ANIMAL WELL-BEING AND BEHAVIOR

Ranging behavior relates to welfare indicators pre- and post-range access in commercial free-range broilers

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ABSTRACT Little is known about the effect of accessing an outdoor range on chicken welfare. We tracked individual ranging behavior of 538 mixed-sex Ross 308 chickens on a commercial farm across 4 flocks in winter and summer. Before range access, at 17 to 19 d of age, and post-range access, at 30 to 33 and 42 to 46 d of age in winter and summer flocks respectively, welfare indicators were measured on chickens (pre-range: winter N = 292; summer N = 280; post-range: winter N = 131; summer N = 140), including weight, gait score, dermatitis and plumage condition. Post-ranging autopsies were performed (winter: N = 170; summer: N = 60) to assess breast burn, leg health, and ascites. Fewer chickens accessed the range in winter flocks (32.5%) than summer flocks (82.1%). Few relationships between welfare and ranging were identified in winter, likely due to minimal ranging and the earlier age of post-ranging data collection compared to summer flocks. In summer flocks prior to range access, chickens that accessed the range weighed 4.9% less ($P = 0.03$) than chickens that did not access the range. Pre-ranging weight, gait score, and overall plumage cover predicted the amount of range use by ranging chickens in summer flocks ($P < 0.01$), but it explained less than 5% of the variation, suggesting other factors are associated with ranging behavior. In summer flocks post-range access, ranging chickens weighed 12.8% less than non-ranging chickens ($P < 0.001$). More range visits were associated with lower weight ($P < 0.01$), improved gait scores ($P = 0.02$), greater breast plumage cover ($P = 0.02$), lower ascites index ($P = 0.01$), and less pericardial fluid ($P = 0.04$). More time spent on the range was associated with lower weight ($P < 0.01$) and better gait scores ($P < 0.01$). These results suggest that accessing an outdoor range in summer is partly related to changes in broiler chicken welfare. Further investigations are required to determine causation.

Key words: broiler, free-range, welfare, health, behavior

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INTRODUCTION

Consumption of free-range chicken meat has increased, partly driven by consumer belief that access to an outdoor range is good for chicken welfare (Magdelaine et al., 2008; de Jonge and van Trijp, 2013; Howell et al., 2016). However, little is known about whether accessing an outdoor range affects the welfare of broiler chickens. Historically, investigating the welfare implications of range use has been difficult; studies that compared chickens housed in free-range and conventional housing have not monitored the individual ranging behavior but rather flock ranging behavior (Weeks et al., 1994; Nielsen et al., 2003; Jones et al., 2007; Zhao et al., 2014; Stadig et al., 2016). Yet, there can be variation within a flock, and not all broiler chickens access the outdoor range when the opportunity is provided (Chapuis et al., 2011; Durali et al., 2014; Taylor et al., 2017a). With the advancement of technology, tracking individual chicken ranging behavior is now possible on commercial farms (Gebhardt-Henrich et al., 2014b; Taylor et al., 2017a; Taylor et al., 2017b). Thus, a more thorough investigation of the welfare implications of accessing an outdoor range is now achievable.

The outdoor range provides a more complex environment than the indoor shed and appears to encourage active and exploratory behaviors (Weeks et al., 1994; Jones et al., 2007; Fanatico et al., 2016). Although relationships have been identified between activity and leg health in broiler chickens (Thorp and Duff, 1988; Reiter and Bessei, 1996), it is unknown if broiler chicken ranging behavior on commercial farms is sufficient to

