Early warning of footpad dermatitis and hockburn in broiler chicken flocks using optical flow, body weight and water consumption

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Abstract:	Footpad dermatitis and hockburn are serious welfare and economic issues for the production of broiler (meat) chickens. We here describe the use of an inexpensive camera system that monitors the movements of broiler flocks throughout their lives and suggests that is possible to predict, even in young birds, the cross-sectional prevalence at slaughter of footpad dermatitis and hockburn before external signs are visible. The skew and kurtosis calculated from our camera-based optical flow system had considerably more power to predict these outcomes in the 50 flocks reported here than water consumption, body weight or mortality and therefore have the potential to inform improved flock management through giving farmers early warning of welfare issues. Further trials are underway to establish the generality of the results.

ABSTRACT

Footpad dermatitis and hockburn are serious welfare and economic issues for the production of broiler (meat) chickens. We here describe the use of an inexpensive camera system that monitors the movements of broiler flocks throughout their lives and suggests that is possible to predict, even in young birds, the cross-sectional prevalence at slaughter of footpad dermatitis and hockburn before external signs are visible. The skew and kurtosis calculated from our camera-based optical flow system had considerably more power to predict these outcomes in the 50 flocks reported here than water consumption, body weight or mortality and therefore have the potential to inform improved flock management through giving farmers early warning of welfare issues. Further trials are underway to establish the generality of the results.

INTRODUCTION

Footpad dermatitis (ulcerated lesions of the pad of the foot) and hockburn (discoloration and lesions of the hocks) are serious welfare and economic issues in the production of broiler (meat) chickens (Bessei 2006, Haslam and others 2007, Meluzzi and others 2008, Shepherd and Fairchild 2010, de Jong and others 2012, Kyvsgaard and others 2013, Elson 2015) but currently, there are few reliable ways of easily assessing these while the birds are still alive and interventions are still possible. Chickens reared for meat frequently live for only 33-42 days and as measures of welfare, producers use either *post-mortem* measures of the cross-sectional prevalence of footpad dermatitis, hockburn and breast blisters recorded at slaughter (SCAHAW 2000, Haslam and others, 2007, Allain and others 2009, Hepworth and others 2010) or labour-intensive methods such as manually sampling birds (Ekstrand and others 1998, de Jong and others 2012, de Jong and others 2016) that give only a snapshot of the state of a flock at a particular time.

Average body weight of birds at 14 days of age has been suggested as a possible indicator of flocks at high risk of later developing a high prevalence of hockburn (Hepworth and others 2010, 2011). The amount of water consumed by the growing birds is also widely recommended as means of assessing welfare (RSPCA 2013, Defra 2013, Red Tractor Assurance 2014, OIE 2016), since both increases and decreases in water consumption can indicate health problems (Butcher and others 1999). However, although the total amount of water consumed over the lifetime of a flock is positively correlated with the prevalence of footpad dermatitis assessed at the slaughter plant (Manning and others 2007), day-to-day changes in estimated water consumption do not appear to be particularly accurate as a welfare indicator (Manning and others 2007) because such changes can be caused by many factors such as leakages, inaccuracy of meters, variation in temperature, drinker type, ventilation rate, the mineral content of the water and diet (SCAHAW 2000, Lott and others 2003).

In this paper, we compare the usefulness of both body weight and water consumption with that of an alternative automated welfare assessment system that monitors the behaviour of chicken flocks using 'optical flow' data derived from inexpensive cameras (Dawkins and others, 2009; Dawkins and others 2012). Optical flow yields measures of behaviour at flock rather than individual level, such as overall levels of flock activity and whether the flock is behaving uniformly or is showing unusual behaviour (Dawkins and others, 2013). Changes in behaviour are increasingly recognized as precursors of clinical signs of disease or other problems (Toscano and others 2010, Lee and others 2011) so that changes in optical flow have the potential to give early warning of disease at the very earliest stages. For example, optical flow patterns observed in chicken flocks as young as three days old have already been shown to predict hockburn prevalence at slaughter (Roberts and others 2012). Similarly, optical flow patterns in chicken flocks of less than seven days old have been shown to predict *Campylobacter* prevalence at slaughter (Colles and others 2016). Needing only simple cameras, optical flow analysis measures the rate of change over time of brightness within different parts of a moving visual image (Beauchemin and Barron 1995, Fleet and Weiss 2005) and thus provides information about tens or hundreds of individuals at once. Using a sample of 50 commercial broiler flocks, we show that optical flow can potentially provide farmers with an inexpensive and easy-to-use early warning system for flocks at increased risk of developing footpad dermatitis and hockburn.

