Assessing the waddle: An evaluation of a 3-point gait score system for ducks

Maja M. Makagon,*[,1] Rebecca Woolley,* and Darrin M. Karcher†

*Department of Animal Sciences, Purdue University; and †Department of Animal Science, Michigan State University

ABSTRACT Impaired walking ability is an economically important welfare problem that affects poultry raised for meat production, including Pekin ducks. To gain a better understanding of the impacts of walking impairments on duck production, and to identify contributing variables and plausible remedies, an accurate measure of walking ability must first be defined. The viability of a 3-point gait score system for characterizing the walking abilities of Pekin ducks was evaluated. Specifically, we examined whether the qualitative gait score categories corresponded to quantitative gait parameter measures, and evaluated the inter- and intra-rater reliabilities of the gait score system. Commercial Pekin ducks aged 13 to 14 d (14 d; 248 ducks), 20 to 21 d (21 d; 350 ducks), and 30 to 32 d (31 d; 368 ducks), were video recorded and gait scored using a 3-point system (GS0 = best gait; GS2 = poor gait) as they crossed a Tekscan® gait analysis system. Gait structure parameters were calculated based on 4 steps made by each duck. The most prominent differences were observed at 21 d and 31 d of age between the ducks with GS0 and GS2, with GS2 scoring ducks walking a shorter total distance, having greater differences in the amount of pressure applied to the right versus left leg, and the amount of time spent standing on 2 feet between steps. Gait score reliabilities were calculated separately for observers who received minimal training (M, N = 10) and those who viewed and discussed the sample cases (V, N = 13). Both groups assessed the gait of ducks from video footage. Inter-rater reliability (Fleiss kappa) was lowest for 14 d old ducks (M: k = 0.47, T: k = 0.62), and best for the 32 d old ducks (V: k = 0.75; T: k = 0.8). Overall, intra-rater reliabilities (Pearson's correlation) were high and were unaffected by the scorer's level of training (M: r = 0.87; V: r = 0.87; t_{21} = 0.43). The results indicate that a 3-point gait score system is a promising tool for assessing the walking ability of ducks at 21 d of age and older.

Key words: Pekin duck, walking ability, gait score

2015 Poultry Science 94:1729–1734
http://dx.doi.org/10.3382/ps/pev151

INTRODUCTION

The ability to accurately estimate the incidence of ducks affected by health and welfare challenges is of economic and ethical importance to the poultry industries. Such estimations enable producers and researchers to examine the impacts of particular welfare challenges, such as impaired mobility, on relevant production outcomes, such as late mortality. When coupled with historical and current management and production data, incidence estimates can additionally provide insight into the underlying causes of a problem and hence its possible remedies.

Impaired mobility, or lameness, is a cause of concern in duck production, and more broadly in the production of meat poultry (ex. Bessei, 2006; Martrenchar, 1999; Mench, 2004; Rodenburg et al., 2005). Due to its possible association with pain (McGeown et al., 1999; Danbury et al., 2000), ducks with moderate to severe walking problems are often culled from the flock, leading to product loss. A study conducted on duck farms in the United Kingdom estimated that 14.2% of 23d old, and 20.6% of 41d old ducks showed signs of moderate to severe walking impairment (Jones and Dawkins, 2010). Evaluation of the incidence of impaired mobility was conducted using a 3-point gait score system, which was a modified version of the systems developed for the assessment of lameness in broilers (Dawkins et al., 2004; Webster et al., 2008). Due to the simplicity and practicality of the method for use on-farm, and the promisingly high level of agreement in scores assigned by multiple evaluators using a 3-point gait score system to assess the walking abilities of broiler chickens (Webster et al., 2008), the method has subsequently been used in another investigation of duck gait (Karcher et al., 2013).

The accuracy of the 3-point system for assessing lameness problems in ducks has, however, not yet been evaluated, raising concerns about the validity of results obtained using this system and the general utility of

Received August 23, 2014.
Accepted April 23, 2015.
[1]Corresponding author: mmakagon@purdue.edu

the tool for evaluating the walking ability of ducks. Evaluations of the tool carried out on other species may not be directly applicable to ducks as physiological differences, including body conformation and the location of the center of gravity, are known to affect the structure of gait even within the same species (e.g. Abourachid, 1991; Reiter and Bessei, 1997; Corr et al., 2003). The overall purpose of our study was to evaluate the 3-point gait score system used to assess the incidence of impaired mobility in commercial Pekin duck flocks.

