain broiler chickens experience as a result of lameness, but rather a starting point for discussion and the development of a logical approach to address this question. Accordingly, if the reader wants to change any of the assumptions regarding the duration and intensity of the pain depicted in any of the Pain-Tracks presented in this Chapter, an interactive web application can be used for this purpose, available at <https://pain-track.org/broilers>. In the application, changes in any of the parameters automatically update estimates of the times in pain calculated here.

To assess the welfare impact of lameness, we focus on the likely time spent in four categories of pain intensity as a result of (1) the physical pain associated with lameness and (2) the hunger and thirst that severely lame birds experience by not being able to reach feeders and drinkers as necessary. All experiences are referred to simply as ‘pain’, which in this framework is defined as ‘any felt negative affective state’ [49]. The fast-growing scenario is represented by the use of conventional fast-growing breeds with an average daily gain (ADG) of 61 g/day (i.e., intermediate to the national average in the US and the EU), slaughtered with 2.55 Kg at 42 days of age. The slower-growing scenario is represented by the use of a breed growing at an average ADG of 45-46 g/day, hence reaching the same slaughter weight in 56 days (Chapter 1).

Lameness is a symptom of multiple and diverse disorders, each of which may have different times of onset, patterns of clinical evolution, pain intensities and prevalence. Therefore, before proposing hypotheses for the duration and intensity of the pain associated with lameness, we review existing knowledge on the main causes of lameness in commercial broiler flocks, and the extent to which they can be associated with the different degrees of lameness in commercial farm settings.

II. Aetiologies of Lameness in Broilers

Lameness is a condition with multiple aetiologies, which can be either of infectious or noninfectious (developmental, degenerative, conformational) origin [8,50,51]. While infectious pathologies will often cause birds to become severely lame, noninfectious causes may affect a larger proportion of individuals, who will often be mildly to moderately disabled [52]. While the causes of lameness are multiple and diverse, bacterial chondronecrosis with osteomyelitis (BCO), tibial dyschondroplasia (TD), varus valgus disease (VVD) and contact dermatitis are documented as common disorders. They are briefly outlined next.

II. 1 Bacterial chondronecrosis with osteomyelitis (BCO)

Bacterial chondronecrosis with osteomyelitis (BCO), sometimes referred to as femoral head necrosis (FHN), is often recognized as the most common cause of lameness in broilers chickens [53,54]. BCO is the result of bacterial infection and necrosis of rapidly growing bones, typically the femora and [tibia](#), that are subjected to mechanical stress [23]. BCO can impair walking ability, cause pain, and also indicate subclinical infections and internal damage.

Several factors are associated with the development of this disease, including the presence of pathogenic bacteria, immunosuppression, fast growth resulting microfractures in the cartilage and bone that can be colonized by bacteria, vascular impairment within the epiphysis, trauma, nutritional deficiencies, and hatchery conditions [23,53]. In a recent study [53], growth plate cartilage abnormalities (a problem typically observed in fast growing breeds) were found to be strongly associated with the development of BCO, possibly by providing a suitable environment for bacterial colonization. A 2017 necropsy assessment of culled and dead birds from 20 commercial farms in Australia found BCO in 22% to 29% of culled/dead birds [53]. Assuming an average cumulative mortality of 5% [55], these prevalence rates translate into about 1.1 to 1.5% of birds in a flock affected by BCO. The latter figures are likely to be an underestimate of the true prevalence of the condition though, as they do not include birds affected by BCO that survive until slaughter

II. 2 Tibial dyschondroplasia (TD)

Tibial dyschondroplasia (TD) is a developmental disorder associated with fast growth. It is caused by inadequate vascularization and mineralization of the growth plate and bones, resulting in abnormal mass of cartilage in the proximal end of the tibia [46,56]. The extra cartilage in the tibia causes angular and rotational abnormalities in the leg and hip, changes in the gait of affected birds and even fractures. Age of onset has been reported to be between 18 and 34 days in fast-growing breeds [56].

Although TD is not a strong predictor of compromised walking ability [57,58], birds with TD generally have higher lameness scores, make less frequent use of behavioral opportunities such as dustbathing, and are more fearful than birds without the condition [59]. Two decades ago, TD was estimated to cause 5 to 25% of lameness [60], although in recent years its prevalence seems to have been reduced as a result of selective breeding [50]. As expected from its association with fast-growth, TD has been reported to be much less common, and less severe, in slower growing genotypes and laying hens [56,58,61].

II. 3 Angular (varus/valgus) disease

Varus/valgus disease (VVD, also known as valgus-varus angulation or ‘twisted legs’) is a deformity causing twisting of the legs (varus: inward twist, valgus: outward twist) as a result of overly-fast weight gain and nutritional deficiencies. Since the cortical bones of fast-growing breeds are highly porous, bone deformities become more likely [62]. Leg angulations can vary in severity, from a relatively mild (between 10-25°) to a tibia-metatarsus angle greater than 45°[62].

VVD has been considered the most significant developmental disorder of the skeleton in broilers [63] and most often occurs in both legs, although the right leg is more commonly affected when the defect is unilateral. Birds affected by VVD are at greater risk of developing a slipped tendon or leg fracture, due to the increased pressure on the deformed leg. Once this occurs, it will be physically impossible to get up and the bird may die of starvation or dehydration.

II. 4 Contact dermatitis

Contact dermatitis is a condition that affects the skin of body areas constantly in contact with wet and/or soiled litter, as moisture in the litter softens the skin surface and increases likelihood of breakdown of its outer barrier [64,65]. In broilers, contact dermatitis is commonly developed on the feet (footpad dermatitis, FPD), hock (hock burn, HB) and in severe cases the breast (breast blisters, BB)[66]. During the early stages of development, there may be a small and superficial lesion, rough abrasion, or mild discolouration of the foot. However, once the skin barrier is broken down, it provides a gateway for opportunistic bacterial infections [67–69]. If the foot is infected, birds will show slight behavioral changes (associated with onset of pain caused by the infection), and varying degrees of lameness [70–73].

If untreated, FPD compromises the internal tissues of the foot, such as the mesoderm, tendons and bones, potentially causing complications such as synovitis (inflammation of the connective tissue in the joint capsule), osteomyelitis (bone infection) [74] or even BCO (see previous section) [75]. Accordingly, lameness has been associated with FPD in some studies [73,76], though in other studies impaired walking ability could not be predicted by the FPD lesion score alone [77]. Recent studies across European countries have reported FPD prevalence values from 1% to 91% (mean 37%), and moderate/severe HB of 0% to 41% (mean 8%) [42].

III. Association between Aetiology, Walking Ability and Pain

The [Cumulative Pain Framework](#) quantifies the likely time spent in pain as a result of each of the many welfare challenges an individual may experience over a period of interest. To this end, it often identifies each of the conditions affecting individuals in a population, as well as their corresponding prevalence, duration and the intensity of the pain they cause.

The quantification of the pain caused by lameness could, in principle, be conducted by estimating how many birds are typically affected by each of the possible aetiologies in commercial broiler flocks, to then establish the clinical evolution of each aetiology and the corresponding intensity of the pain each aetiology may cause over time.

However, many are the factors that make such an approach unfeasible for quantifying the negative affective experiences of birds suffering from lameness. First, intense selection for fast growth has made modern broiler breeds fragile and prone to skeletal abnormalities and infectious challenges in multiple ways. Often, broiler chickens are affected simultaneously by many bone and soft tissue disorders, lesions and infections. The fact that many conditions may occur at the same time, even in seemingly healthy individuals with no gait abnormalities [78], makes it very challenging to isolate the effect of each specific leg disorder on pain. Further, there is little evidence that enables linking the severity of lameness with a certain pathology [50], as each of the different aetiologies of lameness may lead to a range of manifestations and outcomes. In general, correlations between walking impairment and leg pathologies tend to be weak [78]. Importantly, it has long been difficult to assess the frequency of different leg disorders [8] given their multifactorial nature, hence large variability among flocks and countries.

The difficulties associated with characterizing the typical prevalence of the different aetiologies of lameness can be understood through the following analogy. Consider, for example, the case of human respiratory infections at a global scale. The cause of infection in different individuals and populations will be, expectedly, highly heterogeneous, depending on the viruses circulating in different geographic locations and the immunological profile of the host populations (e.g., comorbidities, nutritional deficiencies, to cite a few factors). If we were to quantify the global burden of pain due to respiratory infections in humans, it would be extremely challenging to do it by determining the typical prevalence of each cause of infection, and then establishing the corresponding pain pattern in each case². A more practical approach is to classify individuals according to the severity of their symptoms, and then establish the burden of pain in each severity class. In this case, we could have, for example, the following classes: (i) mild respiratory symptoms, not preventing the accomplishment of the daily routine, (ii) moderate symptoms (e.g., accompanied by fever, throat ache or cough, tiredness), keeping individuals at home, (iii) symptoms of respiratory distress requiring hospitalization and (iv) symptoms requiring ICU care.

Here, we adopt a similar approach to examine the burden of pain associated with lameness in broiler chickens. Instead of investigating the pain possibly associated with each of the different causes of lameness, we examine the possible presence, duration and intensity of the pain associated with the severity of symptoms, as measured by the bird's walking ability (gait score). This approach also has the advantage of enabling a more accurate picture of the prevalence of individuals with different levels of lameness severity, since data on lameness at the farm setting are often based on the measurement of the prevalence of birds in different gait scores³.

Importantly, research on the extent to which lameness is painful in broilers has typically investigated pain relative to walking ability (gait score), as changes in gait and behavior are strategies typically used to reduce pain (by shifting the weight off affected limbs or restricting movement altogether). Therefore, although gait changes do not always indicate pain, with some birds experiencing a non-painful structural abnormality, existing evidence enables investigating the extent to which each gait score can be associated with different categories of pain intensity (or no pain). Since variation in the intensity and duration of pain in each gait score is expected, we incorporate uncertainty about the possible drivers of changes in gait score in each case in the hypotheses formulated (pain-tracks).

² For this reason, many conditions are classified based on a common set of symptoms instead of their underlying aetiology (e.g., 'influenza-like illness' is used to denote the onset of symptoms including fever, shivering, malaise, dry cough, body aches, and nausea, even if not caused by the influenza virus).

³ Although gait score attribution is not precise, the uncertainty in the typical prevalence of each severity category can be incorporated in the modeling process.

IV. Assessing the prevalence of different degrees of lameness

To estimate the prevalence of each gait score category, we searched the literature for data reporting the prevalence of birds in each of the gait score categories of the Bristol Gait Score System (BGSS) (GS0-GS5) at the end of the production cycle in commercial operations. To limit variability due to changes in gait scores over time [79], we considered only data from the year 2000 onwards.

The published data available is shown in Table 2, and includes data from nine countries, seven of which in Europe (Norway, Denmark, UK, the Netherlands, Sweden, Ireland and Italy), in addition to Brazil and New Zealand. Although information on lameness in commercial flocks is available for the US [80], a different gait scoring system was used, for which no quantitative correspondence with the Bristol Gait Score system can be reliably established.

Table 2. Observed prevalence (%) of fast-growing broiler chickens slaughtered at 5 or 6 weeks in each of the Bristol Gait Score system (BGSS, GS0-GS5), as measured in commercial farms from the year 2,000 onwards. Data sources are ordered by the estimated mid-year of data collection. N= Number of Flocks surveyed; Density: stocking density (Kg/m²); SEM: standard error of the mean. Data sources: **Sanotra**: [63]; **Berg**: [81]; **De Jong**: [82]; **Kittelsen**: [77]; **Granquist** [2]; **Tahamtani**: [58]; **Knowles**: [12,71]; **Webster**: [83]; **Tuytens** [84]; **Baxter** [85]. *: estimated from publication (Sanotra provides the proportion of GS4 and GS5 together, hence they were proportionally distributed based on the GS4:GS5 ratio observed in other studies). Means are weighted by the number of flocks observed in each study.

Source	Year	Country	N Flock	GS0	GS1	GS2	GS3	GS4	GS5	GS3+	Density
Slaughter: 5 wks											
Sanotra	2000	DK	28	25.4	20.8	24.0	24.2	5.0	0.6	29.8	41.0
de Jong	2009	UK	10	8.6	39.1	41.4	10.8	0.3	0.0	11.1	28.0
Kittelsen	2012	NO	59	4.8	31.4	39.0	22.7	2.0	0.2	24.9	36.0
Granquist	2015	NO	50	3	44	34	16	2	1	19	27
Tahamtani	2016	DK	32	22.6	41.1	30.8	4.7	0.6	0.1	5.4	40.0
Weighted mean				11.0	29.0	35.0	22.0	3.0	0.0	25.0	
SEM				4.7	4.2	3.1	3.7	0.8	0.2	4.4	
Slaughter: 6 wks											
Knowles	2004	UK	149	2.2	26.6	74.0	24.3	3.1	1.2	28.6	31.0
de Jong	2008	IT	18	0.8	11.2	57.5	25.2	4.2	1.2	30.6	13.0
de Jong	2008	NT	18	1	16	57	22	3	1	26	43
Webster	2011	NZ	20	0.0	5.8	74.4	19.0	0.6	0.2	19.8	
Tuytens	2011	BR	11	0.1	0.6	16.4	68.3	14.0	0.6	82.9	28
Baxter	2021	IR	2	16.0	55.0	26.0	1.0	1.0	0.0	2.0	
Weighted mean				2.0	22.0	68.0	26.0	4.0	1.0	30.0	30
SEM				2.6	8.0	10.0	9.1	2.0	0.2	11.1	

We calculated a pooled prevalence for each gait score using a weighted average, where weights corresponded to the number of flocks investigated by each data source. It is important to note, however,

that most flocks in the sample are from northern European countries, which are possibly not representative of the welfare standards in major chicken producing economies such as the United States, Brazil and China. Indeed, data from 11 randomly chosen farms in Brazil, shown in Table 2 (BR), point to a substantially higher proportion of lame birds, with an average proportion of birds unable to walk ($GS \geq 4$) of 14.6%. This is despite the fact that all Brazilian farms were regularly inspected for quality standards set by the integrator for export to the EU, and average stocking density was low (27.5 Kg/m^2) [84]. If the European countries studied do have better welfare conditions than what is typical for other countries, then the prevalence of lameness reported in the literature is likely to greatly underestimate the average prevalence of lameness at a global level.

