Optical flow, flock behaviour and chicken welfare

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We used a combination of inexpensive camera equipment and statistical analysis of optical flow patterns to analyse the behaviour of 24 commercial broiler (meat) chicken flocks, \textit{Gallus gallus}. Individual birds were not tracked or marked but the skew and kurtosis of flow patterns produced by the collective movements of the flocks were significantly correlated with key welfare measures such as % mortality, numbers of birds with hockburn (damaged leg skin) and abnormal walking behaviour (poor gait) in individual birds. These correlations were already apparent in birds as young as 15–20 days. Optical flow patterns provided an information-rich link between flock and individual that could be important in the development of new ways of assessing the welfare of, and managing, broiler chickens. It could also have wider application to the study of other animal groups as an alternative to more invasive or intrusive methods.

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There is now an array of inexpensive camera/video systems for observing and recording animal behaviour, from tiny cameras that can be put onto flying birds to video surveillance that enable constant monitoring of whole groups. But collecting data is only the first step. Without the ability to sift and analyse the vast quantities of data that can now be collected, the information revolution that the new technology promises is incomplete. The question still remains: having collected the data, what should we now do with them?

We here address this question in the context of a rapidly growing area of ethology: the study of the collective behaviour of large groups of animals (Sumpter 2010). We show that the combination of inexpensive technology and relatively simple statistical analysis of group behaviour can give valuable information quickly and easily from a large and otherwise unwieldy data set. The particular example we use, extracting information about animal welfare from month-long video recordings of flocks of commercial broiler (meat) chickens, \textit{Gallus gallus}, raises many of the same problems that are widely encountered in the study of other animal groups: there were very large numbers of animals (35,000 in each house), they were homogeneous in appearance (making individual tracking computationally very difficult), they could not be visually marked (as it would interfere with behaviour) and they could not be pit-tagged or fitted with loggers (as these could have ended up in the food chain). Some or all of these problems are common to studying animal groups on farms, in zoos or in the wild so that the noninvasive, nonintrusive ‘optical flow’ approach we describe here has the potential to be widely used in other ethological studies.

Optical flow analysis works by detecting the rate of change of brightness in different parts of a moving visual image (Beauchemin & Barron 1995; Sonka et al. 1999; Fleet & Weiss 2005). It is used in a variety of different applications including traffic flow (Bellomo et al. 2009), movement of glaciers (Giles et al. 2009), cell and sperm motility (Shi et al. 2008; Weissleder & Pitter 2008; Cheng et al. 2009) and the study of human crowds (Courty & Corpetti 2007; Ma & Cisar 2008), but has so far been relatively little used for studying groups of nonhuman animals (Bremond et al. 2006). Its great advantage is that whole frames or sections of frames, containing tens or hundreds of individuals can be assessed together and the basic statistical properties of these flow patterns can be derived automatically and continuously (Sonka et al. 1999) using algorithms that are simple enough to deliver results continuously in real time. A key step in using optical flow successfully is, therefore, to establish which statistical properties are most appropriate for a given situation.

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The most obvious statistic to use is the mean flow rate, which indicates the overall level of movement over time in whatever sequence is being looked at. In broiler chickens, flow and higher variance, skew and kurtosis. To test its sensitivity and make it maximally difficult and this is reflected in their higher variance, skew and kurtosis of movement.

Whatever statistic is used, the next step is to validate it and to make sure that it is actually delivering something of biological interest, either instead of an observer being present or as a supplement to direct observation. In the case of broiler chickens, abnormal walking is a key indicator of reduced welfare (Bessei 2006; Renema et al. 2007; Knowles et al. 2008) and is currently measured by the time-consuming method of people ‘gait scoring’ birds by eye (Kestin et al. 1992). If optical flow could be validated as an automated way of monitoring chicken walking ability, this would have important implications for the assessment of their welfare.