For a gait score system to be meaningful, gait definitions should correspond to measurable differences in gait structure. For example, if a particular gait score category is defined based on the presence of a limp one may expect the distance traveled by the bird to be different as it steps forward with its right versus left foot. It is equally reasonable to expect that the amount of pressure placed on the right versus left foot may also differ. An additional requirement is that the definitions are written in a way that allows various users to easily and consistently apply the system. This is particularly important in research settings, as the results of studies can only be compared if gait score definitions are interpreted the same way by different research groups. Therefore, our specific aims were to examine whether gait score categories are related to corresponding differences in quantitative gait parameters, and evaluate whether the gait score category definitions allows for the system to be easily applied by new scorers. Because bird age has been shown to impact gait score in other poultry species, with higher scores being more common among older flocks (Sørensen et al., 2000; Kestin et al., 2001), three ages of ducks were included in these assessments.

MATERIALS AND METHODS

This study was approved by the Purdue Animal Care and Use Committee and the Institutional Review Board at Purdue University.

The walking ability of 966 Pekin ducks was assessed. The ducks were sampled from 13 flocks housed across 7 barns located on a commercial grower farm in northern Indiana. The barns were side curtain ventilated with slatted floors. Flock management practices followed standard industry operation procedures, with the exception that on scheduled research days, ducks which would have typically been culled due to lameness, were left with the flock until the day's data collection was completed. This was done in order to increase the likelihood of observing ducks across a range of walking abilities. The ducks were sampled at 13 to 14 (14 d; 248 ducks), 20 to 21 (21 d; 350 ducks) and 30 to 32 (31 d; 368 ducks) days of age. The ducks were sent for processing a few days after the 31 d evaluation. In order to capture a wide range of walking abilities, an effort was made to sample each flock only once, though this was not always possible due to scheduling constraints.

The majority of ducks (75%) were selected randomly from the flock. These ducks were corralled into small groups in a holding pen just prior to testing. The remaining 25% of the ducks were specifically targeted for testing in order to diversify the sample obtained from each flock. Testing took place within the barn. Individual ducks were weighed and placed at the end of a runway comprised of 2 walls of PVC slabs. A 6 m runway was used to test the first flock, but this was subsequently reduced to 3 m as the ducks tended to stop or turn around before reaching the end. All ducks were video recorded and gait scored as they walked down the runway and across a gait analysis pad (Tekscan HRV2 High Resolution Animal Walkway^{TM} System, Tekscan, Inc., South Boston, MA).

A 3-point rubric for gait scoring ducks was used to evaluate the ducks' walking abilities. Following Karcher et al. (2013), a score of "0" (GS0; best gait) was assigned to ducks that waddled without obvious impediments. Ducks which deemed to have a labored walk or slight limp were assigned a score of "1" (GS1; moderate gait), and those who were reluctant to walk scored a 2 (GS2; poor gait). Duck gait was evaluated as the birds moved towards the observer as this angle provided the observer with a clear view of both legs. One of 3 trained individuals evaluated the gait of the ducks during each farm visit. The gait of all of the ducks was re-scored from video by a single experienced observer in order to confirm inter-observer reliability. Scores assigned by the experienced observer were in good agreement with those assigned by 2 of the on-farm scorers, but only in fair agreement with those of the third on-farm scorer. All of the ducks scored by this individual were re-scored a second time from video by our experienced observer. Intra-rater reliability was found to be high, therefore, gait scores assigned by the experienced observer were used for this set of ducks.

Four steps taken by each duck as it crossed the gait analysis pad were analyzed using the Tekscan Walkway^{TM} animal gait analysis system. Video recordings were reviewed to confirm that the ducks were walking, not running, across the pressure pad. Table 1 defines the gait parameters calculated by the gait analysis system that were used for the analyses. Separate statistical analyses were conducted in SAS 9.3 (SAS Institute, Inc., Cary, NC) for each age group to evaluate the effect of gait score on body weight and on gait parameters. The Proc Mixed procedure was used when data could be transformed to meet assumptions of normality and equal variance. Proc Glimmix was used when data fitted a Gamma or Poisson distribution. Because initial analyses indicated that within each age group, body weight differed across gait score categories, body weight was included in the model as a covariate in all subsequent analyses.

Table 1. Definitions and units of the gait parameters calculated by the Tekscan® gait analysis system.