METHODS

Flocks and housing

The aim of the project was to obtain optical flow, production, water use and welfare records from commercial flocks of broiler chickens and to cover all seasons of the year. Since differences between companies, farms, time of year and management practices are known to have major effects on the health and welfare of birds (Dawkins and others, 2004), the study was designed to minimize the effects of these potentially confounding variables by using 50 flocks from a single farm, and thus standardizing the flocks as far as possible, including having the same farm manager throughout, the same set breeder farms from which the chicks were derived and the same slaughterhouse. The farm chosen had 6 identical houses. 24 flocks (i.e. 4 successive crops from the 6 houses) were studied between October 2010 and June 2011. A further 29 flocks were studied between May 2014 and January 2015. Due to camera failure, optical flow records were obtained from only 50 flocks.

The six identical houses had metal sides and a floor area of 1670 m^2. Each house contained 488 feed pans and 1735 water nipples. Ventilation was standard roof extraction and the houses had windows and perches. Chicks were placed 'as hatched' (mixed sex) as day-olds (33,000-35,000 per house) and grown to 33-35 days of age with a target stocking density of 34 kg/m^2. In some cases, early removal of a proportion of birds ('thinning') occurred but this was unpredictable in both timing and proportion of the flock removed (both these factors were dependent on growth rate and supermarket demand). To avoid the disruption caused by thinning (de Jong and others, 2012), optical flow data were collected only up until 30 days of age, before thinning occurred in any of the flocks.

Hockburn and footpad dermatitis

Slaughterhouse measurements of hockburn and footpad dermatitis are used by producers to set targets for the health and welfare of flocks. The outcome measures used in this study were therefore the same as those used by the farmers themselves – namely data on hockburn and footpad dermatitis on each flock collected by the producer company at slaughter following routine producer procedures. These were recorded as the cross-sectional prevalence of any signs of hockburn or footpad dermatitis, expressed as % of that flock.

Estimated water consumption

Estimated daily water consumption was routinely recorded from house-specific meters by the farm staff and converted to consumption in litres/1000 birds. The data were recorded by the farm staff on flock sheets in each house.

Body weight and daily mortality

Producers supplied daily measurements of bird weights and cumulative mortality (dead plus all culls) for each flock as part of their own routine monitoring. Chickens were routinely weighed by fully automated electronic scales linked to a Fancom FWBU.e agricomputer (http://www.fancom.com/en/broilers/biometrics).

Cameras and recording equipment

Flock behaviour was recorded using custom-built C120 web cameras, connected (two cameras/unit) to a small form-factor industrial PC (Fit-PC2, Anders Electronics plc, London, U.K.) enclosed in a protective waterproof housing. In each house, two units (four cameras) were installed, one on each side of a house at a height of 2.0 +/- 0.1 metres and pointing towards the ground at an angle of 70^{o}. Cameras were positioned so that the field of view contained less than 10% of static objects such as feeders, drinkers, house uprights and connected to a mains power supply. To avoid disturbing the chicks, cameras were installed before the chicks arrived. To avoid possible disturbance caused by thinning (removal of a portion of the flock), data were collected for days 1-30 only (before any thinning occurred).

Optical flow

Optical flow analysis involves detecting the rate of change of brightness within different areas of a moving visual image both temporally and spatially. These changes are combined to give an estimate of local velocity vectors (Beauchemin and Barron 1995, Fleet and Weiss 2005). Each image frame on a video file was divided into 320 x 240 pixel images grouped into 1200 (i.e.40 x 30) 8-by-8 pixel blocks and optical flow statistics (mean, variance, skew, kurtosis) were calculated following methods described in (Dawkins and others 2012, Roberts and others 2012), at 4Hz between 08.00 and 20.00, when the lights were on. For each flock daily means for each statistic were calculated for days 1-30.