As expected, gait scores for birds slaughtered at 6 weeks (hence with a heavier weight) are worse than for those slaughtered at 5 weeks. Since in this analysis our focus is on birds slaughtered at 6 weeks, we only use the prevalence data from the latter group. Table 2 also shows that lameness prevalence is very variable even in this small sample, reflecting flock differences in risk factors such as stocking density (which in this sample varied from 13 to 46 Kg/m^2), genetic strain, the birds' weight, year of data collection, different management practices, as well as measurement differences [86,87]. To take the wide variation in risk factors into account, we tentatively assume that the true average for commercial conditions will lie within 1.96 standard errors of the weighted average (i.e. that this calculated interval includes the true average - but not all data points - should commercial flocks from all countries be represented in the sample). Final estimates are shown in Figure 3. Considering the importance of lameness for the welfare of chickens, surveys on the prevalence of lameness in regions other than Europe, particularly in top chicken producing countries (e.g., US, China, Brazil, India, Mexico, Argentina), are very much needed.

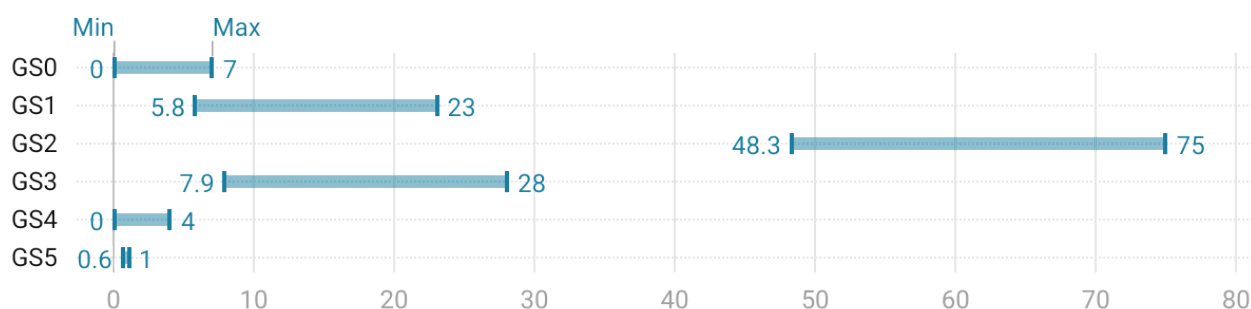


Figure 3. Estimated prevalence (%), by the end of production, of each of the Bristol Gait Score categories (GS0-GS5) in commercial fast-growing broilers kept until 6 weeks of age. Estimated from data in Table 2, considering an uncertainty range for the mean value within 1.96 SEM of the calculated weighted average (weight = number of flocks).

IV. 1 Accounting for on-farm culling

The reported prevalence figures are likely to underestimate the true prevalence of commercial birds affected by leg disorders for several reasons. First, assessments are conducted predominantly in commercial operations that agree to participate. Operations allowing visits are less likely to include situations of poor stockmanship and neglect [12], an effect we refer to as the 'healthy-farm effect'. Accordingly, total cumulative mortality typically reported in the literature by the end of production is lower than, for example, national averages in the United States [55]. Additionally, the prevalence of

severely lame birds may be low because they are culled if they are seen to exhibit high gait scores, or they may die from being unable to reach feeders and drinkers, or even from complications of the leg pathology, such as septicemia. Indeed, the diagnosis of BCO in birds that were culled or died is strongly associated with decreased body weight [53], indicating that severe lameness reduces food and water intake.

Ignoring culls and deaths will result in an underestimated prevalence of birds with severe gait scores. For instance, in Australia, 22 to 29% of culls were diagnosed with BCO [53]. In an earlier study involving 114 flocks in the United Kingdom, leg culls represented 29% of all bird culls [44]. And in more recent trials, lameness accounted for 24% of all deaths and culls [6]. Likewise, KFC's Welfare Outcome Performance Report in 2020 pointed to 21.5% of mortality being attributed to leg culls [88]. We consider the reported range of mortality attributable to severe lameness (~20 to 30%), and make the uncertainty range 5% wider (15 to 35%) given the reduced number of published reports. This is most likely to include only birds with gait scores 4 and 5. Using the National Chicken Council estimate of approximately 5% mortality for 2021 flocks [55], and considering an uncertainty range for total mortality between 2.5 to 7.5% (i.e. within 50% of the reported 5% average), this results in a prevalence of culled birds within 0.6 to 2.2%, which we equally distribute in gait scores GS4 and GS5.

IV. 2 Prevalence of lameness in slower growing genotypes

As reviewed in the Introduction and illustrated in Figure 1, the risk and severity of lameness is strongly linked with fast growth rates. Research has shown that the prevalence of lameness is substantially lower in slower growing genotypes: for example, a large-scale study from 2001 found that traditional and slower growing genotypes tended to have fewer lame birds than modern genotypes reared on the same feeding regimen [11]. In this study, the mean gait score of traditional breeds at 81 days was extremely low (approximately 0.1), indicating excellent walking ability. For the slower-growing genotypes, mean gait score at 81 days was 1.81, also indicative of good leg health at the flock level, compared to a score of 3.02 in modern genotypes (unfortunately, disaggregated data on the percentage of birds in each gait score was not available).

Likewise, a fast-growing Ross strain, with an average daily weight gain (ADG) greater than 60g/day, was shown to have a significantly poorer walking ability with greater percentage of leg culls than the slower-growing Rowan Ranger [89]: at 6 weeks, the percentage of birds with GS2-5 in the fast- and slower-growing breeds was, respectively, 8.8% and 0.3% (nearly 30 times more frequent in fast-growing strains), reaching 85% and 26.9% (SE=2.11, 23-31%) at 9 weeks [89]. In a case study of a commercial farm under the RSPCA Freedom Food program using the slower-growing strain Hubbard JA757 (observed ADG: 43-45 g/d), no moderate or severe case of lameness were reported by 7 weeks of age [90]. And in a large survey of organically reared Hubbard JA757 and CYJA57, the proportion of GS2-5 birds by the end of production (9 weeks) was only 9.8% [58].

Mobility is, accordingly, improved in slower-growing strains, which have been shown to perch, walk, and ground scratch more frequently [91], as well as perform a greater variety of behaviors [92]. In a large experimental trial, 16 broiler genotypes grouped into four growth rate categories (conventional, fastest slow, moderate slow and slowest slow) were tested in two experimental paradigms: the latency to lie (LTL) test (which measures how long the bird can stand before sitting in water, an aversive experience) and the group obstacle test (which evaluates the bird's ability or motivation to cross a physical barrier to gain access to feed and water) [93]. Overall, the slowest growing birds had the longest LTL times and higher number of obstacle crossings, suggesting important improvements in functional leg strength.

Two studies from 2020 compared gait scores between fast- and slower-growing commercial strains raised under similar conditions [6,43], finding substantially higher percentages of individuals with moderate and severe lameness in faster-growing genotypes. In one of these studies [6], a slower-growing breed (Hubbard JA 757, ADG: 46g/d) was compared against three fast-growing strains (Cobb500, JA308 and Hubbard Flex, ADG: 63g/d). The prevalence of fast-growing birds with GS3 to GS5 (GS3+) was within the range expected for fast-growing strains in commercial conditions (Table 1 and Figure 3: ~15% to 45%), ranging from approximately 27% to 39% [6]. This indicates that the experimental conditions were not artificially better (or worse) than those experienced at the farm level with regard to risk factors for lameness. In the second study [43], the authors compared one fast-growing (ADG: 58g/d) with three slower-growing breeds (SG₁: 44 g/d, SG₂₋₃: 47 g/d). Fast-growing birds had substantially worse (higher) gait scores. Among the slower-growing breeds, those with even a slightly lower growth rate had less leg culls (SG₁: 0.49%, SG₂₋₃: 0.62%-0.78%), postmortem rejections (SG₁: 0.14, SG₂₋₃: 0.45-0.6%), and birds with a GS_≥3 (SG₁: 0.5%, SG₂₋₃: 2.5-3.5%).

To our knowledge, there is no published data on the proportion of birds in each of the gait score categories for slower-growing breeds, growing at approximately 45-46 g/day, under commercial conditions. The only data available, disaggregated by gait score, is from the two experimental trials previously described. Their results are described in Table 3. We use these data to estimate the possible range of proportions representative of commercial conditions (Figure 4). Since only the results of Dixon [6] are available for birds grown up to 8 weeks of age, we assume that the average for commercial conditions will lie within up to $\pm 80\%$ of this observed value. We use a large coefficient of variation to determine the uncertainty range given the paucity of data - surveys of slower-growing flocks kept on commercial conditions are critically needed.

Table 3. Average prevalence (%) of slower-growing broiler breeds in each of the Bristol Gait Score categories (GS1-GS5), as reported in two recent experimental trials. Dixon: [6], Rayner: [43]. For Rayner, data were obtained from charts with WebPlotDigitizer (<https://automeris.io/WebPlotDigitizer>). GS4 and GS5 scores were estimated from the proportion of leg culls (distributed between the GS4 and GS5 using the same GS4:GS5 ratio as that typical in fast-growing strains; Table 1).

Source	Growth (g/d)	Weeks	GS0	GS1	GS2	GS3	GS4	GS5
Rayner	44	7	13.9	63.1	22.5	0.7	0.45	0.04
Rayner	47	7	5.7	51.0	40.9	2.6	0.71	0.07
Rayner	47	7	6.1	52.9	37.5	3.5	0.56	0.06
Dixon	46	7	18.5	46.3	31.3	3.8	0.91	0.09
Dixon	46	8	7.4	33.5	41.8	17.3	0.91	0.09

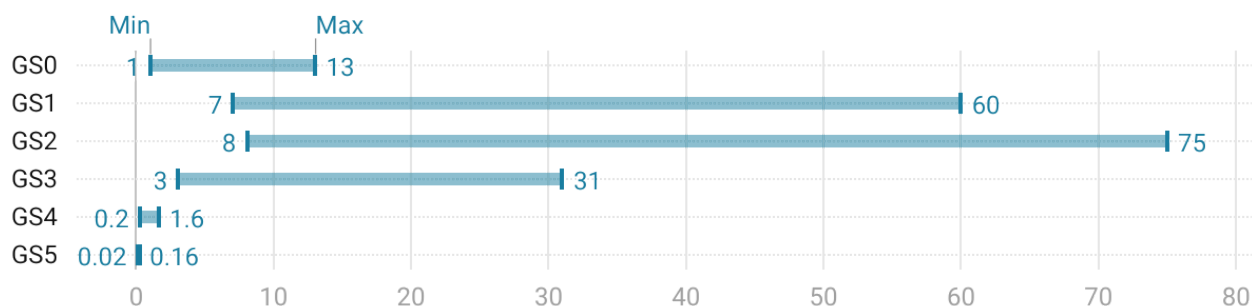


Figure 4. Estimated prevalence (%), by the end of production, of birds with each gait score in slower-growing broilers kept until 8 weeks. Estimated from data in Dixon 2020 ($\pm 80\%$ of observed value in week 8), Table 3.

V. Pain Intensity in Each Gait Score

In this section we examine neurophysiological, behavioral and pharmacological evidence of pain in lame chickens to estimate the extent to which the different gait scores may be associated with pain of different intensities. As described more thoroughly elsewhere [49], each intensity category is defined by specific criteria (Box 1), relating to the disruptive character of the pain experience: from a minimally disrupting (Annoying) to a tormenting state (Excruciating).

In assessing pain in non-verbal subjects, uncertainty in the classification of pain intensity is often present. Therefore, instead of classifying the intensity of a painful experience into a single category, we use existing evidence to inform the probability that the pain belongs to each intensity category: the greater the strength of the evidence that pain matches the criteria defining a certain category, the greater the probability attributed to that category. The attribution of probabilities to intensity categories is also helpful in that it enables accounting for the possible heterogeneity in the experiences of pain, from a single cause, in a population. GS3 gait scores may result from a number of different causes, each possibly associated with a different intensity of pain. In this sense, probabilities can be used to reflect the estimated proportion of the GS3 population that experiences pain at each of the four intensity levels. Although estimates are always open to revision as knowledge advances, this process reduces uncertainty and channels debate productively into more explicit boundaries about the levels of pain experienced.

Box 1 Definition of Pain Intensity Categories

Annoying: experiences of pain perceived as aversive, but not intense enough to disrupt the animal's routine in a way that alters adaptive functioning or affects the behaviors that animals are motivated to perform. Similarly, Annoying pain should not deter individuals from enjoying pleasant experiences with no short-term function (e.g., play) and positive social interactions. Sufferers can ignore this sensation most of the time. Performance of cognitive tasks demanding attention are either not affected or only mildly affected. Physiological departures from expected baseline values are not expected to be present. Vocalizations and other overt expressions of pain should not be observed.

Hurtful: experiences in this category disrupt the ability of individuals to function optimally. Different from Annoying pain, the ability to draw attention away from the sensation of pain is reduced: awareness of pain is likely to be present most of the time, interspersed by brief periods during which pain can be ignored depending on the level of distraction provided by other activities. Individuals can still conduct routine activities that are important in the short-term (e.g., eating, foraging) and perform cognitively demanding tasks, but an impairment in their ability or motivation to do so is likely to be observed. Although animals may still engage in behaviors they are strongly motivated to perform (i.e., exploratory, comfort, sexual, and maintenance behaviors), their frequency or duration is likely to be reduced. Engagement in positive activities with no immediate benefits (e.g., play in piglets, dustbathing in chickens) is not expected. Reduced alertness and inattention to ongoing stimuli may be present. The effect of (effective) drugs (e.g., analgesics if pain is physical, psychotropic drugs in the case of psychological pain) in the alleviation of symptoms is expected.

Disabling: pain at this level takes priority over most bids for behavioral execution, and prevents all forms of enjoyment or positive welfare. Pain is continuously distressing. Individuals affected by harms in this category often change their activity levels drastically (the degree of disruption in the ability of an organism to function optimally should not be confused with the overt expression of pain behaviors, which is less likely in prey species). Inattention and unresponsiveness to milder forms of pain or other ongoing stimuli and surroundings is likely to be observed. Relief often requires higher drug dosages or more powerful drugs. The term Disabling refers to the disability caused by 'pain', not to any structural disability.

Excruciating: all conditions and events associated with extreme levels of pain that are not normally tolerated even if only for a few seconds. In humans, it would mark the threshold of pain under which many people choose to take their life rather than endure the pain. This is the case, for example, of scalding and severe burning events. Behavioral patterns associated with experiences in this category may include loud screaming, involuntary shaking, extreme muscle tension or extreme restlessness. Another criterion is the manifestation of behaviors that individuals would strongly refrain from displaying under normal circumstances, as they threaten body integrity (e.g., running into hazardous areas or exposing oneself to sources of danger, such as predators, as a result of pain or of attempts to alleviate it). The attribution of conditions to this level must therefore be done cautiously. Concealment of pain is not possible.