Measure (unit)	Definition
Total Time (s)	The total time to complete four steps.
Total Distance (cm)	The total distance traveled in four steps.
Diff – Stride time (s)	The difference in the average time to complete a step forward with its right leg versus its left. The absolute values of the data were used to standardize for differences that were due to impairment of the right versus left side.
Diff – Stride Distance (cm)	The difference in the average distance traveled as the duck stepped with its right versus left leg. The absolute values of the data were used to standardize for differences that were due to impairment of the right versus left side.
Diff – Pressure (kPa)	The difference in the average pressure exerted on the right versus left foot as the duck took 4 steps forward. The absolute values of the data were used to standardize for differences that were due to impairment of the right versus left side.
Diff – Initial Time on Two Feet (s)	The difference in the time a duck spent with both feet on the ground as it stepped with its right versus left foot. The absolute values of the data were used to standardize for differences that were due to impairment of the right versus left side.
Diff – Stride Distance Corrected (cm)	The difference in the average distance traveled as the duck stepped forward on its right versus left leg corrected for (divided by) the total distance traveled in four steps. The absolute values of the data were used to standardize for differences that were due to impairment of the right versus left side.

To evaluate whether multiple scorers would interpret and use the gait score system in the same way, the gait scores of the ducks were assessed from video by 23 undergraduate students recruited from an applied animal behavior course at Purdue University. The students, none of whom reported having previous experience with any type of gait score system, were randomly assigned to one of 4 groups. Two of the groups were given a copy of the scoring rubric to read and provided with the opportunity to ask questions (10 students). Students in the remaining 2 groups were provided with the same materials and additionally shown and given the opportunity to discuss sample videos depicting ducks with varying gaits (13 students). The minimal training provided to the groups is reasonably representative of the training available to individuals who are new to this assessment tool. Following their respective training sessions, the students were shown a series of video clips of ducks walking towards them which were recorded during the on-farm assessment described above, and asked to independently score the gait of each duck.

The videos included 3 examples of ducks from each age group (14 d, 21 d, and 32 d) thought to be representative of each of the 3 gait score categories (GS0–2). To allow for intra-rater reliability to be assessed each clip was included twice, bringing the total number of video clips to 54. The order of the 54 clips was randomized twice to produce 2 versions of the video. To account for clip order effects, each version was viewed by students from each of the training groups.

Intra-rater (Fleiss kappa) and inter-rater (Pearson's correlation) reliabilities were calculated separately for the scorers who were only shown the rubric, and those shown the rubric and the sample videos. Within these groups, separate analyses were conducted to evaluate the reliabilities of the gait scores assigned to ducks in the 3 age groups.

RESULTS

Table 2 summarizes the results of the analyses evaluating the effects of gait score on body weight and gait parameters. Regardless of flock age, gait score affected the average total distance traveled, average difference in pressure exerted on the right versus left foot, and the average difference in the amount of time that the ducks spent supporting themselves on 2 feet as they took a right versus a left step forward. The observed differences in the gait parameters were significant for ducks with GS0 versus GS2 scores. The mean outcome variables for ducks in the GS1 group tended to be similar (most $P > 0.05$) to those of ducks with a score of either GS0 or GS2.

The outcomes of the intra- and inter-rater reliability tests were similar for observers who received the absolute minimal training and those given the opportunity to also discuss sample video (Table 3). Inter-rater reliability was poor when the evaluated ducks were 14 d old, but improved to fair and good when the focal ducks were 21 d and 32 d old. Intra-rater reliabilities were high, with average Pearson's correlation scores above 0.76 across the age groups.

DISCUSSION

For the impacts of impaired mobility on commercial duck welfare and production to be better understood, the methodologies used to evaluate walking issues in research and production settings must be critically assessed. Across poultry species, gait score systems are the most commonly used tools for evaluating the walking abilities of birds raised for meat (Mench, 2004). For the results of gait score analyses to be meaningful, and to allow for comparisons to be made across assessments or studies, gait score definitions should correspond to measurable differences in gait structure and be

Table 2. Variable means (SE values) calculated for ducks from each gait score category and age group. P-values associated with the effects of gait score on the outcome variable were calculated separately for each age group. The superscripts reflect significant ($P < 0.05$) differences among gait scores within each age category. Body weight was included as a co-variable in all gait parameter analyses.