The aim of this study was to see whether our preliminary findings on the use of optical flow patterns of flock movement were sufficiently robust to be useful as a practical way of assessing chicken welfare on commercial farms. We collected optical flow data on 24 commercial flocks of broilers and predicted that reduced welfare (as measured by higher mortality, abnormal walking and higher incidence of leg and foot damage) would be correlated with lower mean optical flow and higher variance, skew and kurtosis. To test its sensitivity and make it maximally difficult for the optical flow system to pick out differences between the flocks, we chose flocks that were as similar to each other as possible in size, stocking density and housing. To test its ability to provide useful information at different stages of the birds’ lives, we collected optical flow data continuously every 15 min throughout the entire lives of the flocks, from day-old to 35 days when they were taken to slaughter.

METHODS

Twenty-four commercial broiler flocks were used for this study, which was conducted on a single site in the U.K. Four identical houses were studied simultaneously, with six replications over time, between October 2010 and June 2011.

Animals and Husbandry

Broiler chickens of mixed sexes and of one of two commercial breeds were placed in the houses as day-olds (33 000–35 000/house) and grown to 35 days old with a target final stocking density of 38 kg/m². Each house was 1670 m² and contained 488 feed pans and 1735 water nipples. Ventilation was standard roof extraction. There was no thinning (early removal of a proportion of the flock) or changes to floor space at different ages. Lighting, feeding, temperature and other husbandry regimes were in accordance with practice recommended by the breeder companies (Cobb 2008; Aviagen 2009).

Production Data

The production company supplied the following information: total mortality (% of flock dead before slaughter); total culls (% total mortality from culling); daily mortality and culls (recorded on a daily basis by the farm manager); growth rate (average daily bird growth weight calculated from daily recording with automatic weighers in each house and additional weekly weighing by hand); hockburn (% of birds with any permanent discoloration to the hocks, assessed at the slaughter plant post mortem and after cleaning and defeathering); pododermatitis (% of birds with any lesion to the foot pad, assessed at the slaughter plant post mortem and after cleaning and defeathering). In addition, the company supplied information on gas consumption per house, water consumption per house, age at which the birds were sold, total weight sold and the farm manager’s recordings of relative humidity (RH) measured with a hand-held RH meter. Company data were validated as far as possible; for example, the totals of the mortality and cull data as they were recorded on the daily house sheets were checked against the final flock mortality and culls as given by the company and the company provided data before being told optical flow results for that flock. Systematic bias in the collection of post mortem data was controlled for by collecting data from the slaughterhouse ‘blind’ (i.e. the staff assessing hockburn and pododermatitis at the slaughter plant operated to standard company procedures and did not know which flocks they were assessing).

Welfare Measures

In addition to information about the mortality, hockburn and pododermatitis, birds were assessed for their walking ability. Gait scores were collected by the farm manager who had been trained to use the 6-point Bristol Gait Score (Kestin et al. 1992) and gait scored 60 birds/house on day 28. The results were expressed as a mean gait score for that flock. As a validation of these data, a second observer used a 3-point score (Dawkins et al. 2004; Webster et al. 2008) and gait scored a total of 100 individuals on days 32–34. On the first half of the data, the two scores were significantly positively correlated (Spearman rank correlation: $r_s = 0.71, N = 12$, $P < 0.01$), which was taken as validation of the observer.

Recording Equipment

The behaviour of the broiler flocks was recorded using waterproof and custom-built C120 web cameras (Logitech International S.A. Plc., Romanel-sur-Morges, Switzerland), connected (two cameras/unit) to a small form-factor (115 × 101 × 27 mm) industrial PC (Fit-PC2, Anders Electronics Plc., London, U.K.) enclosed in a protective waterproof casing. In each chicken house, two units (four cameras) were installed on each side of a house at a height of 200 cm (±10 cm), and connected to a domestic power supply. Machines were programmed to operate the optical flow package between 0800 and 1900 hours and were left running from day 1 to day 35.