Statistical analysis

The cross-sectional prevalence of hockburn and footpad dermatitis were analysed using multivariable linear regression models. Logistic regression models could not be fitted to the estimated prevalence data because the sample size (n) used at the slaughter plant to estimate the prevalence was not recorded.

For each day's data, all possible univariable and multivariable linear regression models were fitted to the data with between 1 and 7 of the potential predictors. For each day, the best of these models was selected on the basis that it maximized the adjusted R^2 statistic. Once this model had been chosen, it was refitted to data from flocks with complete data for the model predictors (not just those flocks with complete data for all seven predictors for that day), non-significant predictors ($p>0.05$) were dropped and the reduced model refitted until all of the remaining predictors were significant.

We analysed data up to 15 days of age to investigate the basis for an early warning system for farmers. Some data were missing due to cameras not working. Data from days 1, 2 and 3 were not analysed because only 8 flocks had optical flow data from day 1, only 36 flocks had data from day 2 and only 38 flocks and flocks had data from day 3. The number of flocks (observations) used for the analysis is shown in Tables 1 and 2.

RESULTS

The mean prevalence of footpad dermatitis in the 53 flocks was 51.6% (standard deviation 23.4) and of hockburn 20.5% (standard deviation 16.4%). There was a positive correlation between footpad dermatitis and hockburn (Pearson $r=0.53$, $n=50$, $p<0.01$). Mean cumulative mortality to 30 days was 3.4% (standard deviation 1.07). Mean 30-day body weight was 1.6 kg (standard deviation 0.09). Data and number of flocks recorded for each age for daily means for water consumption, body weight, cumulative mortality and the four optical flow variables (mean, variance, skew and kurtosis) are given in Supplementary Information Table S1.

The best adjusted R^2 models for the prevalence of footpad dermatitis and hockburn are shown by age in Tables 1 and 2 respectively. The data at 4 days of age produced the best models (in terms of adjusted R^2) for both footpad dermatitis and hockburn. Table 3 and Figure 1a show the best fit linear regression model for the prevalence of footpad dermatitis, i.e. it includes only those predictors (out of the possible 7) that reached significance at $p<0.05$. This shows that as early as day 4 of life both skew and kurtosis of optical flow are highly significant predictors of future (as measured at slaughter) footpad damage. Estimated water consumption and body weight did not reach significance as predictors in the multivariable model for 4 days of age, nor did the mean or variance of optical flow. Table 4 and Figure 1b show the corresponding best fit linear regression model for the prevalence of hockburn. The importance of optical flow predictors is again apparent: body weight, estimated water consumption and cumulative mortality appear as part of the highest adjusted R^2 model, but did not reach significance as predictors in the multivariable model for 4 days of age.

DISCUSSION

A particular strength of this study is the objective manner in which the predictors (estimated water consumption, body weight, cumulative mortality as well as optical flow) were collected prospectively, that is before the levels of hockburn and footpad dermatitis had been determined. Furthermore, the assessments of hockburn and footpad dermatitis were made using routine company practices, avoiding biases that could arise due to bespoke study-specific methods of assessment. Optical flow data were collected from standard camera positions but not analysed until after the flocks had been cleared.

Hockburn and footpad dermatitis were correlated here as has been found previously (Haslam and others 2007). Both conditions have a genetic component (Bizeray and others 2000, Haslam and others 2007, Shepherd and Fairchild 2010, Ask, 2010) and are also affected by environmental factors, particularly poor quality litter (Eichner and others 2007, Haslam and others 2007, Martins and others 2013).

Chicken flocks where some individuals have hockburn or footpad dermatitis can be seen as 'mixed ability' flocks – that is, they contain a mixture of birds with healthy and unhealthy legs and feet. Optical flow analysis of the movements of such flocks detects this as changes in both the skew and kurtosis of flock movement, in comparison with healthier flocks, which are more homogeneously healthy and more uniform in their movement. The skew and kurtosis of optical flow were, together, highly predictive of footpad dermatitis and hockburn at slaughter, but each detected a different measure of the heterogeneity in the movement of a flock. The skew values reported here (range 1.0 to 6.7, Figure 1) suggests that there are some flocks with an increase in asymmetry in the movement distribution, indicating a flock in which the commonest kind of movement (the mode) is displaced from the mean or average movement.