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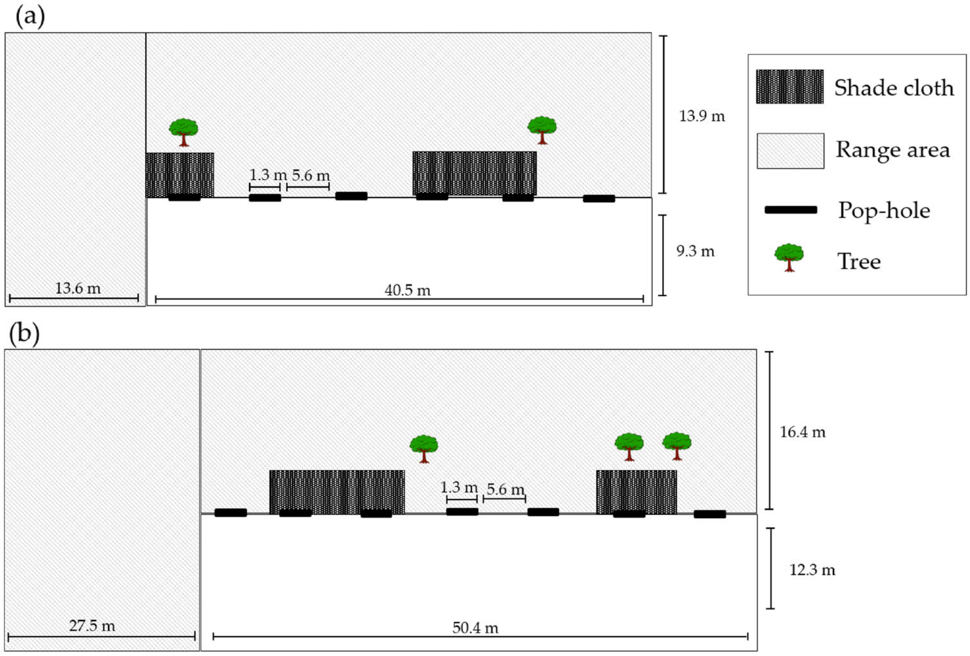

Figure 1. Diagram of the study sheds and range areas (a) shed 1, which housed flocks A and C, and (b) shed 2, which housed flocks B and D.

result in improved leg health and decreased associated conditions such as dermatitis and breast burn.

Durali et al. (2014) indicated that Ross 308 broiler chickens that spent more time on the range (> 8.7 hours in total) had lower body weight after range access than chickens that spent less time on the range (<1.1 hours total). The cause of reduced body weight in relation to ranging behavior is unknown. However, the consequence of lower body weight, reflecting slower growth rate, may improve chicken welfare by reducing the risk of growth-related metabolic diseases, such as ascites, sudden death syndrome, and deep pectoral myopathy (Julian, 1998; Julian, 2005).

While accessing an outdoor range may impact the welfare of broiler chickens positively or negatively, some welfare conditions may encourage range use. Nielsen et al. (2003) attributes low range use in faster-growing broiler strains, compared to slower-growing strains, to poor leg health. Indeed, poor gait score is often correlated with reduced activity in broiler chickens (Weeks et al., 2000; Caplen et al., 2014). Thermoregulation may be an additional challenge for chickens that are motivated to range. In Australia, chickens are typically permitted access to an outdoor range at 21 d of age based on the appropriate level of plumage cover. However, individual variation in plumage cover could affect ranging behavior in terms of motivation to visit the range or the duration of range visits. Thermal resistance was found to be greater in free-range broiler chickens compared to conventionally housed chickens, and the authors hypothesized that this reflected plumage cleanliness (Ward et al., 2001), but they did not assess these measures before the chickens were provided with range access or monitor individual ranging behavior.

Thus, ranging may affect the welfare state of an individual broiler chicken or vice-versa. Therefore, this paper aimed to identify relationships between the individual ranging behavior of broiler chickens and welfare indicators in commercial situations, with a focus on health. We hypothesized that chicken welfare prior to range access would be related to subsequent ranging behavior when access to the range was provided and that welfare indicators would be altered after range access in relation to ranging behavior.

MATERIALS AND METHODS

All animals used in this study were approved by the University of Melbourne Animal Ethics Committee (animal ethics approval number 1,413,428.3).