Optical Flow

Optical flow analysis involves detecting the rate of change of brightness in each area of an image frame both through time and...
spatially (Sonka et al. 1999). These changes are combined to give an estimate of local velocity vectors. For example, if white objects on a black background remain stationary from one image to the next, there will be no change of brightness and no ‘flow’. But if some of the white objects move between frames, some of the white areas will become dark and vice versa and this will be registered as a net ‘flow’. Optical flow can be detected down to pixel level but for reasons of economy of processing, we chose to divide each image frame in the video file into 1200 (= 40 × 30) 8-by-8 pixel blocks and to estimate optical flow in each block. Our approach calculated, on a frame-by-frame basis, the spatial mean, variance, skewness and kurtosis of the estimated flow velocities over the image. During video capture the computer automatically delivered these four optical flow measures (mean, variance, skew and kurtosis) aggregated from each sequence of 3600 image frames, representing a 15 min block of real time. Further details are given in Dawkins et al. (2009) and Lee et al. (2011). All sequences were subsequently reviewed to remove spurious changes caused by abrupt changes in light conditions and delayed auto gain from the cameras on restarting after power outages.

Statistical Analysis

We analysed the optical flow data in ways that avoided artefacts caused by the increasing body size of birds as they grew (Sonka et al. 1999) by comparing each flock at the same age (and, as the birds were being grown to a standard body weight, this meant the same size). We compared flocks using the optical flow data for that day only, using correlation coefficients (Pearson). To test the hypothesis that a few outliers could be dominating the correlation we checked the results using ‘leave-one-out cross validation’ and by using rank rather than linear correlation. Results indicated a high degree of robustness to outliers and no significant changes to the conclusions. Significance values are given for one-tailed tests since the direction of correlation was clearly predicted in advance (see above).

Ethical Note

Our study was purely observational and simply recorded what would have happened on the farm anyway. The cameras were installed before the chicks arrived so caused them no disturbance. Checking of cameras was carried out as part of the routine inspection of the house by farm staff. Gait scoring was also part of normal farm routine.

RESULTS

The 24 flocks showed a mean mortality ± SD of 3.35 ± 0.91% (N = 24, range 2.37–6.46%) and an average gait score of 1.92 ± 0.23 (N = 24, range 1.64–2.38). The narrow range of recorded gait scores provided a good test of whether the optical flow approach could discriminate between the flocks. A summary of the correlations between the different optical flow measures on day 30 of the birds’ life and the key welfare measures (% mortality, % culls, % hockburn, % pododermatitis and gait score) is shown in Table 1.

<table>
<thead>
<tr>
<th>Optical flow</th>
<th>% Mortality</th>
<th>% Culls</th>
<th>% Hockburn</th>
<th>% Pododermatitis</th>
<th>Mean gait score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>-0.42**</td>
<td>-0.31</td>
<td>-0.36</td>
<td>0.09</td>
<td>-0.33</td>
</tr>
<tr>
<td>Variance</td>
<td>0.003</td>
<td>0.09</td>
<td>-0.02</td>
<td>0.27</td>
<td>0.27</td>
</tr>
<tr>
<td>Skew</td>
<td>0.42**</td>
<td>0.35*</td>
<td>0.57***</td>
<td>0.33</td>
<td>0.42**</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>0.45**</td>
<td>0.38*</td>
<td>0.56***</td>
<td>0.32</td>
<td>0.48**</td>
</tr>
</tbody>
</table>

The figures shown are the values of Pearson r.

\*p < 0.05; **p < 0.025; ***p < 0.01.

is, higher mortality, higher (less good) gait scores and, in particular, high incidence of marked hocks or ‘hockburn’.

Fig. 1a shows how the relationship between mean optical flow and flock mortality changed with bird age. There was an increasing and negative relationship between mortality and mean optical flow before 30 days although the correlation did not reach significance until day 30. Fig. 1b shows similar age correlations for skew, which rose from the age of 15 days onwards, as did those for kurtosis of flow (Fig. 1c). For hockburn (marked hocks), the correlations with optical flow (skew and kurtosis) were also already significant at around 15 days of age and remained so for the rest of the birds’ lives (Fig. 2a, b). For gait score, the skew and kurtosis of flow were significantly correlated with gait not only on the day on which gait scores were measured (day 28) but for several days beforehand (Fig. 3a, b).