Variable (unit)	Gait Score	13 d	21 d	32 d
Body Weight (g)	GS0	0.95 (0.01)^{a}	1.69 (0.01)^{a}	2.99 (0.02)^{a}
	GS1	0.79 (0.03)^{b}	1.57 (0.03)^{b}	2.81 (0.07)^{b}
	GS2	0.64 (0.03)^{c}	1.18 (0.05)^{c}	2.50 (0.11)^{c}
	p-value	*<0.001*	*<0.001*	*<0.001*
Total Time (s)	GS0	0.88 (0.02)	0.84 (0.02)^{a}	0.97 (0.03)
	GS1	0.94 (0.06)	0.94 (0.03)^{b}	0.95 (0.06)
	GS2	0.85 (0.08)	1.13 (0.12)^{c}	1.13 (0.10)
	p-value	*0.29*	*<0.001*	*0.18*
Total Distance (cm)	GS0	38.73 (0.59)^{a}	45.83 (0.61)^{a}	45.41 (0.70)^{a}
	GS1	32.39 (1.17)^{b}	38.60 (0.80)^{b}	39.99 (1.45)^{b}
	GS2	29.36 (1.61)^{b}	33.51 (1.51)^{c}	31.45 (1.46)^{c}
	p-value	*0.001*	*<0.001*	*<0.001*
Diff – Stride Time (s)	GS0	0.70 (0.27)^{a}	0.05 (0.01)	0.11 (0.02)
	GS1	3.08 (1.69)^{a}	0.08 (0.01)	0.06 (0.01)
	GS2	0.10 (0.01)^{b}	0.16 (0.05)	0.06 (0.02)
	p-value	*<0.001*	*0.21*	*0.32*
Diff – Stride Distance (cm)	GS0	3.07 (0.19)	3.07 (0.18)	4.35 (0.22)
	GS1	2.55 (0.37)	3.00 (0.29)	3.37 (0.32)
	GS2	3.01 (0.56)	3.07 (0.45)	3.80 (0.66)
	p-value	*0.16*	*0.96*	*0.32*
Diff – Pressure (kPa)	GS0	14.35 (0.90)^{b}	15.14 (1.17)^{b}	17.03 (0.85)^{b}
	GS1	16.18 (2.32)^{a,b}	18.08 (1.87)^{b}	21.06 (2.40)^{a,b}
	GS2	21.08 (2.80)^{a}	27.13 (4.45)^{a}	28.22 (3.82)^{a}
	p-value	*0.01*	*0.02*	*0.02*
Diff – Initial Time on Two Feet (s)	GS0	3.17 (1.17)^{a}	1.38 (0.35)^{a}	2.32 (0.42)^{c}
	GS1	11.32 (4.26)^{a}	1.94 (0.47)^{a}	5.28 (2.42)^{b}
	GS2	0.10 (0.03)^{b}	1.76 (0.87)^{b}	16.76 (4.36)^{a}
	p-value	*<0.001*	0.02	<0.001
Diff – Stride Distance Corrected	0	0.09 (0.01)	0.07 (0.00)	0.10 (0.01)
	1	0.08 (0.01)	0.08 (0.01)	0.09 (0.01)
	2	0.10 (0.02)	0.09 (0.01)	0.12 (0.02)
	p-value	*0.64*	*0.22*	*0.34*

Table 3. The average Pearson's correlation scores (standard errors) and Fleiss kappa coefficient, indicating the intra-rater reliabilities and inter-rater reliability, respectively, calculated for observers who were only shown the rubric, and those who were shown the rubric and the videos during training. Separate analyses were conducted for gait scores assigned to 14, 21, and 32 d old ducks.

Scorer group	Flock age	Pearson's coefficient	Fleiss kappa coefficient
Rubric	14 d	0.76 (0.06)	0.47
	21 d	0.90 (0.02)	0.72
	32 d	0.94 (0.03)	0.75
Rubric + Videos	14 d	0.83 (0.04)	0.62
	21 d	0.86 (0.03)	0.72
	32 d	0.94 (0.02)	0.80

descriptive enough to allow different users to interpret and apply the gait score system in a similar way. We found that the 3-point gait score system categories corresponded with measures of gait structure, and were associated with good within- and between-rater agreement, however these outcomes were affected by the age of the scored ducks.