As reviewed in sections II and III, gait impairment can have several causes, of both infectious and non-infectious origin. In general, the evidence clearly shows that changes in gait score resulting from inflammation are painful. For example, experimental studies have shown the sensitization of nociceptors in the ankle and hock joints of chickens following natural or induced inflammation [94–99], providing direct neural evidence of pain. In these experiments, nociceptive sensitization was also accompanied by typical pain-coping behaviors (one-legged standing, sitting) and severe lameness. In addition to inflammation caused by infection or trauma, conditions resulting in a deformity can produce abnormal strain on tendons and muscles, also leading to inflammation and pain [100]. Moreover, several nociceptive fibers were identified by mechanical stimulation in the skeletal muscle of the chicken leg [101], indicating that pain may be present as a result of skeletal deformities, even in the absence of inflammation.

Accordingly, behavioral observations of lame broilers (particularly $GS \geq 2$) have shown that they spend more time sitting and less time walking, preening, dustbathing, or visiting the feeder, a potential coping strategy to reduce pain [59,102]. Similarly, in a kinematic analysis of gait abnormalities, the authors suggest that the slower walking velocity of lame birds ($GS3$) may be an attempt to minimize discomfort [18]. Similarly, in a study where half of the body weight of lame broilers was alleviated using a suspended harness, locomotor activity (distance traveled) increased [103]. Altogether, these observations suggest a level of disruption compatible with the definition of the Hurtful category of intensity (Box 1).

The painful nature of gait abnormalities was also examined by testing the walking ability of lame broilers following the administration of non-steroidal anti-inflammatory drugs (NSAIDs), known for their anti-inflammatory and analgesic effect. In an early study, the authors observed a dose-dependent improvement in gait score during a self-selection feed trial involving the use of carprofen, a drug routinely used for treatment of musculoskeletal pain [5]. Carprofen has also been shown to increase the walking speed of lame birds (GS3) to the point of no difference between the time they took to complete an obstacle course and that taken by sound (GS0) birds [104]. Significant increases in walking speed following NSAID treatment (carprofen and meloxicam) were also documented in naturally lame (GS ≥ 3) broilers [105]. Similarly, the latency to lie (LTL) in a shallow water bath (an aversive stimulus) also increased in lame birds (GS3-4) following NSAID treatment [106]. In this case, gait score was a more effective predictor of LTL than body mass, which the authors interpreted as indicating that LTL was more directly related to the sensation of discomfort produced by lameness than the effect of fatigue linked to heavy weight [106]. Once more, the observed effect of the analgesic drugs is compatible with at least the Hurtful category of intensity for GS3 birds.

Still, other studies failed to corroborate evidence that GS3 broilers would self-select NSAID-treated food or have their walking ability improved by these treatments [4,107]. These findings indicate that, for some individuals, changes in gait patterns may be influenced primarily by changes in body conformation or non-painful pathologies that compromise walking ability [3,108,109]. Therefore, the possibility of ‘no-pain’ cannot be completely ruled out, even for GS3 birds.

Next we discuss and summarize the extent to which the pain experienced by birds in each gait score is consistent with each intensity category.

GS1 and GS2: although most experiments discussed previously focused on broilers with GS ≥ 3 , a recent investigation by Riber and colleagues (2021) showed that behaviors involving greater physical exertion (standing while feeding, perching, comfort behaviors) were performed less frequently by GS2 than GS1 and GS0 birds [110]. More interestingly, for some of these behaviors, administration of carprofen led to behavioral changes suggesting that all birds tested (GS0, GS1 and GS2) may have been limited by pain [110]. This level of disruption suggests that the intensity of the pain is compatible with the Hurtful category of pain. However, further observations have shown that, although GS2 birds took a longer time to reach the end of a runway than GS0 and GS1 birds, administration of carprofen did not change this pattern [111]. Similarly, there was no effect of gait score or carprofen in a conditioned place preference paradigm, failing to confirm that the differences in locomotor ability were associated with pain [111]. Based on the latter findings, we conservatively assume that pain intensity in GS2 birds is more likely (60%) to be in the Annoying (or no pain) categories. Given the lack of knowledge to distribute the probability between these two categories, we assume maximum uncertainty and distribute them equally. The remaining 40% is attributed to the Hurtful category, the least intense category for which the effect of analgesics is expected, as observed by Riber and colleagues. For birds with GS1, we assume the maximum experienced intensity is Annoying, but give the same weight to the possibility of no pain.

	GS1
Excruciating	
Disabling	
Hurtful	
Annoying	50%
No Pain	50%

	GS2
Excruciating	
Disabling	
Hurtful	40%
Annoying	30%
No Pain	30%

GS3: the pharmacological and behavioral evidence previously reviewed point to the intensity of the pain associated with GS3 being compatible predominantly with the Hurtful category of intensity. However, considering the failure of some studies to corroborate evidence that GS3 broilers self-select NSAID-treated food, we cannot rule out the possibility of no pain or only mild pain. We therefore assume that the likelihood of Hurtful pain may range from 60 to 80%, hence we adopt a point estimate of 70%. Because a Disabling intensity cannot be ruled out either, the remaining 30% probability is equally distributed between the No Pain, Annoying intensity and Disabling intensity (i.e., we consider that evidence is not sufficient to enable us to give more weight to any of these possibilities). These probabilities may be also interpreted as the proportion of the time spent in pain of different intensities by GS3 individuals.

	GS3
Excruciating	
Disabling	10%
Hurtful	70%
Annoying	10%
No Pain	10%

GS4 and GS5: it is generally accepted that individuals with major gait impairment (GS4) or incapable of walking (GS5) are in substantial pain [41], enough to prevent the animal from feeding and drinking as required (GS4) or entirely (GS5). GS4 and GS5 are more likely to be associated with infectious conditions than other gait scores, which are often accompanied by severe inflammation [8] and limited ability to function [112]. To our knowledge, however, systematic data on the prevalence of infectious lameness in different gait scores is not yet available. Müller and collaborators [113] also observed that severely lame birds (GS4-5) had lower weight and a greater relative adrenal mass than broilers with no or mild gait abnormalities, indicating increased adrenal activity and evidence of inflammatory processes as a consequence of chronic stress. Given the severe disruption of behavior in GS4 and GS5 birds, we assume that in both cases pain intensity is more likely to be of a Disabling⁴ nature. For GS5 birds, who cannot even walk, pain is expected to be predominantly Disabling, preventing nearly all forms of normal behavior. For GS4 birds, a lower likelihood of Disabling pain is attributed since some normal behavior is still possible. We conservatively assume that Excruciating pain (an extreme level of pain, Box 1) is not present for birds due to lameness-causing conditions in any gait score.

	GS4
Excruciating	

⁴ The term Disabling refers to a severe compromise in the ability to behave normally as caused by 'pain', not by any structural disability.



VI. Time spent in each gait score state

Given the multifactorial nature of lameness and the multiplicity of pathologies associated with gait abnormalities, it is currently not possible to accurately establish the typical time individuals will spend in a specific gait score over the production cycle. While some individuals may be affected by gait changes as a result of acute conditions of very rapid progression, others conditions may impair walking ability more gradually. The onset of visible gait impairments can also be highly variable.

Here, we try to encompass these uncertainties into estimates of the time that broilers spend in each gait score. To this end, we assume that (1) individuals experiencing more severe levels of lameness will have experienced prior levels of severity before, even if only briefly (that is, individuals at GS3 will have experienced GS2 and GS1, individuals at GS2 will have experienced GS1, and so on) and (2) the progression of lameness severity over time can follow a wide range of patterns, from an acute and rapid development, to a more gradual and slow progression.

In Figure 5 we illustrate these assumptions by considering the temporal progression of lameness in fast-growing birds that reach slaughter age (42 days) with **GS3**. The gray area in the figure represents the wide estimated uncertainty interval for the onset and pattern of disease progression. The gray area is estimated, given the lack of published data on the timing of lameness onset. For example, for birds with GS3 at slaughter, the onset of GS1 under this hypothetical scenario is likely between 6 and 17 days of age (blue lines), the onset of GS2 between 8 and 23 days (green lines) and the onset of GS3 between 10 and 31 days (orange lines). This translates into the following times spent in each gait score: 11 to 31 days in a GS3 state, 2 to 7 days in a GS2 state, and 2 to 7 days in a GS1 state. Although values outside the grey area are expected, the intervals portrayed represent the usual time a fast-growing broiler likely spends in each gait score. Naturally, this is a simplifying assumption that should be refined as knowledge advances. Considering the large impact that lameness has on the welfare of broilers, further research in this area is critically needed.

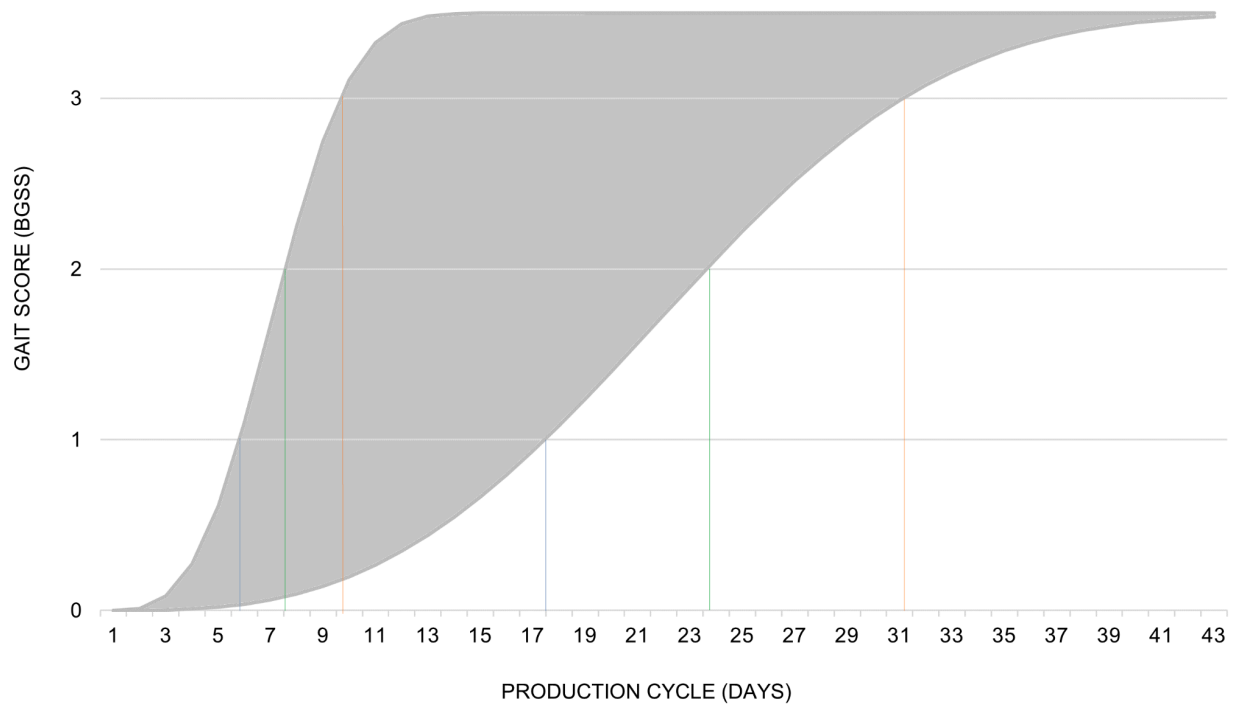


Figure 5. Model of possible patterns of lameness progression over the production cycle for birds that reach slaughter age with GS3. The model shows patterns ranging from an acute and rapid progression (upper limit) to a gradually developing gait abnormality (lower limit). In both limits, we assume a sigmoid pattern of progression, as is typical of many diseases. Blue, green and orange lines: onset of GS1, GS2 and GS3, respectively. Maximum and minimum onset values represent the estimated typical interval of onset experienced by broilers in each gait score (individual values outside this range are thus possible).

The times spent in each gait score, as determined in Figure 5, are then used to fill in the duration values in Pain-Track 1 (bottom rows). The duration of the time spent in each gait score excludes the estimated time spent sleeping. Although information on the extent to which birds experience pain while sleeping is lacking, to err on the side of caution and avoid inflating the estimated times in pain, we conservatively assume that no pain is felt when individuals are asleep (justification for the estimates of the time that broiler chickens spend sleeping are provided in Chapter 1).

Pain-Track 1 depicts the hypothesis for the temporal evolution of the pain endured by broiler chickens that reach slaughter age with GS3. The probabilities attributed to each intensity category are those determined and justified in section V. Total time in pain (hours) is the sum of the time in pain at each intensity in each of the segments of the Pain-Tracks (in this case, the sum of the time in pain in segments GS1+GS2+GS3). For a detailed review of the method, see Alonso & Schuck-Paim [49] and the Appendix.

Pain-Track 1. Hypothesis for the temporal evolution of the pain endured by fast-growing broiler chickens that reach slaughter (42 days) with GS3. (a) time in GS1 until onset of GS2; (b) time in GS2 until onset of GS3, (c) time in GS3 until slaughter. Estimated sleeping time: 4 to 10 h/day. The table on the right shows the estimated time in pain (hours) as a result of lameness endured by an individual that reaches the slaughter age with GS3.

	GS1	GS2	GS3		TOTAL TIME IN PAIN (h)
Excruating				Excruating	
Disabling			10%	Disabling	40 [18-62]
Hurtful		40%	70%	Hurtful	320 [170-470]
Annoying	50%	30%	10%	Annoying	110 [68-150]
No Pain	50%	30%	10%		

Onset	6 - 17 d	8 - 24 d	10 - 31 d
Duration in days	2 - 7 (a)	2 - 7 (b)	11 - 32 (c)
Duration - SLEEP (h)	28 - 140	28 - 140	154 - 640

The above Pain-Track is, naturally, specific to fast-growing individuals that reach the slaughter age with GS3. Fast-growing individuals reaching slaughter age with other gait scores have obviously very different experiences: a bird with GS4 at slaughter will have a different experience in terms of pain intensity and duration than one that reaches slaughter with, say, GS2 or GS3. Therefore, a specific Pain-Track is needed to depict the experience of fast-growing individuals reaching slaughter with each gait score. Another set of Pain-Tracks is needed for slower-growing birds reaching slaughter with each gait score. The duration of the experience in fast- and slower-growing birds is likely different, given their longer lifespan and the possibility that the onset of lameness is later.

In Appendix B we apply the same rationale used for the development of Pain-Track 1 to fast- and slower-growing birds reaching slaughter with each of the possible gait scores. In each case, the estimated progression of lameness until slaughter is determined similarly to the model shown in Figure 5, only adjusting the gait score at slaughter as required. In all cases, the justification for the pain intensity is that given in section V.