DISCUSSION

These results show that several measures of optical flow were significantly correlated with key welfare measures in broiler chickens. Specifically, mean optical flow rate in 30-day-old birds was negatively correlated with flock mortality, and both the skew and kurtosis of the movement distributions were positively correlated with % flock mortality, % culls, % birds scored as having hockburn and poor gaits. Strikingly, some of these correlations were already apparent when the birds were much younger than 30 days. As early as 15 days of age, the skew and kurtosis of optical flow provided information about which flocks would end up having higher mortality and damaged hocks 20 or so days later. Over a week before the gait scoring was done, skew and kurtosis already indicated which flocks were most likely to be scored as having the best and worst gaits.

The different measures of optical flow were not equally informative. Contrary to our predictions and previous findings (Dawkins et al. 2009), neither the mean flow rate nor the variance was significantly correlated with gait score. We suggest that this may be the result of the narrow range of gait scores found in this study. Aydin et al. (2010) showed that although the rate of movement in small groups of birds with the most abnormal gaits (Bristol Gait scores of 4 and 5) was different from that of groups of birds with scores of 0–3, there was a great deal of overlap among these groups, so that it was difficult to distinguish between the movement of birds with gait scores of 0, 1, 2 or 3. None of the flocks in the present study had an average gait score above 2.38. Mean flow rate may therefore be sufficient to discriminate between healthy walkers and very lame birds but less able to detect smaller differences in walking ability such as we observed in this study. Skewness and kurtosis, on the other hand, were both significantly correlated with mortality, hockburn and gait score, even though the 24 flocks in this study were selected to be as similar as possible. This suggests that these measures might be sensitive enough to be useful on standard commercial flocks. [Direct comparisons with the
U.K. national average are difficult because information is scarce and measurements are taken at different bird ages, but Knowles et al. (2008) gave 1.98 as the U.K. gait score mean for prethinned birds and 2.18 for 40 day olds, compared to the 1.92 for the average gait reported here. The flocks were at least within the normal range of gaits expected in U.K. flocks.

The importance of these results is that they provide the basis for automated assessment of broiler chicken welfare (Veissier et al. 2008; Kristensen & Cornou 2011). Skew and kurtosis of movement within a flock predicted as early as 15 or 20 days.

![Figure 1](#) Correlation coefficients ($r$) between % mortality (as measured at the end of a flock’s life) and optical flow measures taken on different days of life. (a) The correlation between mortality and mean flow at different ages. (b) The correlation between mortality and the skew of flow at different ages. (c) The correlation between mortality and the kurtosis of flow at different ages. In each case, the thick line indicates the value of $r_{22}$ and the thin lines indicate the thresholds for different levels of significance.

![Figure 2](#) Correlation coefficients ($r$) between incidence of hockburn (as measured post mortem at the slaughter plant) and optical flow measures on different days of life. (a) The correlation between hockburn and skew of flow at different ages. (b) The correlation between hockburn and kurtosis of flow at different ages. In each case, the thick line indicates the value of $r_{22}$ and the thin lines indicate the thresholds for different levels of significance.
flocks were most at risk of having high mortality, hockburn and poor gaits, and this paves the way for the development of interventions that could both improve welfare and be a valuable management tool for producers.

Conclusions

Optical flow patterns can provide an easy way of analysing the behaviour of large groups of animals from video records. The optical flow measures described here (mean, variance, skew and kurtosis) did not track individual animals, but characterized the overall movement of whole flocks of chickens. Nevertheless, the optical flow patterns detected at group level, especially the skew and kurtosis of movement, were correlated with behaviour and welfare at the individual level, such as whether a high percentage of chickens were walking abnormally. Optical flow thus provides an information-rich link between individual and group and potentially has wide application to the study of flocks, herds and other animal groups as an alternative to other more intrusive or invasive methods.

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References