Consistent differences in quantitative parameters of gait structure were found across age groups between ducks deemed to have the best (GS0) and the worst (GS2) walking abilities. Despite this, within each age category, except at 21 d of age, ducks completed 4 steps in a similar amount of time, and the ducks deemed to scored as GS2 traveled a shorter total distance as compared to those scored GS0 (Table 2). In addition to traveling a shorter distance, the time it took for 21 d old ducks to complete the 3 strides increased as walking ability decreased. Body weight was included as a covariable in the statistical model. Therefore, the difference in body sizes was unlikely to be the main reason for the difference in total distance traveled. The differences more likely suggests that the GS2 ducks had a labored walk. The greater difference in the average amount of pressure exerted on the right versus left foot coupled with the greater difference in the amount of time that a GS2 duck spent supporting itself on its right versus left foot as it moved forward indicate that poor gait was associated with a pronouncedly uneven walk or limp. These results suggest that the "reluctance to walk", which defines a GS2, is due to a progression of the walking problems associated with a GS1, a labored walk or slight limp.

Gait parameters associated with GS1 versus GS0 or GS2 were only detectable at older flock ages. At 21 d old, GS1 ducks took an intermediate amount of time to complete the 4 steps. On average, GS1 ducks traveled an intermediate total distance as compared to ducks with GS0 and GS2 scores at 21 d and 32 d of age. At 32 d of age, the difference in the amount of time ducks spent on their left versus right foot as they propelled themselves forward was intermediate for GS1 ducks as compared to the GS0 and GS2 groups. A likely reason why gait measures of 14 d old GS1 ducks did not differ from those of GS0 and GS2 ducks is that mobility issues became more common and/or pronounced as the ducks aged, resulting in a more obvious separation between the categories. Assessment of the incidence of ducks within each gait score category was outside of the scope of this study, but a decline in walking ability has been associated with increased age in other poultry species selected for fast growth. The walking abilities of broiler chickens have, for example, been shown to decrease between 17 and 38 d of age (Vestergaard and Sanotra, 1999) and when measured at 28, 42, and 49 d of age (Sørensen et al., 2000).

Low variation in the walking abilities of 14 d old ducks could also explain why inter-rater reliability was acceptable for 21 d and 32 d old, but not 14 d old ducks. The interpretation of what constitutes a "slight" limp or "labored" walk is likely to be more challenging and variable when most ducks walk well and the disparity in walking abilities is low. The smaller size of the younger ducks may have additionally made it more difficult for scorers to detect slight impairments, leading to higher rates of misclassification of ducks.

Inter-rater reliabilities for 21 d and 32 d old ducks were within a similar range (fair to moderate reliability) to those reported for the 6-point Bristol gait score system, popularly used to assess the walking abilities of broilers (e.g. Kestin et al., 1992; Garner et al., 2002). Training did not impact inter-rater reliabilities, meaning that the scorers interpreted and applied the system in a similar way with very minimal training. This is a promising result, as the training received by scorers in the minimally trained groups (those shown only the rubric) is representative of that available to most new users of gait score systems. Although it was not tested, it is likely that inter-rater reliability would have been higher if scorers had been offered extensive training, or if the system was evaluated by individuals with previous experience with gait scoring of birds or of working with ducks. Importantly, intra-rater reliability of the scorers was satisfactory for all duck age groups, indicating that individual scorers were consistently scoring ducks in the same manner.

CONCLUSIONS

The lack of a defined differentiation of GS1 ducks and the inter-rater reliability associated with the scoring of the walking abilities of 14 d old ducks raises concern about the utility of the system for assessing the walking ability of young ducks. However, at older duck ages, the gait score assignments do relate to quantifiable differences in walking ability, and are associated with acceptable levels of intra- and inter-rater agreement. Therefore, this study provides initial support for the validity and reliability of the 3-point gait score system for use with ducks over 21 d of age. It remains unclear whether the 3-point system is fully able to capture the differences between the categories of walking abilities, or whether additional separation of gait parameters could be achieved using a 5-point gait score system for ducks, such as the one developed by O'Driscoll and Broom (2011) based on the Bristol gait score system for broilers (Kestin et al., 1992). Future work should focus on further validation of both the 3-point and 5-point gait score systems using additional parameters, assessment of intra- and inter-rater reliabilities of ducks assessed on-farm, development of assessments appropriate for evaluating younger aged ducks, and determination of the relationship between gait score and duck health and welfare.