The kurtosis describes a different feature of the flock behaviour, which is the extent to which the balance between the centre and the 'tails' of the distribution deviate from what is expected in a normal population. The high kurtosis reported here for some flocks implies that there is a deviation in the direction of 'fat tails' – in other words, an unusually high number of birds moving very much faster or slower than the mean. Although it seems counter-intuitive to say that the presence of a few fast moving birds is a sign of an 'at risk' or poor welfare flock, the flock that is in real trouble is the one where fast movement has become relatively rare. Healthy flocks have uniformly high levels movement, with few outliers and therefore low kurtosis.

Lower skew (for a given level of kurtosis) and higher kurtosis (for a given level of skew) are thus indicative of heterogeneity in flock movement that is predictive of two key welfare outcomes, footpad dermatitis and hockburn. Optical flow can thus provide early warning of these key welfare issues, enabling farmers to make interventions (such as extra litter) to prevent symptoms becoming more serious.

However, it is still not clear exactly how the correlations between optical flow, hockburn and pododermatitis arise (Dawkins and others, 2013). One possible connection could be that flocks with a tendency to sit for long periods of time spend more time with their legs in contact with litter and so are more likely to develop hockburn. But other routes, such as infections that make the birds both less active and more prone to gut disorders that then lead to poorer quality litter that in turn affects their legs and feet also need to be investigated.

The best fit multivariable linear regression model showed that skew and kurtosis of optical flow had more predictive power than estimated water consumption, body weight or cumulative mortality, thus confirming the value of optical flow as a flock management tool.

The next step will be to repeat similar studies in additional farms, in particular those run by other companies to explore the generality of the results.

ETHICS

This study used broiler flocks that were reared commercially by industry partners, in line with standard industry practice. We performed non-invasive, non-intrusive camera observations of birds, and thus the need for approval under the Animals (Scientific Procedures) Act of 1986 was waived. All prevailing local, national and international regulations and conventions, and normal scientific ethical practices have been respected.

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CONTRIBUTIONS

MSD designed and organized the study, collated the results and drafted the paper. SJR and TN developed the optical flow algorithms and RJC ran the trials and drew the figures. CAD performed the statistical analysis.

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Table 1. Best adjusted R^2 models for each age of birds as predictors of footpad dermatitis prevalence.

Age (days)	Obs. used	Best adjusted R^2	Model
1	(8)		
2	(36)		
3	(38)		
4	**43**	**31.8%**	**Water4 Weight4 CumulMort4 OFVar4 OFSkew4 OFKurt4**
5	43	24.3%	Water5 CumulMort5 OFVar5 OFSkew5 OFKurt5
6	45	23.6%	Water6 CumulMort6 OFMean6 OFSkew6 OFKurt6
7	45	30.7%	Water7 CumulMort7 OFSkew7 OFKurt7
8	47	21.9%	Water8 CumulMort8 OFVar8 OFSkew8 OFKurt8
9	47	21.2%	Water9 CumulMort9 OFVar9 OFSkew9 OFKurt9
10	48	20.7%	Water10 CumulMort10 OFVar10 OFSkew10 OFKurt10
11	50	17.9%	Water11 CumulMort11 OFVar11 OFSkew11 OFKurt11
12	49	16.6%	Water12 CumulMort12 OFVar12 OFSkew12 OFKurt12
13	49	16.4%	CumulMort13 OFSkew13 OFKurt13
14	49	21.7%	CumulMort14 OFSkew14 OFKurt14
15	49	19.3%	Water15 OFVar15

The variable names are: estimated water consumption (Water), average weight (Weight), cumulative mortality (CumulMort), and optical flow statistics: mean (OFMean), variance (OFVar), skew (OFSkew) and kurtosis (OFKurtosis). The number at the end of the name reflects the age in days to which each predictor related.

Table 2. Best adjusted R^2 models for each age of birds as predictors of hockburn prevalence. (Variable names as in Table 1.)