Study Site and Animals

Mixed-sex Ross 308 broiler chicken flocks (n = 4) were studied from 1 farm in Victoria, Australia, across 2 seasons (winter: flocks A and B; summer: flocks C and D). Flocks contained chickens from the same hatchery with comparable management practices. Chickens were housed in mechanically fan ventilated sheds (Figure 1) with adjacent range areas. Shed 1 (40.5 m × 9.3 m) housed 6,000 chickens (flocks A and C) and shed 2 (50.5 m × 12.3 m) housed 10,000 chickens (flocks B and D). Additional natural ventilation was provided when automatic curtains were lowered 1 to 2 m on the side walls of the shed stopping 1 m above the shed floor. The shed wall was solid from the ground to 1 m above, therefore chickens had no visual contact with the range area even when the curtains were fully opened, except through opened range doors. Curtains were automatically raised and lowered dependent on the temperature and humidity in the shed. Stocking density in all flocks was kept below 28 kg/m^2, achieved by removing 1/3 of each flock at 35 d of age, referred to hereafter as "partial depopulation." Food and water were provided ad libitum inside the shed, but never on the range. Light (20 to 25 lux) was provided on a 23:1 cycle when chicks were aged 1 to 7 d then a 16:8 cycle until slaughter age excluding 3 d before partial depopulation and before all remaining chickens were transported for slaughter at 45 to 49 d of age, hereafter referred to as "complete depopulation," when the light cycle was 20:4.

Range areas (Figure 1) were accessible through manually operated doors (1.3 × 0.4 m) described hereafter as "pop-holes." Flocks were raised according to the Free Range Egg and Poultry Australian (**FREPA**) standards, which specify that chickens must be fully feathered before range access can be provided Free Range Egg & Poultry Australia Ltd 2015. Therefore, chickens were first provided with access to the outdoor range at 21 d of age; initial access to the range at 21 d is typical of Australian industry practice. The number of d and h/d the range was available for ranging was weather dependent and dictated by farm management. Restriction of range access by farm staff was not dictated by 1 variable (e.g., temperature) but often a combination of various variables (e.g., low temperature, high rainfall, and fast wind speed), but the decisions for restricting range access were not recorded. Range areas >1 m from the shed were covered in grass and was kept at a length of 10 to 20 cm (based on visual observations) by farm management during periods that the chickens had access to the range. The range area for shed 1 was flat. The range area for shed 2 had an approximate 45° slope beginning 7.5 m from the shed wall. Both range areas were fenced; the back fence was 16 m from an adjacent road for shed 1 and another chicken shed in shed 2. Each range contained natural and artificial structures (Figure 1). Both range areas contained 2 rectangular shade cloth structures, 7 to 10 m in length, that ran adjacent to the shed wall 3 m into the range and 3 m above 3 pop-holes in each shed.

Tracking Individual Range Use

Individual chicken range use was tracked by the Gantner Pigeon Radio Frequency Identification System (2015 Gantner Pigeon Systems GmbH, Benzing, Schruns, Austria), with a bespoke program, Chicken Tracker, that was developed for the use of tracking commercial chickens and previously validated and used on a commercial farm to track laying hens (Gebhardt-Henrich et al., 2014a; Gebhardt-Henrich et al., 2014b). Between 3 to 5 d before range access was first permitted, chickens (flock A: N = 146; flock B: N = 146; flock C: N = 139; flock D: N = 141) were randomly selected from 10 evenly spread areas within the shed; locations varied according to width and length of the shed and distance from pop-holes. Chickens were fitted with a silicone leg band (Shanghai Ever Trend Enterprise, Shanghai, China) containing a unique ID microchip (Ø4.0/34.0 mm Hitag S 2048 bits, 125 kHz) that registered as the chickens walked over the antenna. Antennas were attached to both sides of each pop-hole (i.e., indoor and outdoor) to determine the direction of movements by each tagged chicken, hence permitting calculation of ranging frequency and duration. Antennas were placed in the shed before placement of the chicks to minimize disturbance. Chickens were tracked from d 1 that range access was permitted (21 d of age) until 30 to 33 d of age in winter flocks (total 9 to 12 d) and 43 to 45 d of age in summer flocks (total 22 to 24 d). Although chickens in winter flocks were provided with access to the range after partial depopulation, logistical concerns from industry participants restricted the tracking of chickens after partial depopulation.