For GS4 and GS5 birds, however, more than one Pain-Track must be developed. This is because the lifespan of these birds may be shortened by culling or by their natural death prior to slaughter given their compromised ability to reach feed and water, affecting the duration of the pain experience. We consider two scenarios in each case. In the first, birds are not culled and may reach the slaughter age or die from dehydration (the most limiting resource). In the second scenario, birds are culled before slaughter. In both scenarios, the cumulative time in pain is the result of the pain from lameness as well as the pain from thirst and hunger. The impact of hunger and thirst on GS4 and GS5 birds and their likely survival rates is discussed in Appendix A.

VII. The burden of pain from lameness in fast- and slower-growing broilers

In this section we summarize the burden of pain endured by fast- and slower-growing broilers as a result of lameness based on the estimated times in pain described in the Pain-Tracks (Pain-Track 1 and Pain-Tracks S2-S10).

Figure 6 describes the duration of pain experienced by an individual who reaches the slaughter age in each of the gait scores for the two scenarios analyzed. In all cases, no pain is assumed to occur during sleep. In the case of GS4 and GS5 birds, the pain experienced is the sum of the physical pain from the leg disorder and the pain endured as a result of thirst and hunger (Appendix A). Uncertainty ranges incorporate the expected variability in the progression of lameness over time (Figures 5 and Figures S2-S10), in the underlying pathologies, as well as uncertainty regarding the intensity of pain at each point in time (section V). However, if the reader wants to change any of the assumptions regarding the duration and intensity of the pain depicted in any of the Pain-Tracks, an interactive web application can be used for this purpose, available at <https://pain-track.org/broilers>. In the web application, changes in any of the parameters automatically update estimates of the times in pain.

Overall, severely lame birds ($\geq$ GS4) are estimated to spend a substantial time in Disabling and Hurtful pain, both as a result of the pain associated with lameness and hunger (thirst is less likely to reach a Disabling intensity; see Appendix A). The main exception is in the case of birds that are culled once becoming unable to move, in which case the estimated time in Disabling pain is shorter.

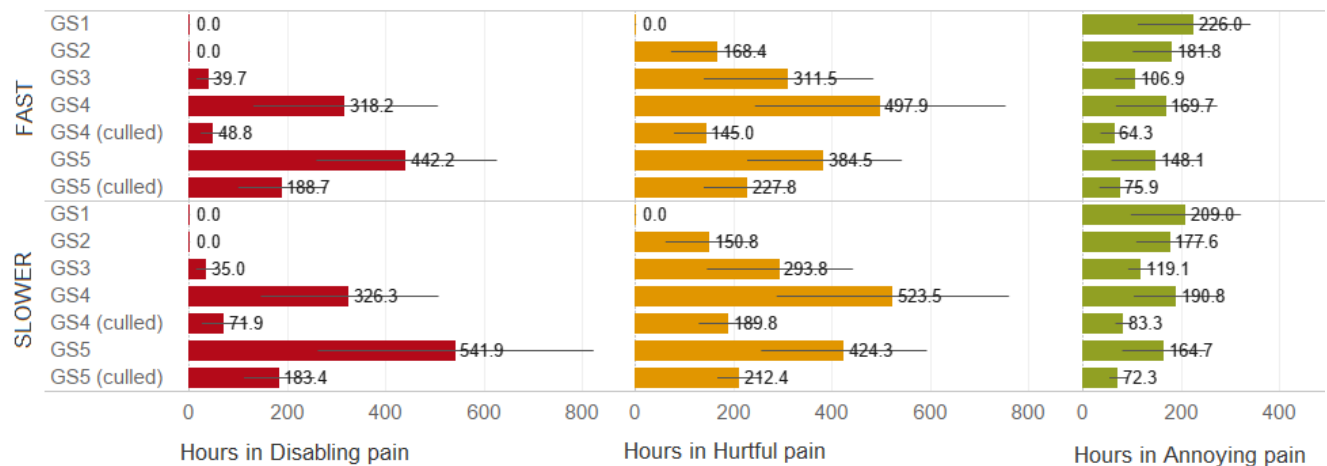


Figure 6. Estimated time (hours) endured at each level of pain intensity by broilers with different gait scores (GS1-GS5) at slaughter. FAST: fast-growing birds slaughtered in 42 days. SLOWER: slower-growing birds slaughtered at 56 days. Error bars represent 90% uncertainty ranges.

These estimates are conservative, in that they do not take into account other indirect consequences of lameness. For example, birds with severe lameness may also be exposed to systemic bacterial infection. Dehydration is also known to cause a number of lesions and ulcerations in the gizzard mucosa, which may provide another port of entry for infections [114]. Therefore, some of these birds may become septic, a condition associated with extreme levels of pain [115]. Likewise, severe gait impairment (GS4) or the complete inability to move (GS5) may also be associated with the frustration to perform highly motivated

behaviors. Pain may disrupt sleep, causing higher gait score birds to experience their pain for a greater number of hours awake. The pain resulting from infectious diseases and behavioral deprivation is analyzed separately in other chapters of this book, but it is important to note that the reduction of severely lame birds from a population would likely translate into a reduction of the time in Disabling pain greater than that estimated in this chapter.

Figure 7 shows the total time endured at each level of pain intensity by an “average” population member (as defined in Box 2). In this case, the times in pain at each intensity level endured by birds in each gait score are summed across all gait scores, after being weighted by the prevalence of each gait score (section IV) in the population. The results show the estimated time in each level of pain as a result of lameness (pain from all gait scores). Times are shorter than those shown in Figure 6, since most birds in a flock are estimated to have no or only mild lameness ($GS \leq 2$, section IV), and a relatively small proportion of individuals reaches gait scores GS4 and GS5.

Box 2 Time in Pain endured by the Average Population Member

Although pain inherently concerns individuals, we operationally accept that the collective welfare of the members of a population can also be determined. Measuring cumulative pain at the population level is also necessary to account for the heterogeneity in the exposure of population members to different challenges. For example, while lameness is experienced by a large fraction of broiler chickens, events such as fatal cases of ascites are only experienced by a few individuals.

Therefore, measurement efforts must consider the prevalence of each welfare challenge, so that pain is determined for the average member of the population (which may not necessarily correspond to any real organism). At the population level, the time spent at each level of pain intensity as a result of each challenge is determined by multiplying it by its prevalence. For example, if a condition causes 10 hours of Disabling pain and 70% of the population are affected, then the average member of this population could be said to experience 7 hours of Disabling pain due to the condition. Measurements at the population level enable comparing the impact of different practices and conditions across demographics, geographies and time.

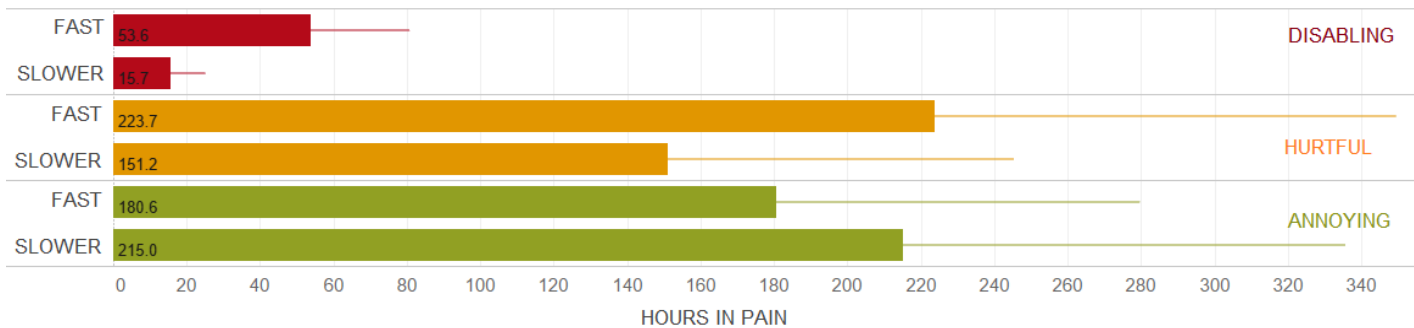


Figure 7. Total time endured at each level of pain intensity (hours) by an “average” broiler chicken (Box 2) as a result of lameness (sum of times in pain at each intensity spent by birds in each gait score, weighted by the estimated prevalence of each gait score in the population). Error bars represent 90% uncertainty ranges.

As shown in Figure 7, estimates are highly variable. This variability results from the uncertainty about the pathologies underlying gait abnormalities, those associated with disease progression, intensity of pain and the wide variation in the prevalence in the different gait scores.

The results show that, on average, approximately 38 hours of Disabling pain⁵ endured by an 'average' broiler (Box 2) as a result of lameness could be averted through the substitution of fast- by slower-growing breeds growing to 56 days, despite their longer lifetime . As discussed, this is because, using our estimates, most slower-growing birds do not become severely affected and so on average endure shorter accumulated pain times.

It is important to emphasize that the benefits of slower growing strains are more strongly determined by their genetics than by the reduced stocking density that can be associated with the production of alternative breeds. For example, although in Norway the mean slaughter weight is low (1.2 kg) and the maximum allowed animal density is relatively low (36 kg/m²) [77], moderately and severely lame birds are still observed in Norwegian flocks in relatively high numbers (Table 2). This is consistent with the conclusion of the European Food Safety Agency, that animal husbandry options to prevent the negative side effects of genetic selection for fast growth are limited [116].

Finally, it is important to note that the present analysis is focused on alternative broiler breeds with only a slightly lower growth rate (ADG=44-47 g/day), grown up to 8 weeks. Should breeds with lower growth rates be used (e.g., ADG ≤ 42 g/day), such as those typically used in free-range and organic production, the prevalence of lameness would be expected to decrease even further, reducing the time in pain despite their typically longer life spans (9-12 weeks). For example, the prevalence of gait scores GS2-5 in the slower-growing Rowan Range (ADG=38-42g/day [117]) at 9 weeks of age was 26.9% [89], less than the very conservative estimate of 30-89% used here. Similarly, in organically reared Hubbard JA757 and CYJA57, the proportion of GS2-5 birds by the end of production was only 9.8% [58]. This suggests that the present results are likely to reflect the minimum benefits achieved, in terms of time in pain due to lameness, by the use of slower-growing birds. Further reductions in growth rate should result in a greater reduction in the time spent in pain, despite the longer life of these individuals. Surveys reporting the prevalence of slower-growing birds in different gait scores in commercial conditions are very much needed.

VIII. Research Gaps and Opportunities

1. Considering the importance of lameness for the welfare of chickens, surveys on the prevalence of lameness in regions other than Europe, particularly in top chicken producing countries (e.g., US, China, Brazil, India, Mexico, Argentina), are very much needed. Studies should strive to describe disaggregated data on the prevalence of birds within different gait scores, as opposed to calculated scores only.

⁵ (53.6 - 15.7 hours), see Fig.7

2. No published data is available on the proportion of birds in each gait score for slower-growing breeds growing at <50g/day in commercial conditions. The only data available, disaggregated by gait score, is from experimental trials. Surveys of flocks kept in commercial conditions are critically needed.
3. To our knowledge, there is no published data on the progression of lameness in broiler chickens over time, either in commercial or experimental settings. Longitudinal studies are needed to establish possible patterns of disease progression for birds that end up reaching the end of the production cycle with different gait scores. This knowledge is critical to establish more accurately the time that broilers affected by lameness spend in pain.
4. Data is very scarce on the onset of lameness in slower-growing breeds of broilers. Knowledge is not yet available on the extent to which the onset of lameness changes for birds with different growth rates.
5. The impact of lameness on the welfare of broiler chickens depends to a great extent on how long severely lame birds (BGSS GS4 and GS5) spend in this condition. Little information is available on the extent to which leg culling is implemented in the industry, or how long these birds spend in this condition before being culled or dying.
6. Further research is needed on the extent to which behavioral differences are present in birds with different gait scores, especially dustbathing and performance of cognitive tasks, which would help you establish the intensity of the pain endured by birds in each gait score category.

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Appendix A. SURVIVAL, HUNGER AND THIRST IN GS4 AND GS5 BIRDS

Gait scores 4 and 5 define those individuals that are severely impaired in their walking ability (GS4) or incapable of locomotion (GS5). Individuals in these categories may not live to slaughter age, given reduced (GS4) or complete cessation (GS5) of feed and water intake.

Impact of Pain from Thirst in birds with gait scores GS4 and GS5

To understand survival rates in GS4 and GS5 birds, we must examine how long they can survive with limited or no access to the most biologically limiting resource: water. Although a 2020 veterinary textbook suggests that poultry can survive up to five days without water [118], direct evidence from case studies and water deprivation trials conducted in the 1960's suggest that survival times may be much longer [52,119]. In a case study of commercial fast-growing broilers grown to 84 days [52], the average plasma osmolality (an indicator of dehydration) of randomly chosen birds was 375 mOsmol/kg (s.e.=8.7) in GS4 and GS5 birds and 339 mOsmol/kg (s.e.=8.7) in GS2 and GS3 birds. Based on the authors' regression relating osmolality with time of water deprivation, GS4 and GS5 birds had been, on average, unable to drink for more than 5 days, with some individuals with osmolality levels corresponding to 7 days without water. Considering the reported mortality of 5% per day, and that GS4 and GS5 birds comprised 65% of that flock, it is likely that these individuals would survive for many more days. Consistent with this, in an old trial involving extreme feed and water deprivation in broiler chickens aged 0, 1, 4 and 8 weeks⁶ [119], average survival times were, respectively, 5, 7, 16 and 23 days. Still, in commercial conditions, particularly at high stocking densities, temperature and humidity, survival times could be shorter. Therefore, we tentatively estimate that the cessation of food and water intake may take anything from 5 to 25 days to kill a broiler. The interval proposed is purportedly wide to accommodate heterogeneity among individuals in terms of age, size and walking ability, all of which affect the likelihood of survival from dehydration.

The effects of dehydration are often studied based on the percentage of body mass loss, as it will largely determine clinical symptoms. In Figure S1 we plot the observed percentages of body mass loss as a function of feed and water deprivation times in 8-week-old broiler chickens [119]. These times are used as a basis to determine the duration of each stage of dehydration in the Pain-Tracks.

⁶ Such a trial would not be allowed nowadays for ethical considerations.