ACKNOWLEDGMENTS

We gratefully acknowledge Maple Leaf Farms Inc. (Leesburg, IN) for generously providing resources for this study, and particularly Michael Turk, Daniel Shafer, and Kevin Murdoch for supporting this project. We thank Cara Robison (Michigan State University) and Chad Risch (Maple Leaf Farms, Inc.) for overseeing and assisting with on-farm data collection, and Stephanie Robles (Purdue University) for her help in gait pad data analysis and reliability testing. For assistance in various phases of data collection we thank: Prafulla Regmi, Robert Van Wyhe, Diondra Voisch, Lachelle Devoe, and Meredith Rice from Michigan State University, and Luna KC, Kayla Winemiller, and Danyi Ma from Purdue University. We thank Richard Blatchford and two anonymous reviewers for providing constructive feedback on the manuscript.

REFERENCES

Abourachid, A. 1991. Comparative gait analysis of two strains of turkey, *meleagris gallopavo*. Brit. Poult. Sci. 32:271–277.

Bessei, W. 2006. Welfare of broilers: a review. World's Poult. Sci. J. 62:455–466.

Corr, S. A., M. J. Gentle, C. C. McCorquodale, and D. Bennett. 2003. The effect of morphology on walking ability in the modern broiler: a gait analysis study. Anim. Welfare 12:159–171.

Danbury, T. C., C. A. Weeks, J. P. Chambers, A. E. Waterman-Pearson, and S. C. Kestin. 2000. Self-selection of the analgesic drug carpofen by lame broiler chickens. Vet. Rec. 146: 307–311.

Dawkins, M. S., C. A. Donnelly, and T. A. Jones. 2004. Chicken welfare is influenced more by housing conditions than by stocking density. Nature 427:342–344.

Garner, J. P., C. Falcone, P. Wakenell, M. Martin, and J. A. Mench. 2002. Reliability and validity of a modified gait scoring system and its use in assessing tibial dyschondroplasia in broilers. Brit. Poult. Sci. 43:355–363.

Karcher, D. M., M. M. Makagon, G. S. Fraley, S. M. Fraley, and M. S. Lilburn. 2013. Influence of raised plastic floors compared with pine shaving litter on environment and Pekin duck condition. Poult. Sci. 92:583–590.

Kestin, S. C., S. Gordon, G. Su, and P. Sørensen. 2001. Relationships in broiler chickens between lameness, liveweight, growth rate and age. Vet. Rec. 148:195–197.

Kestin, S. C., T. G. Knowles, A. E. Tinch, and N. G. Gregory. 1992. Prevalence of leg weakness in broiler chickens and its relationship to genotype. Vet. Rec. 131:190–194.

Jones, T. A., and M. S. Dawkins. 2010. Environment and management factors affecting Pekin duck production and welfare on commercial farms in the UK. Brit. Poult. Sci. 51:12–21.

Martrenchar, A. 1999. Animal welfare and intensive production of turkey broilers. World's Poult. Sci. 55:143–152.

McGeown, D., T. C. Danbry, A. E. Waterman-Pearson, and S. C. Kestin. 1999. Effect of carprofen on lameness and chickens. Vet. Rec. 144:668–671.

Mench, J. A. 2004. Lameness. Pages 3–15 in Measuring and Auditing Broiler Welfare. C. Weeks, and A. Butterworth, eds. CABI Publishing, Oxfordshire, UK.

O'Driscoll, K. K. M., and D. M. Broom. 2011. Does access to open water affect the health of Pekin ducks (*Anas platyrhynchos*)? Poult. Sci. 90:299–307.

Reiter, K., and W. Bessei. 1997. Gait analysis in laying hens and broilers with and without leg disorders. Equine Vet. J. S23:110–112.

Rodenburg, T. B., M. B. M. Bracke, J. Berk, J. Cooper, J. M. Faure, D. Guemene, G. Guy, A. Harlander, T. Jones, U. Knierim, K. Kuhnt, H. Pingel, K. Reiter, J. Serviere, and M. A. W. Ruis. 2005. Welfare of ducks in European duck husbandry systems. World's Poult. Sci. J. 61:633–646.

Sørensen, P., G. Su, and S. C. Kestin. 2000. Effect of age and stocking density on leg weakness in broiler chickens. Poult. Sci. 79:864–870.

Vestergaard, K. S., and G. S. Sanotra. 1999. Relationships between leg disorders and changes in the behavior of broiler chickens. Vet. Rec. 144:205–209.

Webster, A. B., B. D. Fairchild, T. S. Cummings, and P. A. Stayer 2008. Validation of a three point gait-scoring system for field assessment of walking ability of commercial broilers. J. Appl. Poult. Res. 17:529–539.