Welfare Assessments

Indicators of welfare were assessed prior to range access (17 to 19 d of age; winter: N = 292; summer: N = 280), described hereafter as "pre-ranging" measures, and 9 to 12 d after the range was first available (30 to 33 d of age), described hereafter as "post-ranging I" measures in all flocks (winter: N = 131; summer: N = 144). Welfare indicators were also assessed at 42 to 46 d of age in summer flocks (N = 140), described hereafter as "post-ranging II" measures. Post-ranging II measures were not collected for winter flocks for logistical reasons. Timing of data collections were chosen based on typical Australian industry standards; initial range access at 21 d of age (pre-ranging data collection), partial depopulation at 35 d of age (post-ranging I data collection) and complete depopulation around 49 d of age (post-ranging II data collection).

All tracked chickens were caught and placed in a temporary pen the day before data collection. Welfare indicators were measured on randomly chosen chickens before range access in summer and winter flocks. In summer flocks, welfare indicators were measured on randomly chosen chickens at post-ranging I and chickens that were tested before range access but not at post-ranging I were selected for testing at post-ranging II. Due to minimal ranging in winter flocks, post-ranging I welfare indicators were taken from chickens in winter flocks based on the total number of range visits, selecting non-ranger vs. class of relatively high-frequency ranging chickens to ensure sufficient sampling for analysis. Chickens were placed into subgroups in temporary pens based on their ranging frequency class, then randomly chosen from this pool. In all flocks, post-ranging analysis only included chickens that were repeatedly measured (e.g., assessed at both pre- and post-ranging data collections).

At all data collection time points (pre-ranging and post-ranging I and II), sex, weight, gait score, and body condition scores were collected from each chicken. After pre-ranging data collection, the chickens were fitted with a leg band to track range use and sprayed with blue or green stock paint (FIL Tell Tail, GEA, New Zealand) on tail and wing feathers to identify chickens for post-ranging I and II data collection.

Gait scores were assessed by standing directly behind the chicken and, when required, encouraging the chickens to walk by slow human approach and gentle tactile contact with a clipboard. Gait scores were assessed in less than 30 s using a 6-point gait score scale (Kestin et al., 1992) and later condensed into 3 scores; normal = score 0, affected = score 1 or 2, or lame = score 3 or 4; no scores of 5 were recorded at any time point. Foot pad dermatitis (**FPD**) was scored using a 5-point scale (Welfare Quality ®, 2009), recording the highest score from either foot. The FPD scores were later condensed into 4 scores, only 3 chickens had the maximum score of 4 throughout all flocks. Therefore, scores 3 and 4 were combined. Hock burn (**HB**) was scored on a binary scale; absence or presence on either leg. Breast plumage cover was scored on a 4-point scale; plumage cover on breast: 75 to 100% = score 1, 50 to 74% = score 2, 25 to 49% = score 3, and 0 to 24% = score 4. Overall plumage cover was scored on a 3-point scale; overall plumage over (excluding breast area): 75 to 100% = score 1, 50 to 74% = score 2, and < 49% = score 3. Vent, breast, and overall cleanliness was assessed using a 3-point scale, modified from Welfare Quality ® (2009); clean = score 1, discolored = score 2, and severe discoloration and mattered, clumped feathers > 10 cm = score 3.