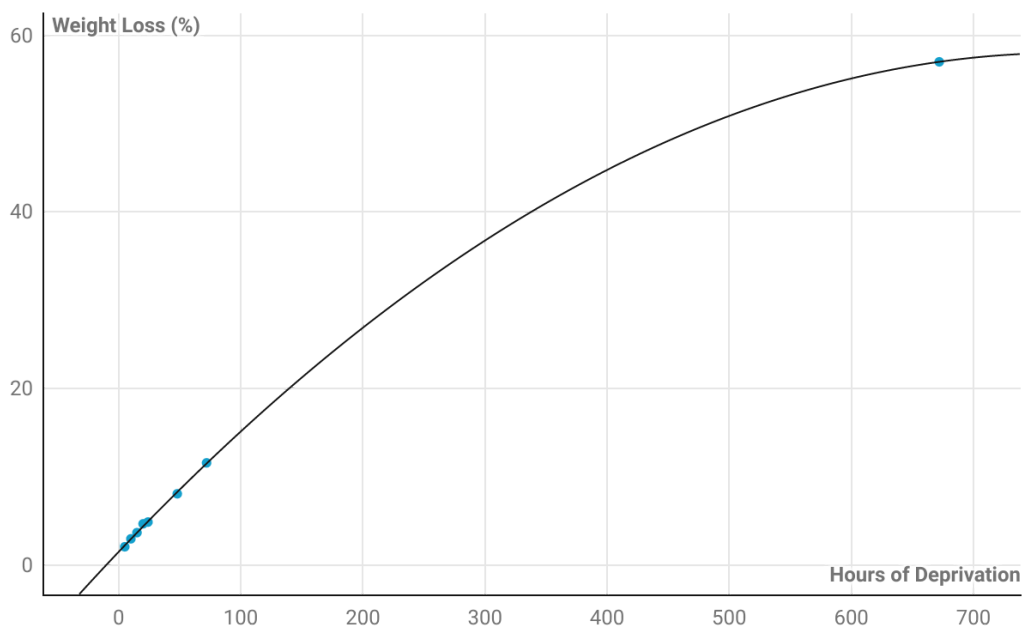


Figure S1. Weight loss (%) as a function of time of feed and water deprivation in broiler chickens aged 8 weeks and kept at 27 °C (source: [119]).

Dehydration often becomes noticeable after 1-2% of loss of water volume. With mild dehydration subjects experience thirst and discomfort, an adaptive mechanism to ensure they seek and consume water [120]. Water is possibly the most critical of all survival needs. As with food, attending to this drive should take precedence over other motivations, as failure to do so can severely impair biological functioning. Thus, we find it unlikely that after some hours of deprivation this is a sensation that can be classified into the Annoying category (i.e. be easily ignored, Box 1). Indeed, the demand for water is inelastic in most species [121]. In laying hens, two hours of water deprivation leads to frustration-induced aggression towards a subordinate hen [122]. In humans, symptoms can include loss of appetite, elevated body temperatures and fatigue. Therefore, in Pain-Track S1 we distribute the likelihood of pain between the Annoying and Hurtful intensity categories over the course of the first 24 hours of deprivation. This would correspond to a situation where the first 12 hours thirst is predominantly of an Annoying nature, and the next 12 hours of a predominantly Hurtful nature.

Symptoms become increasingly severe with greater water loss [123]. With over 5% water loss, human patients can become sleepy, experience nausea, and may feel tingling in their limbs. In birds, the stress of going without water might also trigger a molt. In an experiment involving water deprivation in White Leghorn hens, changes in the electrocardiogram (particularly tachycardia) started 24 hours after the onset of water deprivation [124]. Temperature also dropped and blood cholesterol significantly increased. The amplitudes of the ECG components continued to increase daily as weight loss and dehydration became more intense. Therefore, in segment II of Pain-Track S1 (5-10% water loss) we attribute a high probability to the Hurtful category, but do not rule out the possibility that for some individuals (estimated at 20%) thirst may already reach the Disabling level.

If greater than 10% of body weight is lost in water in humans, cardiac output is diminished, and oxygen delivery to the tissues falls [125]. Some authors have suggested that most birds would require veterinary care when reaching 10% weight loss due to dehydration [126]. When this increases to 10% to 15%, muscle cramps may be experienced, vision can be compromised and urination is reduced and may become painful. Studies report that 40% of humans experience muscle cramps following dehydration, which are considered to have pain intensity between moderate and severe [127]. We estimate that when dehydration surpasses 10% of body weight lost in water (segment III of Pain-Track S1), the likelihood of Disabling pain increases to 50%.

Although there have been suggestions that a loss of between 15-25% of the body water in mammals and birds [123,128] would be lethal, earlier experiments with chickens report higher figures. For example, a 45% loss of body water prior to death due to water deprivation has been reported in birds from 8 to 18 weeks of age [129]. Likewise, in trials with chickens (0 to 8 weeks of age) deprived of feed and water, a maximum weight loss of 57% prior to death was observed [119] (Fig.S1). Evidence of the pathophysiology of extreme dehydration in humans suggest, however, that pain intensity may in fact subside in this last stage. In rats, dehydration has been shown to cause a significant decrease in pain perception, probably as a consequence of alterations in the metabolism of dopamine and serotonin [130]. Pain and discomfort can be also moderated by the accumulation of ketones in the body, as the body uses fat instead of carbohydrates to satisfy its energy needs. This process generates a form of self-sedation, the causes of which are still unknown but may be related to the metabolism of central neurotransmitters [131]. In segment IV (>15% mass loss) we therefore assume no Disabling pain, and distribute the likelihood of pain among the Annoying (40%), Hurtful (40%) and 'no pain' (20%) categories.

Pain-Track S1. Hypothesis for the temporal evolution of the pain from thirst, an aversive (negatively valenced) state that signals the need for water as a function of mass loss from dehydration. Estimated sleeping time: 4 to 10 hours/day.

	I. <5% mass loss	II. 5-10% mass loss	III. 10-15% mass loss	IV. >15% mass loss
Excruating				
Disabling		20%	50%	
Hurtful	50%	80%	50%	40%
Annoying	50%			40%

Timeline	0-24 h	24-72 h	72-100 h	100-600 h
Duration (h)	24h	48 h	28 h	1-500 h
Duration - SLEEP (h)	14-20	28-40	18-24	294-420

Impact of Pain from Hunger in birds with gait scores GS4 and GS5

The motivation to seek food and eat is ubiquitous in the natural world, and one of the most powerful drivers of animal behavior [132]. As we discuss in Chapter 6, chronic feed restriction in broiler breeders is associated with multiple symptoms indicative of distress, including significant changes in blood heterophil

to lymphocyte ratios, plasma circulating corticosterone, ghrelin, serotonin, dopamine, brain heat shock protein levels, and changes in the production of new neurons in the hippocampus [133][134][135]. The greater the severity of feed restriction, the more substantial the changes.

Behavioral symptoms of frustration due to hunger are also widely documented, with the time spent in locomotor, foraging and pecking activities increasing substantially with the severity of feed restriction [133]. Feed-restricted breeder birds also forgo important activities such as resting, preening and comfort behaviors [133], and are willing to expose themselves to otherwise highly aversive stimuli to gain access to a foraging opportunity, even in the absence of actual food rewards, suggesting that food is not ‘out of sight, out of mind’ [136]. Increased levels of aggression and abnormal sexual behavior are also widespread [137]. Compensatory feed intake has also been shown to be linearly associated with the level of feed restriction [138]. Interestingly, in an experiment with Ross breeders [139], hens sitting firmly in a nest to lay an egg left the nest on nearly all occasions when feed was concurrently delivered, indicating that the motivation to feed was higher than the motivation to use a nest (a highly valued resource).

These findings indicate the highly distressful nature of hunger in broiler chickens. GS4 and GS5 birds are considerably lighter, and likely experience feed restriction levels that are at least as severe as those experienced by broiler breeders. Here we assume that GS4 birds experience the same level of hunger as broiler breeders during mid-rearing (who consume 45-60% of the ad libitum feed intake), and that GS5 birds will be at least as hungry as breeders during early-rearing (when feed intake can be only 25% of ad libitum intake). The detailed justification for the distribution of probabilities is provided in Chapter 6.

	GS4		GS5
Excruciating	0%	Excruciating	0%
Disabling	40%	Disabling	60%
Hurtful	55%	Hurtful	40%
Annoying	5%	Annoying	0%
Duration - SLEEP (h)	14-18 h		14-18 h

Culling Practices

GS4 and GS5 birds may be culled. The time for the identification of severely lame birds, followed by their culling, depends on each farm’s management practices and the quality of stockmanship, and may be highly variable. Since no data is available on the average length of time these individuals spend in this condition before being culled, we tentatively estimate that culling, when it is practiced, occurs 1 to 5 days after birds become severely compromised in their walking ability. Readers are encouraged to contribute with data that enables refining this estimate.

Appendix B. PAIN-TRACKS

Fast-growing birds reaching slaughter age with GS1

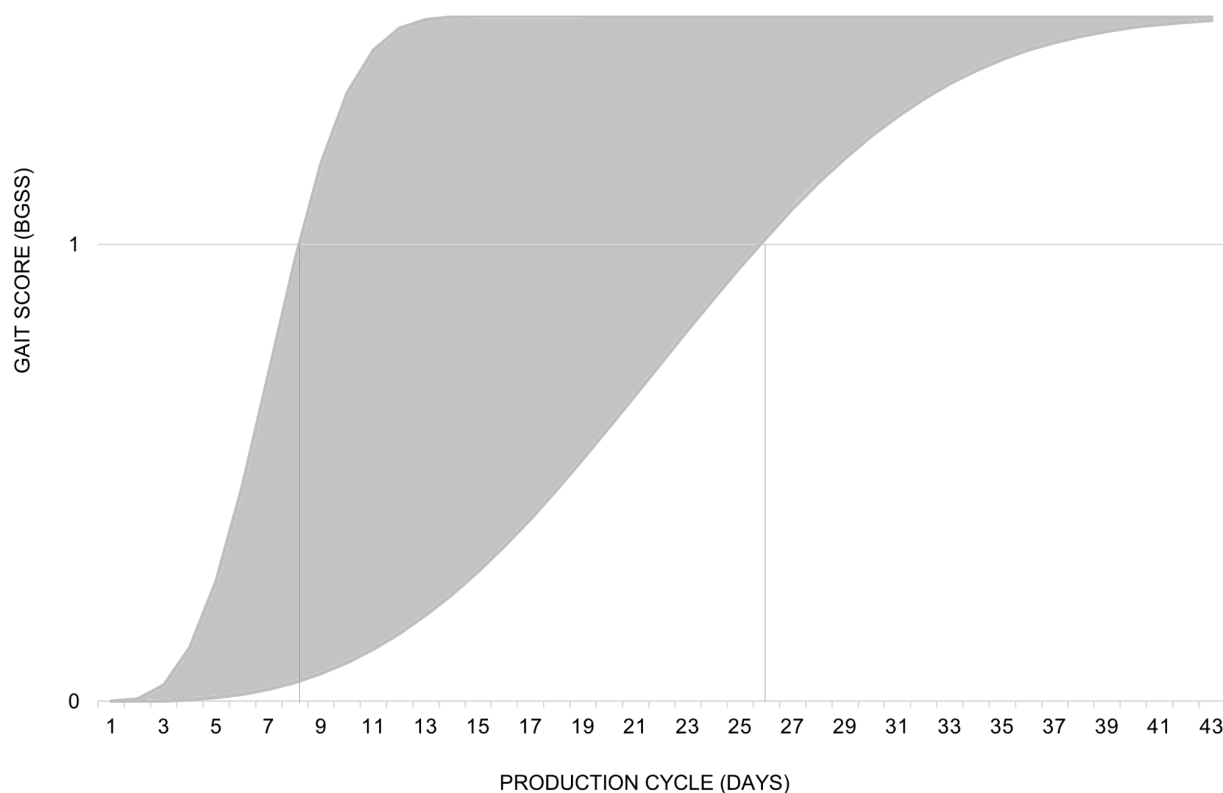


Figure S2. Model of possible patterns of lameness progression over the production cycle for birds that reach the slaughter age with **GS1**, ranging from an acute and rapid progression (upper limit) to a gradually developing gait abnormality (lower limit). Maximum and minimum onset values (blue) represent the estimated typical interval of onset experienced by broilers in GS1.

Pain-Track S2. Hypothesis for the temporal evolution of the pain endured by broiler chickens that reach the slaughter age at **42 days** with GS1. Ages of onset (A) are determined based on the model shown in Figure S2. (a) time in GS1 until slaughter at 42 days. Estimated sleeping time: 4-10 hours/day. Table on the right: time in pain by affected individuals.

	GS1		TOTAL TIME IN PAIN (h)
Excruciating		Excruciating	
Disabling		Disabling	
Hurtful		Hurtful	
Annoying	50%	Annoying	230 [120-330]
No Pain	50%		
Onset (A)	8 - 26 d		
Duration in days (B)	16 - 34 (a)		
Duration - SLEEP (h)	224 - 680		

Fast-growing birds reaching slaughter age with GS2

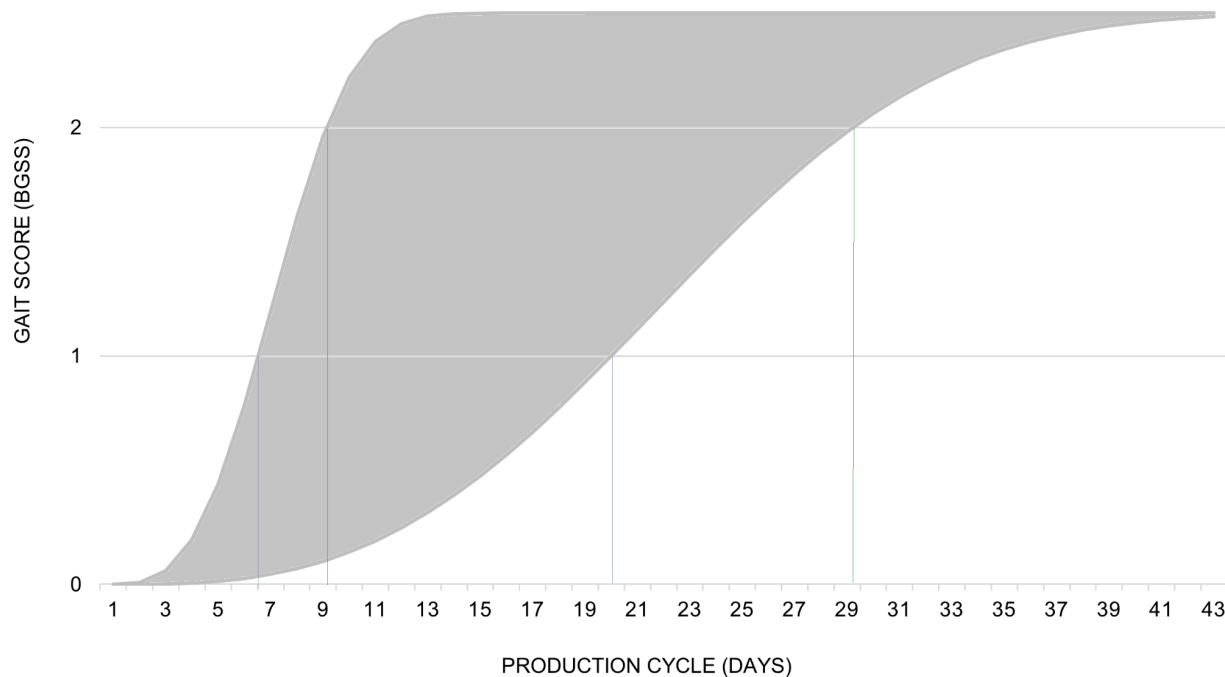


Figure S3. Model of possible patterns of lameness progression over the production cycle for birds that reach slaughter with **GS2**, ranging from an acute and rapid progression (upper limit) to a gradually developing gait abnormality (lower limit). Maximum and minimum onset values (blue and green lines) represent the estimated typical interval of onset experienced by broilers in GS1 and GS2 (hence individual values outside this range are also possible).