Age (days)	Obs. used	Best adjusted R^2	Model
1	(8)		
2	(36)		
3	(38)		
4	**43**	**29.8%**	**OFMean4 OFSkew4 OFKurt4**
5	43	23.8%	OFSkew5 OFKurt5
6	45	27.6%	Weight6 OFSkew6 OFKurt6
7	45	22.7%	Weight7 OFMean7 OFVar7 OFSkew7 OFKurt7
8	47	24.3%	Weight8 OFMean8 OFVar8 OFSkew8 OFKurt8
9	47	21.0%	Weight9 OFSkew9 OFKurt9
10	48	21.2%	Weight10 OFSkew10 OFKurt10
11	50	25.3%	Weight11 OFMean11 OFVar11 OFSkew11 OFKurt11
12	49	25.2%	Weight12 OFMean12 OFSkew12 OFKurt12
13	49	25.7%	Weight13 OFMean13 OFVar13 OFSkew13 OFKurt13
14	49	29.0%	Weight14 OFMean14 OFSkew14 OFKurt14
15	49	25.6%	Weight15 OFSkew15 OFKurt15

Table 3. Parameter estimates for the best fit multivariable linear regression model for the prevalence of footpad dermatitis. (Variable names as in Table 1.)
Adjusted R^2 = 23.0%; n=44. If fixed effects are added for the 6 houses, the estimates are very similar: OFSkew4: -31.14, SE=9.79, t=-3.18, p=0.0030; OFKurtosis4: 2.75, SE= 0.83, t=3.32, p=0.0021.

Variable	Estimate	SE	t	p
Intercept	94.58	14.78	6.40	<0.0001
OFSkew4	-31.88	8.46	-3.77	0.0005
OFKurtosis4	2.81	0.73	3.85	0.0004

Table 4. Parameter estimates for the best fit multivariable linear regression model for the prevalence of hockburn. (Variable names as in Table 1.)
Adjusted R^2 = 30.29%; n=44. If fixed effects are added for the 6 houses, the estimates are very similar: OFSkew4: -28.45, SE=7.31, t= -3.89, p=0.004; OFKurtosis4: 2.50, SE=0.62, t= 4.04, p=0.0003.

Variable	Estimate	SE	t value	p
Intercept	55.14	11.13	4.96	<0.0001
OFSkew4	-27.15	6.37	-4.26	0.0001
OFKurtosis4	2.45	0.55	4.42	<0.0001

Figure Captions

Figure 1 Plots of the best fit regression models for A) the prevalence of footpad dermatitis and B) the prevalence of hockburn as a function of the optical flow skew and kurtosis at 4 days of age (see Tables 3 and 4 for the parameter estimates). The observed data are overlaid over the regression model predictions.

FIGURE !

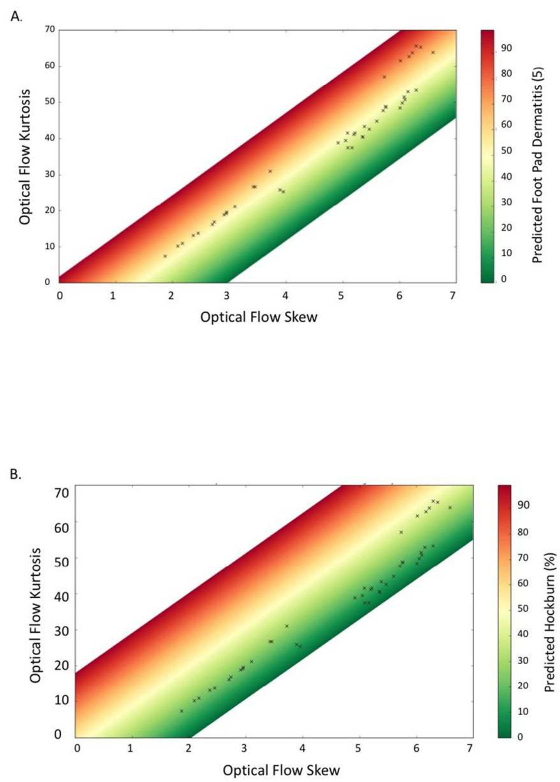

Figure 1 Plots of the best fit regression models for A) the prevalence of footpad dermatitis and B) the prevalence of hockburn as a function of the optical flow skew and kurtosis at 4 days of age (see Tables 3 and 4 for the parameter estimates). The observed data are overlaid over the regression model predictions

437x619mm (72 x 72 DPI)