Gait and body condition assessors were trained to score chickens from videos and live assessments prior to data collection. Assessors were blind to chicken's ranging behavior. Inter-observer reliability (N = 3) for body condition scores was measured once. Intra-observer reliability (N = 10) for gait scores were measured at 2 time points (17 d of age, 31 d of age) in all flocks and additionally at 45 d of age in summer flocks. Kendall's concordance coefficient was used to determine the level of agreement between observers (0.0 to 1.0; complete disagreement to complete agreement). Intra-observer reliability for condition scores ranged from 0.5 to 0.9 (df = 2; agreement $P < 0.05$). Intra-observer reliability for gait scores ranged from 0.6 to 0.9 (df = 9; agreement $P < 0.01$).

Autopsy Examinations

Postmortem autopsies were conducted at post-ranging I and II data collections from a randomly selected sub-sample of chickens according to ranging behavior (non-ranger vs. class of relatively high frequency ranging chickens) in winter flocks (flock A: N = 73; flock B: N = 97) and summer flocks (flock C: N = 30; flock D: N = 30). Chickens were euthanized using an intravenous injection of pentobarbitone. The same person performed all postmortem autopsies and was blind to chicken's ranging behavior. Skin was removed from the abdomen and the top of both legs. The prevalence of breast blisters was assessed before legs were removed from hip joint and both hip joints were scored for femoral head necrosis (**FHN**) using an 8-point scoring system from Wideman et al. (2012). Scores for each leg were summated and categorized as normal = score 1, femoral head separation = score 2, progressive necrosis = score 3 and femoral head necrosis = score 4. Incisions were made into the tibia of both legs and presence and severity of tibial dyschondroplasia (**TD**) was scored using a 4-point scoring system from Garner et al. (2002); no signs of TD = score 0, abnormal cartilage under growth plate = score 1, cartilage extended one-fourth of the way down the tibiotarsus = score 2 and cartilage extended more than one-fourth of the way down the tibiotarsus = score 3. The body cavity was opened and the presence or absence of fluid in the abdomen and pericardial sac were noted. The heart was removed, stored in 70% ethanol and later dissected to obtain right ventricle and total ventricular weights. An ascites index was calculated (right ventricle: total ventricle weight ratio) as an indicator of pulmonary hypertension and a potential preclinical sign of ascites (Wideman and French, 1999).

Statistical Analysis

Individual Ranging Behavior Radio Frequency Identification data were cleaned with SAS^{TM} (v 9.3, SAS institute Inc., Cary, NC) using a modified macro (Gebhardt-Henrich et al., 2014b). All range visits shorter than 10 s were treated as false positives and removed from analysis. Statistical analysis was performed with SPSS statistical software (v22, IBM Corp, Armonk, NY). Ranging behavior varied greatly between seasons and therefore seasonal replicate data were never pooled or compared. Chickens were excluded from analysis if functional tags were not recovered at the end of the trial; sample sizes presented throughout the manuscript are corrected for chickens excluded from the analysis. Normality of data were assessed by Kolmogorov-Smirnov and Shapiro-Wilk normality test statistics and histograms unless otherwise stated.

In the subsequent result section, we first compared welfare indicators from ranging (**R**) and non-ranging (**NR**) chickens, and we then investigated relationships between welfare indicators from R chickens and the amount of range use (total number of range visits and total time spent on the range). Chickens that did not access the range throughout the study were classified as NR chickens and chickens that accessed the range at least once were classified as R chickens. Analysis of welfare indicators and the amount of range use were only performed on R chickens. Ranging was minimal in winter flocks, therefore only summer flocks were analyzed to investigate relationships between welfare and the amount of range use (total number of range visits and total time spent on the range). Relationships between ranging and post-ranging I and post-ranging

II welfare indicators were similar in summer flocks. Therefore, only post-ranging II results are reported, and described as "post-ranging" indicators.