Pain-Track S3. Hypothesis for the temporal evolution of the pain endured by broiler chickens that reach slaughter age (**42 days**) with GS2. Ages of onset (A) are determined based on the model shown in Figure S3. (a) time in GS1 until onset of GS2; (b) time in GS2 until slaughter at **42 days**. Estimated sleeping time: 4-10 hours/day. Table on the right: time endured in pain (hours) by one affected individual.

	GS1	GS2		TOTAL TIME IN PAIN (h)
Excruciating			Excruciating	
Disabling			Disabling	
Hurtful		40%	Hurtful	180 [92-260]
Annoying	50%	30%	Annoying	180 [110-260]
No Pain	50%	30%		
Onset (A)	6 - 20 d	9 - 29 d		
Duration in days (B)	3 - 9 (a)	13 - 33 (b)		
Duration- SLEEP (h)	42-180	182 - 660		

Fast-growing GS4 birds

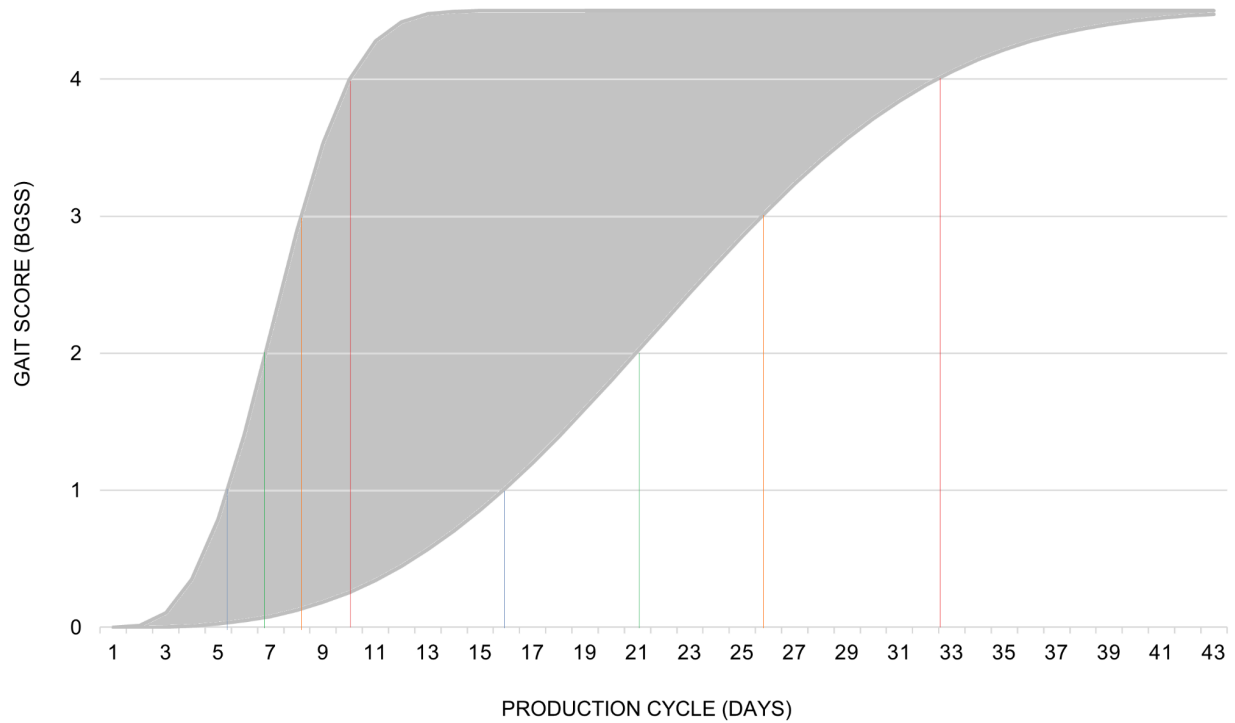


Figure S4. Model of possible patterns of lameness progression (grey area) over the production cycle for birds that reach slaughter with GS4, ranging from an acute and rapid progression (upper limit) to a gradually developing gait abnormality (lower limit). Blue, green, orange and red lines: onset of GS1, GS2, GS3 and GS4, respectively. Maximum and minimum onset values represent the estimated typical interval of onset experienced by broilers in each gait score (hence individual values outside this range are also possible).

Pain-Track S4. Hypothesis for the temporal evolution of the pain endured by broilers that reach slaughter with GS4. Ages of onset (A) are determined based on the model shown in Figure S4. (a): GS1 to GS2, (b): GS2 to GS3, (c) GS3 to GS4, (d): GS4 to 42 days. Estimated sleeping time: 4-10 hours/day. The table on the right shows the time endured in pain (hours) by one affected individual.

PAIN LAMENESS	GS1	GS2	GS3	GS4	TIME IN PAIN
Excruating					
Disabling			10%	60%	180 [88-280]
Hurtful		40%	70%	40%	200 [130-290]
Annoying	50%	30%	10%		54 [29-79]
No Pain	50%	30%	10%		

Onset	6 - 16 d	7 - 21 d	8 - 26 d	10 - 33 d
Duration in days	1 - 5 (a)	1 - 5 (b)	2 - 7 (c)	8 - 24* (d)
Duration - SLEEP (h)	14 - 100	14 - 100	28 - 140	112 - 480

PAIN THIRST	GS1	GS2	GS3	GS4				TIME IN PAIN
				<5% loss	5-10% loss	10-15%	>15% loss	
Excruating								
Disabling					20%	50%		14 [11-17]
Hurtful				50%	80%	50%	40%	130 [74-200]
Annoying				50%			40%	100 [40-160]

Duration - SLEEP	14 - 20	28 - 40	8 - 20	62 - 400
Duration in days			8 - 24*	

PAIN HUNGER	GS1	GS2	GS3	GS4	TIME IN PAIN
Excruating				0%	
Disabling				40%	120 [51-190]
Hurtful				55%	160 [71-250]
Annoying				5%	15 [6-23]

Duration - SLEEP (h)	112 - 480
Duration in days	8 - 24*

Pain-Track S4 - culling. Hypothesis for the temporal evolution of the pain endured by broilers that are **culled** with GS4. Ages of onset (A) are determined based on the model shown in Figure S4. (a): GS1 to GS2, (b): GS2 to GS3, (c) GS3 to GS4, (d): GS4 to 42 days (estimated time to culling since onset of GS4: 1-5 days). Estimated sleeping time: 4 to 10 hours/day. The table on the right shows the time endured in pain (hours) by one affected individual.

LAMENESS	GS1	GS2	GS3	GS4	TIME IN PAIN
Excruiating					
Disabling			10%	60%	29 [17-42]
Hurtful		40%	70%	40%	100 [62-140]
Annoying	50%	30%	10%		54 [30-78]
No Pain	50%	30%	10%		

Onset	6 - 16	7 - 21	8 - 26	10 - 33
Duration in days	1 - 5 (a)	1 - 5 (b)	2 - 7 (c)	1-5
Duration - SLEEP (h)	14 - 100	14 - 100	28 - 140	14 - 100

THIRST	GS1	GS2	GS3	GS4	TIME IN PAIN
				<5% loss	5-10% loss
Excruiating					
Disabling					20%
Hurtful				50%	80%
Annoying				50%	

Duration - SLEEP	14 - 20	14 - 40
Duration in days	2-3*	

HUNGER	GS1	GS2	GS3	GS4	TIME IN PAIN
Excruiating				0%	
Disabling				40%	14 [11-17]
Hurtful				55%	19 [9-30]
Annoying				5%	2 [1-3]

Duration - SLEEP (h)	14-100
Duration in days	1-5

Fast-growing GS5 birds

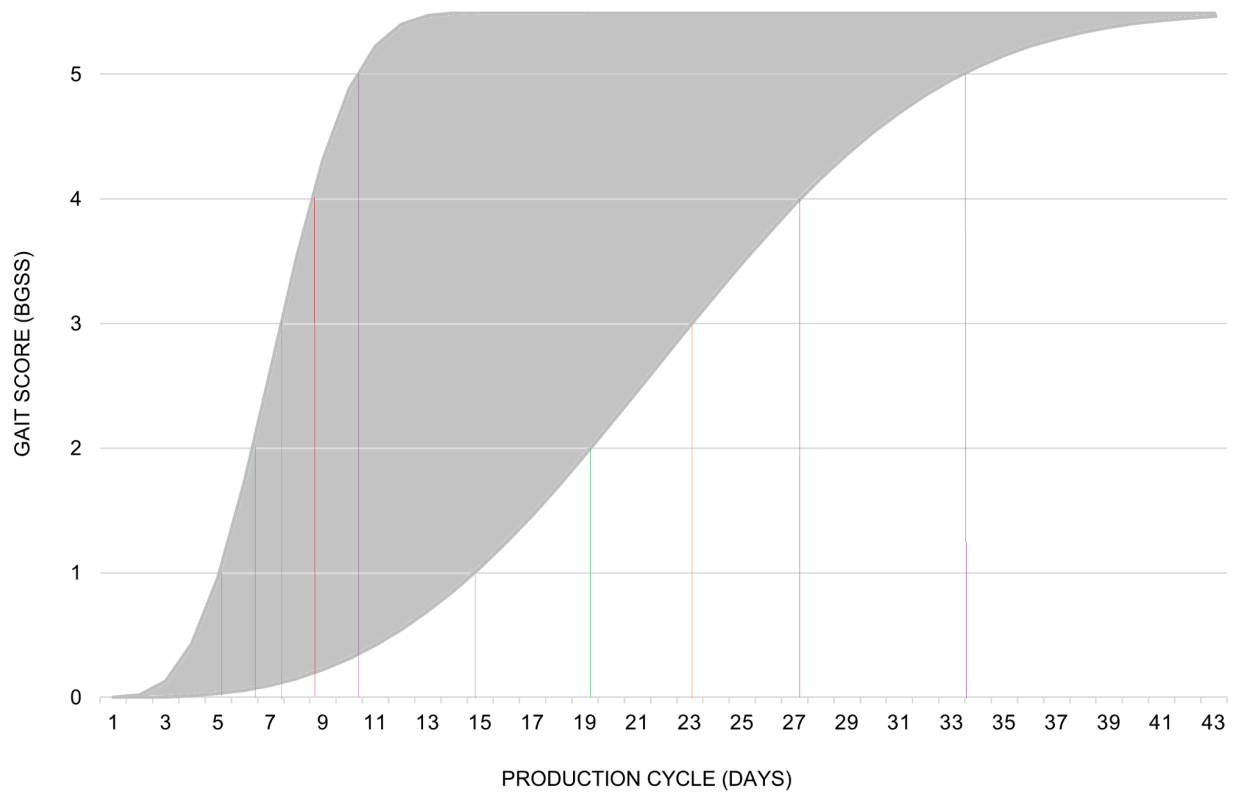


Figure S5. Model of possible patterns of lameness progression over the production cycle for birds that reach slaughter with GS5, ranging from an acute and rapid progression (upper limit) to a gradually developing gait abnormality (lower limit). Blue, green, orange, red and purple lines: onset of GS1, GS2, GS3, GS4 and GS5, respectively. Maximum and minimum onset values represent the estimated typical interval of onset experienced by broilers in each gait score (hence individual values outside this range are also possible).

Pain-Track S5. Hypothesis for the temporal evolution of the pain endured by broilers that reach the slaughter age (**42 days**) with GS5. Ages of onset (A) are determined based on the model shown in Figure S5. (a): GS1 to GS2, (b): GS2 to GS3, (c) GS3 to GS4, (d): GS4 to **42 days**. Estimated sleeping time: 4 to 10 hours/day. The table on the right shows the time endured in pain (hours) by one affected individual.

PAIN LAMENESS	GS1	GS2	GS3	GS4	GS5	TIME IN PAIN
Excruciating						
Disabling			10%	60%	90%	260 [160-360]
Hurtful		40%	70%	40%	10%	120 [85-150]
Annoying	50%	30%	10%			43 [25-62]
No Pain	50%	30%	10%			
Onset	5 - 15 d	6-19 d	7-23 d	9-27	11-34	
Duration in days	1 - 4 (a)	1 - 4 (b)	2 - 4 (c)	2- 7 (d)	8-17(e)	
Duration - SLEEP (h)	14 - 80	14 - 80	28 - 80	28- 140	112-340	

PAIN THIRST	GS1	GS2	GS3	GS4	GS4, GS5	TIME IN PAIN		
				<5% loss	5-10% loss	10-15%	>15% loss	
Excruciating								
Disabling					20%	50%		14 [11-17]
Hurtful				50%	80%	50%	40%	140 [75-200]
Annoying				50%			40%	100 [41-160]
Duration - SLEEP				14 - 20	28 - 40	8 - 20	62 - 400	
Duration in days		4-12			10 - 24*			

PAIN HUNGER	GS1	GS2	GS3	GS4	GS5	TIME IN PAIN
Excruciating				0%	0%	
Disabling				40%	60%	170 [100-230]
Hurtful				55%	40%	140 [83-190]
Annoying				5%	0%	4 [2-7]
Duration - SLEEP (h)				28-140	112-340	
Duration in days				2-7	8-17	

Pain-Track S5 (culling). Hypothesis for the temporal evolution of the pain endured by broilers that are **culled** GS5. Ages of onset (A) are determined based on the model shown in Figure S5. (a): GS1 to GS2, (b): GS2 to GS3, (c) GS3 to GS4, (d): GS4 to GS5, (e) GS5 to culling, estimated at 1-5 days after GS5 onset. Estimated sleeping time: 4 to 10 hours/day. The table on the right shows the time endured in pain (hours) by one affected individual.

PAIN LAMENESS	GS1	GS2	GS3	GS4	GS5	TIME IN PAIN
Excruating						
Disabling			10%	60%	90%	110 [56-160]
Hurtful		40%	70%	40%	10%	100 [69-130]
Annoying	50%	30%	10%			59 [38-80]
No Pain	50%	30%	10%			

Onset	5 - 15 d	6-19 d	7-23 d	9-27	11-34
Duration in days	1 - 4 (a)	1 - 4 (b)	2 - 4 (c)	2- 7 (d)	1-5 (e)
Duration - SLEEP (h)	14 - 80	14 - 80	28 - 80	28- 140	14-100

PAIN THIRST	GS1	GS2	GS3	GS4		GS5	TIME IN PAIN
				<5% loss	5-10% loss	10-15%	
Excruiating							
Disabling					20%	50%	14 [11-17]
Hurtful				50%	80%	50%	63 [45-81]
Annoying				50%			29 [11-46]

Duration - SLEEP	14 - 20	28 - 40	8 - 20	1 - 80
Duration in days	2-7 days	1-5 days		

PAIN HUNGER	GS1	GS2	GS3	GS4	GS5	TIME IN PAIN
Excruating				0%	0%	
Disabling				40%	60%	68 [69-99]
Hurtful				55%	40%	69 [36-100]
Annoying				5%	0%	4 [2-7]

Duration - SLEEP (h)	28-140	14-100
Duration in days	2-7	1-5

Slower-growing birds reaching the slaughter age with GS1

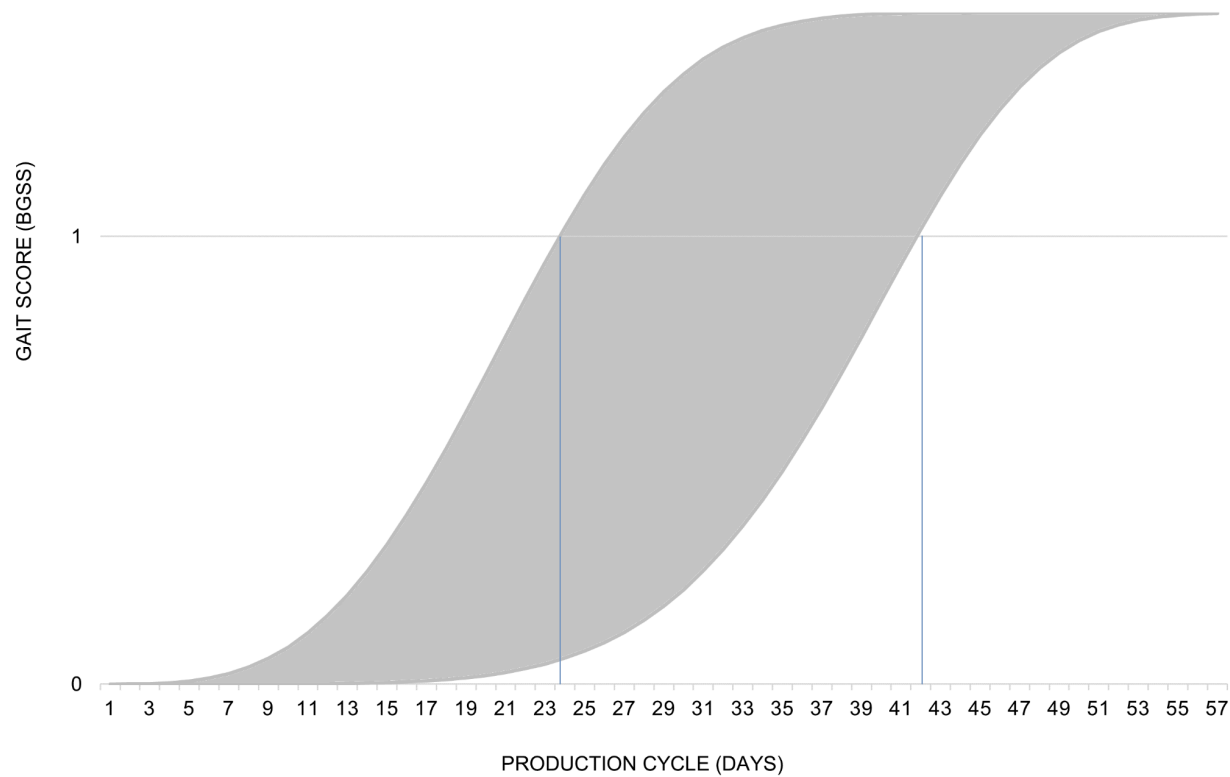


Figure S6. Model of possible patterns of lameness progression over the production cycle for slower-growing birds that reach slaughter with GS1, ranging from an acute and rapid progression (upper limit) to a gradually developing gait abnormality (lower limit). Blue lines: onset of GS1. Maximum and minimum onset values represent the estimated typical interval of onset experienced by broilers in each gait score (hence individual values outside this range are also possible).

Pain-Track S6. Hypothesis for the temporal evolution of the pain endured by slower-growing broiler chickens that reach the slaughter age (**56 days**) with GS1. Ages of onset (A) are determined based on the model shown in Figure S6. (a) time in GS1 until slaughter at 56 days. Estimated sleeping time: 4 -10 h/day. The table on the right shows the time endured in pain -by one affected individual.

	GS1		TOTAL TIME IN PAIN
Excruciating		Excruciating	
Disabling		Disabling	
Hurtful		Hurtful	
Annoying	50%	Annoying	210 [110-310]
No Pain	50%		

Onset (A)	24 - 42 d
Duration in days (B)	14 - 32 (a)
Duration - SLEEP (h)	196 - 640

Slower-growing birds reaching the slaughter age with GS2

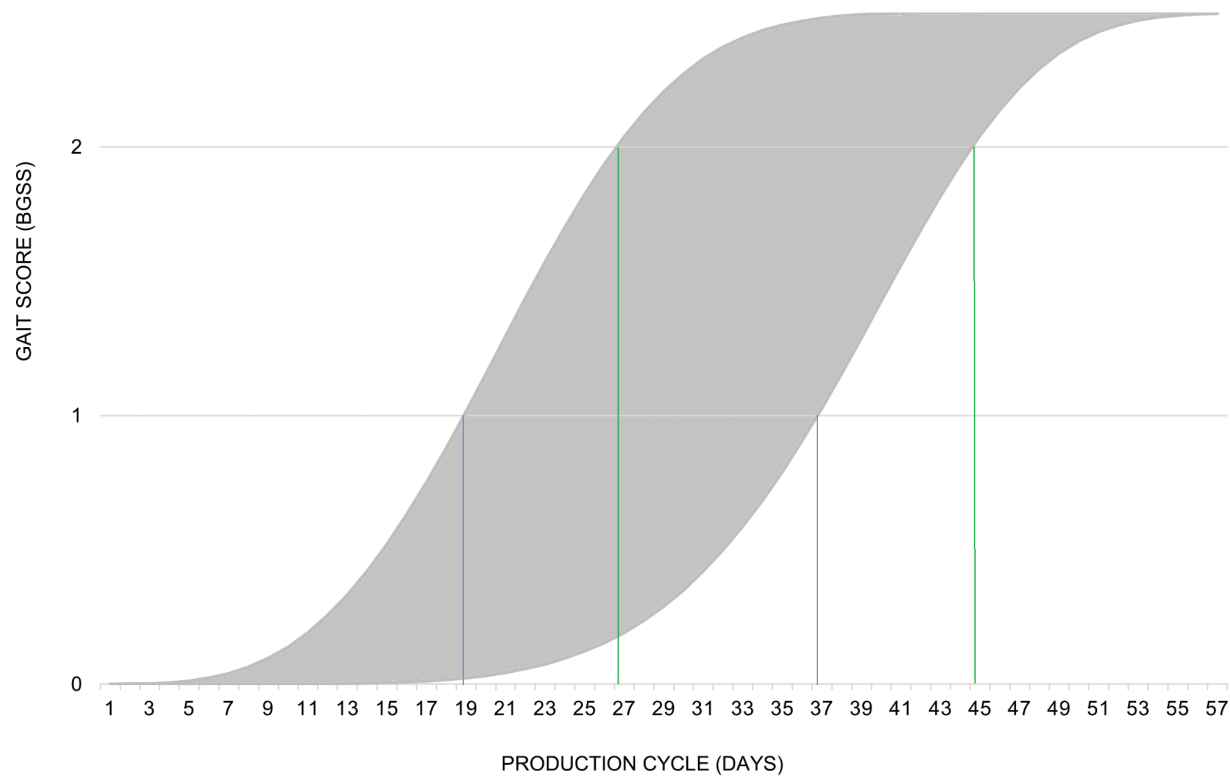


Figure S7. Model of possible patterns of lameness progression over the production cycle for slower-growing birds that reach slaughter with GS2, ranging from an acute and rapid progression to a gradually developing gait abnormality. Blue and green lines: onset of GS1 and GS2, respectively. Maximum and minimum onset values represent the estimated typical interval of onset experienced by broilers in each gait score (hence individual values outside this range are also possible).

Pain-Track S7. Hypothesis for the temporal evolution of the pain endured by slower-growing broiler chickens that reach the slaughter age (56 days) with GS2. Ages of onset (A) are determined based on the model shown in Figure S7. (a) time in GS1 until onset of GS2; (b) time in GS2 until slaughter at 56 days. Estimated sleeping time: 4 to 10 h/day. The table on the right shows the time endured in pain (hours) by one affected individual.

	GS1	GS2		TOTAL TIME IN PAIN
Excruciating			Excruciating	
Disabling			Disabling	
Hurtful		40%	Hurtful	164 [83-240]
Annoying	50%	30%	Annoying	178 [110-240]
No Pain	50%	30%		
Onset (A)	19 - 37 d	26 - 45 d		
Duration in days (B)	7 - 8 (a)	11 - 30 (b)		
Duration- SLEEP (h)	98 - 160	154 - 600		

Slower-growing birds reaching the slaughter age with GS3

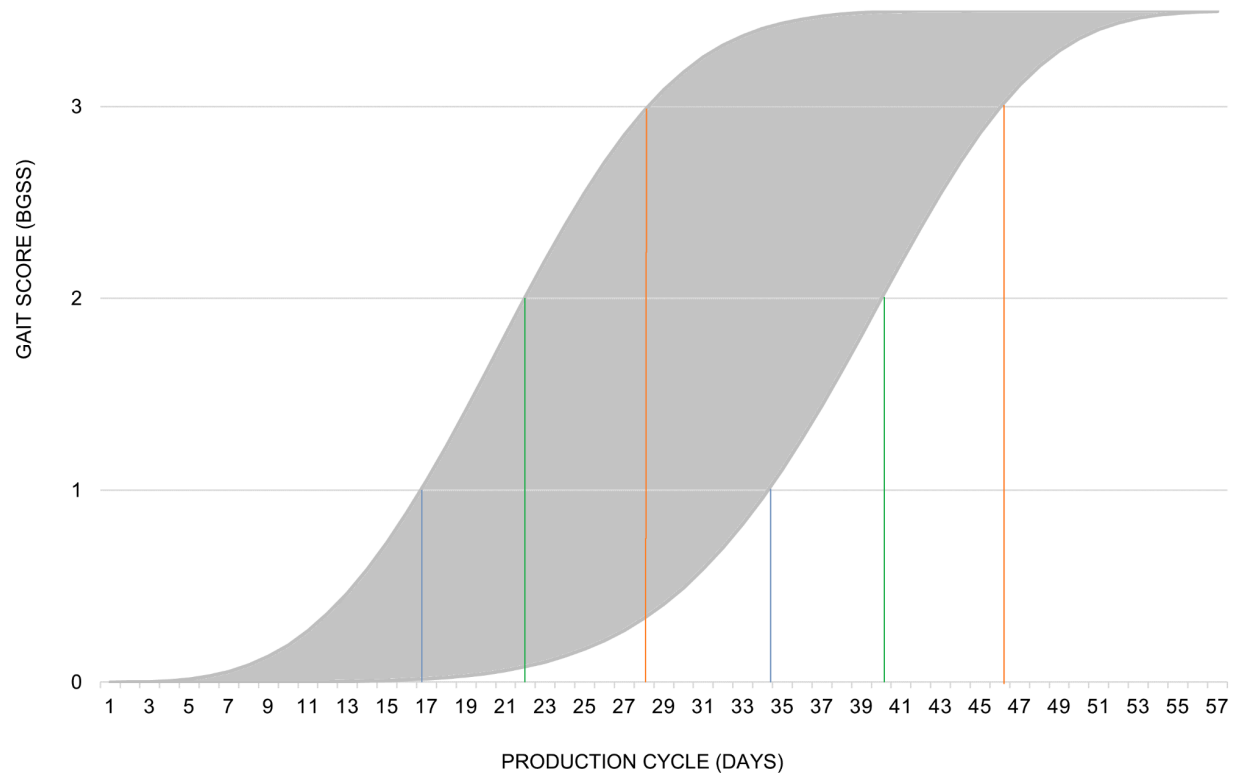


Figure S8. Model of possible patterns of lameness progression over the production cycle for slower-growing birds that reach slaughter with GS3, ranging from an acute and rapid progression to a gradually developing gait abnormality. Blue lines, green and orange lines: onset of GS1, GS2 and GS3, respectively. Maximum and minimum onset values represent the estimated typical interval of onset experienced by broilers in each gait score.

Pain-Track S8. Hypothesis for the temporal evolution of the pain endured by slower-growing broiler chickens that reach the slaughter age (**56 days**) with GS3. Ages of onset (A) are determined based on the model shown in Figure S8. (a) time in GS1 until onset of GS2; (b) time in GS2 until onset of GS3, (c) time in GS3 until slaughter at 56 days. Estimated sleeping time: 4 to 10 h/day. The table on the right shows the time endured in pain (hours) by one affected individual.