Comparison of Pre-ranging Welfare Indicators Between R and NR Chickens and Relationships With the Amount of Range Use Relationships between pre-ranging welfare indicators and R and NR chickens or the total number of range visits, total time spent on the range and were investigated using General Linear Mixed Models (**GLMM**) for continuous normally distributed data or Generalized Linear Mixed Models (**GLIMM**) with a binary logistic or multinomial logistic link function for binary and ordinal data respectively. Each model included flock, individual nested within flock, sex, assessor and weight as random variables where appropriate. Response variables that were significantly associated with the amount of range use at the $P \leq 0.1$ level were included in prediction models.

Predicting Ranging Behavior R and NR Chickens With Pre-Ranging Welfare Indicators Indicators of welfare that differed at $P \leq 0.1$ level were included in a logistic regression to assess the impact of each welfare indicator on the likelihood that chickens would access the range or not. The most parsimonious models are reported, determined by goodness of fit tests calculated by Omnibus model coefficients and Hosmer and Lemeshow tests and the amount of variation the model accounted for, determined by Nagelkerke R square values.

Predicting the Amount of Range Use by R Chickens With Pre-Ranging Welfare Indicators The total number of range visits data did not meet the criteria for normality, even after transformation. Therefore, a GLIMM with a Poisson distribution and log link function was used to predict the total number of range visits when access to the range was provided with pre-ranging welfare indicators. The number of range visits were dependent variables; welfare indicators were the independent variables; and flock, individual nested within flock, and sex were random variables.

Total time spent on the range data were square root transformed and subsequently met the criteria for normality. Thus, a linear regression model was used to predict the total time spent on the range when access was provided with pre-ranging welfare indicators. Total time spent on the range met the criteria for heteroscedasticity and multicollinearity, confirmed by P-P and residual plots. All possible models were run, and the final model included variables that resulted in the best fit, determined by changes in F values ($P < 0.05$) via a forward stepwise regressions analysis and comparisons of adjusted r^2 values. The most parsimonious models are reported with statistically useful variables in the model.

Comparison of Post-Ranging Welfare Indicators Between R and NR Chickens and Relationships With the Amount of Range Use Comparisons between R and NR chicken post-ranging welfare indicators and the relationships between the total number of range visits (frequency) or total time spent on the range (duration) and post-ranging welfare indictors were analyzed with GLMM for continuous data that met the criteria for normality or GLIMM for non-parametric variables. The GLIMM with a multinomial logistic or binary logistic distribution and link function were used to assess ordinal and binary welfare indicators respectively. In all models, welfare indicators were dependent variables, individuals were the subject variable and time point of data collection (pre- and post-ranging) were the within subject variable. Interactions between time point of data collection (pre- or post-ranging) and range use (R vs NR, frequency or duration) were included to indicate changes associated with range use independent of pre-ranging differences. However, non-significant interactions were removed ($P > 0.05$) to improve model fit, confirmed by Akaike Information Criterion values. Flock, individual nested within flock, sex, assessor, and weight were included as random variables where appropriate.

RESULTS

Ranging Behavior

In winter flocks, 32.5% of tracked chickens accessed the range, whereas in summer flocks 82.1% of tracked chickens accessed the range. Ranging behavior varied between chickens within the same flock (Table 1). Full descriptions of flock and intra-individual ranging behavior were previously reported (Taylor et al., 2017a; Taylor et al., 2017b). Due to the large variation in ranging behavior between seasonal replicates, seasonal replicate data were analyzed and are presented separately.

Part I: Comparisons of Welfare Indicators Between R vs NR Chickens

Comparison of Pre-ranging Welfare Indicators Between R and NR Chickens In summer flocks prior to range access, R chickens weighed less than NR chickens ($F_{(1274)} = 4.74$, $P = 0.03$; Table 2) but there was no difference between R and NR chickens before range access in winter flocks (weight $P = 0.61$; Table 2).

In winter flocks prior to range access, R chickens had more breast plumage cover than NR chickens ($F_{(1127)} = 4.65$, $P = 0.03$), but there was no difference between R and NR chickens in summer flocks ($P = 0.39$).