	GS1	GS2	GS3		TOTAL TIME IN PAIN
Excruciating				Excruciating	
Disabling			10%	Disabling	35 [16-54]
Hurtful		40%	70%	Hurtful	303 [170-440]
Annoying	50%	30%	10%	Annoying	119 [95-140]
No Pain	50%	30%	10%		
Onset (A)	17 - 34 d	22 - 40 d	28 - 46 d		
Duration in days (B)	5 - 6 (a)	6 - 8 (b)	10 - 28 (c)		
Duration - SLEEP (h) (C)	70 - 120	84 - 160	140 - 560		

Slower-growing GS4 birds

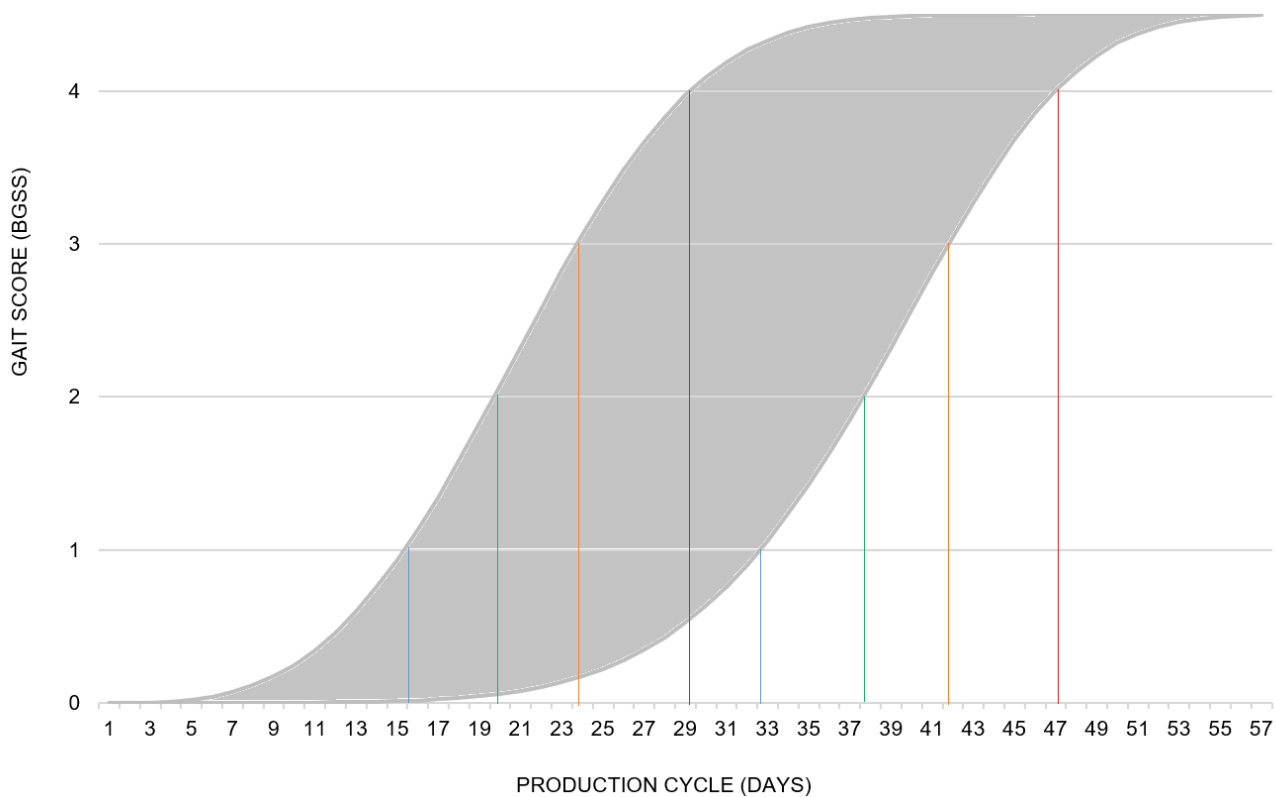


Figure S9. Model of possible patterns of lameness progression (grey area) over the production cycle for slower-growing birds with GS4, ranging from an acute and rapid progression (upper limit) to a gradually developing gait abnormality (lower limit). Blue lines, green, orange and red lines: onset of GS1, GS2, GS3 and GS4, respectively. Maximum and minimum onset values represent the estimated typical interval of onset experienced by broilers in each gait score (hence individual values outside this range are also possible).

Pain-Track S9. Hypothesis for the temporal evolution of the pain endured by broilers that reach the slaughter age (**56 days**) with GS4. Ages of onset (A) are determined based on the model shown in Figure S9. (a): GS1 to GS2, (b): GS2 to GS3, (c) GS3 to GS4, (d): GS4 to 56 days. Estimated sleeping time: 4 to 10 hours/day. The table on the right shows the time endured in pain (hours) by one affected individual.

PAIN LAMENESS	GS1	GS2	GS3	GS4	TIME IN PAIN
Excruating					
Disabling			10%	60%	191 [85-297]
Hurtful		40%	70%	40%	227 [154-300]
Annoying	50%	30%	10%		72 [59-85]
No Pain	50%	30%	10%		

Onset	16-33	20-38	24-42	29-47
Duration in days	4 - 5 (a)	4 - 5 (b)	5 - 6 (c)	9-24*
Duration - SLEEP (h)	56- 100	56- 100	70- 120	126-480

PAIN THIRST	GS1	GS2	GS3	GS4	TIME IN PAIN
				<5% loss 5-10% loss 10-15% >15% loss	
Excruating					
Disabling				20% 50%	14 [11-17]
Hurtful			50%	80% 50%	138 [73-203]
Annoying			50%		104 [39-169]

Duration - SLEEP	14 - 20	28 - 40	8 - 20	76- 400
Duration in days		8 - 24*		

PAIN HUNGER	GS1	GS2	GS3	GS4	TIME IN PAIN
Excruating				0%	
Disabling				40%	121 [50-192]
Hurtful				55%	167 [70-264]
Annoying				5%	15 [7-23]

Duration - SLEEP (h)	126-480
Duration in days	9-24*

Pain-Track S9 (culling). Hypothesis for the temporal evolution of the pain endured by broilers that are culled with a gait score GS4. Ages of onset (A) are determined based on the model shown in Figure S9. (a): GS1 to GS2, (b): GS2 to GS3, (c) GS3 to GS4, (d): GS4 to culling (estimated time to culling since onset of GS4: 1-5 days). Estimated sleeping time: 4 to 10 hours/day. The table on the right shows the time endured in pain (hours) by one affected individual.

LAMENESS	GS1	GS2	GS3	GS4	TIME IN PAIN
Excruiating					
Disabling			10%	60%	44 [18-70]
Hurtful		40%	70%	40%	128 [102-154]
Annoying	50%	30%	10%		72 [59-85]
No Pain	50%	30%	10%		

Onset	16-33	20-38	24-42	29-47
Duration in days	4 - 5 (a)	4 - 5 (b)	5 - 6 (c)	1-5
Duration - SLEEP (h)	56- 100	56- 100	70- 120	14 - 100

THIRST	GS1	GS2	GS3	GS4	TIME IN PAIN
				<5% loss 5-10% loss	
Excruiating					
Disabling				20%	5.4 [3-8]
Hurtful				50% 80%	30 [20-40]
Annoying				50%	8.5 [7-10]

Duration - SLEEP	14 - 20	14 - 40
Duration in days	2-3*	

HUNGER	GS1	GS2	GS3	GS4	TIME IN PAIN
Excruiating				0%	
Disabling				40%	23 [5-30]
Hurtful				55%	31 [7-55]
Annoying				5%	2.8 [0.7-4.9]

Duration - SLEEP (h)	14-100
Duration in days	1-5

Slower-growing GS5 birds

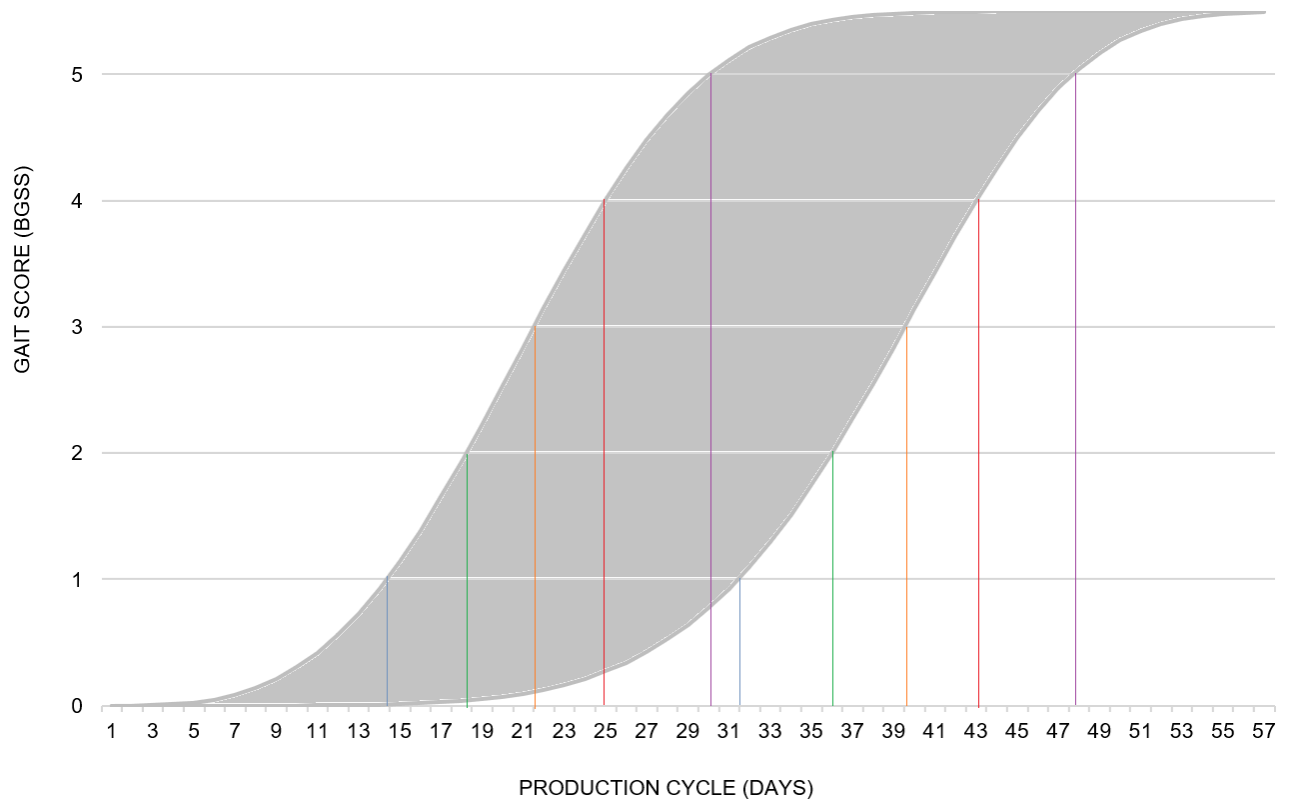


Figure S10. Model of possible patterns of lameness progression (grey area) over the production cycle for slower-growing birds with GS5, ranging from an acute and rapid progression (upper limit) to a gradually developing gait abnormality (lower limit). Blue lines, green, orange, red and purple lines: onset of GS1, GS2, GS3, GS4 and GS5, respectively. Maximum and minimum onset values represent the estimated typical interval of onset experienced by broilers in each gait score (hence individual values outside this range are also possible).

Pain-Track S10. Hypothesis for the temporal evolution of the pain endured by broilers that reach slaughter age (**56 days**) with GS5. Ages of onset (A) are determined based on the model shown in Figure S10. (a): GS1 to GS2, (b): GS2 to GS3, (c) GS3 to GS4, (d): GS4 to **56 days**. Estimated sleeping time: 4 to 10 hours/day. The table on the right shows the time endured in pain (hours) by one affected individual.

PAIN LAMENESS	GS1	GS2	GS3	GS4	GS5	TIME IN PAIN
Excruciating						
Disabling			10%	60%	90%	319 [153-485]
Hurtful		40%	70%	40%	10%	135 [110-161]
Annoying	50%	30%	10%			60 [44-76]
No Pain	50%	30%	10%			

Onset	15 - 31d	18-36 d	21-40 d	25-43	30-48
Duration in days	3 - 5 (a)	3 - 4 (b)	3 - 4 (c)	4-5 (d)	8-24*(e)
Duration - SLEEP (h)	42- 100	42- 80	42- 80	56-100	112-480

PAIN THIRST	GS1	GS2	GS3	GS4		GS4, GS5	TIME IN PAIN
				<5% loss	5-10% loss	10-15%	
Excruciating							
Disabling					20%	50%	14 [11-17]
Hurtful				50%	80%	50%	135 [68-202]
Annoying				50%			101 [34-168]

Duration - SLEEP	14 - 20	28 - 40	8 - 20	62- 400
Duration in days	10 - 24*			

PAIN HUNGER	GS1	GS2	GS3	GS4	GS5	TIME IN PAIN
Excruciating				0%	0%	
Disabling				40%	60%	209 [98-320]
Hurtful				55%	40%	161 [86-236]
Annoying				5%	0%	3.9 [2.8-5]

Duration - SLEEP (h)	56-100	112-480
Duration in days	4-5	8-24*

Pain-Track S10 (culling). Hypothesis for the temporal evolution of the pain endured by broilers that are **culled** with GS5. Ages of onset (A) are determined based on the model shown in Figure S9. (a): GS1 to GS2, (b): GS2 to GS3, (c) GS3 to GS4, (d): GS4 to GS5, (e) GS5 to culling, estimated at 1-5 days after GS5 onset. Estimated sleeping time: 4 to 10 hours/day. The table on the right shows the time endured in pain (hours) by one affected individual.

PAIN LAMENESS	GS1	GS2	GS3	GS4	GS5	TIME IN PAIN
Excruciating						
Disabling			10%	60%	90%	183 [134-233]
Hurtful		40%	70%	40%	10%	236 [203-267]
Annoying	50%	30%	10%			89 [66-111]
No Pain	50%	30%	10%			

Onset	15 - 31d	18-36 d	21-40 d	25-43	30-48
Duration in days	3 - 5 (a)	3 - 4 (b)	3 - 4 (c)	4-5 (d)	1-5 (e)
Duration - SLEEP (h)	42- 100	42- 80	42- 80	56-100	14-100

PAIN THIRST	GS1	GS2	GS3	GS4		GS5	TIME IN PAIN
				<5% loss	5-10% loss	10-15%	
Excruciating							
Disabling					20%	50%	14 [11-17]
Hurtful				50%	80%	50%	43 [37-49]
Annoying				50%		40%	8.5 [7-10]

Duration - SLEEP	14 - 20	28 - 40	8 - 20	1 - 80
Duration in days	5 days	1-5 days		

PAIN HUNGER	GS1	GS2	GS3	GS4	GS5	TIME IN PAIN
Excruciating				0%	0%	
Disabling				40%	60%	65 [38-92]
Hurtful				55%	40%	66 [36-87]
Annoying				5%	0%	3.9 [2.8-5]

Duration - SLEEP (h)	56-100	14-100
Duration in days	4-5	1-5