There was no difference in gait scores, FPD, HB, plumage cleanliness or plumage cover between R chickens and NR chickens before range access in either season (gait score: summer $P = 0.22$, winter $P = 0.74$; FPD: winter $P = 0.41$, summer $P = 0.51$; HB: summer $P = 0.35$, winter $P = 0.87$; vent cleanliness: summer $P = 0.75$, winter $P = 0.27$; breast cleanliness: summer $P = 0.63$, winter $P = 0.67$; overall cleanliness:

Table 1. Ranging behavior (mean and standard error of the mean (SEM)) from d 1 of range access (21 d) until partial depopulation (30 to 33 d of age; winter and summer flocks) and complete depopulation pick-up (42 to 46 d of age; summer flocks only). Data includes chickens that accessed the range a minimum of 1 time.

	Winter flocks		Summer flocks	
	Mean ± SEM	Min—max	Mean ± SEM	Min—max
Ranging before partial depopulation				
Range availability (d)	7		9.5 ± 1.0	(9–10)
Daily range availability (h)	5.6 ± 0.6	(3–7.2)	10.8 ± 0.6	(2.0–13.5)
Total number of range visits	13.8 ± 1.8	(1–71)	21.1 ± 1.2	(1–116)
Total time spent on the range (h)	1.8 ± 0.2	(10 s – 8.7 h)	7.3 ± 0.4	(15 s – 42 h)
Mean duration per range visit (min)	11.9 ± 2.8	(10 s – 2.9 h)	23.8 ± 1.0	(115 s – 1.9 h)
Number of d the range was accessed	3.1 ± 0.2	(1–7)	4.7 ± 0.1	(1–9)
Ranging before complete depopulation				
Range availability (d)			17.0 ± 1.0	(16–18)
Daily range availability (h)			10.4 ± 0.6	(2.0–14.0)
Total number of range visits			38.6 ± 2.6	(1–151)
Total time spent on the range (h)			12.9 ± 0.9	(20 s – 54.7 h)
Mean duration per range visit (min)			21.7 ± 1.1	(20 s – 1.6 h)
Number of d the range was accessed			8.3 ± 0.3	(1–17)

summer $P = 0.65$, winter $P = 0.91$; overall plumage cover: summer $P = 0.32$, winter $P = 0.47$; Table 2).

Predicting R and NR Chickens with Pre-Ranging Welfare Indicators In winter flocks, there were no welfare indicators that could predict R and NR chickens.

In summer flocks, lower pre-ranging weight was predictive of accessing the range (β: $-$ 4.19, CI: 0.00, 0.89, Exp (B): 0.02, $P = 0.04$). The model correctly classified 81.0% of cases ($\chi^2_{(3)} = 14.95$, $P \leq 0.01$). Including sex improved the model ($P < 0.05$) but did not predict range use ($P = 0.06$).

Comparison of Post-Ranging Welfare Indicators Between R and NR Chickens In summer flocks, R chickens gained less weight from pre- to post-ranging than NR chickens (interaction between time point (pre- and post-ranging) and range use (R or NR): $F_{(1270)} = 15.44$, $P < 0.001$; Table 2). There was no interaction between ranging, time of data collection, and sex ($P = 0.97$) or sex and range use ($P = 0.72$) on body weight but there was a main effect 'there was a main effect of gait score for ranging' sex ($F_{(1270)} = 76.38$, $P < 0.001$). In summer flocks, there was no interaction between pre- and post-ranging gait scores and ranging, but there was a main effect of gait score for ranging (gait score $F_{(1262)} = 4.74$, $P = 0.03$; Table 2). There was no difference between in weight or gait scores between R and NR chickens in winter flocks (weight: $P = 0.61$; gait scores: $P = 0.31$) but severe gait scores were rare in winter flocks (Table 2).

In summer flocks, R chickens had lower vent cleanliness scores (cleaner), ascites indexes and prevalence of pericardial fluid after range access than NR chickens (vent score: interaction between time point and range use $F_{(1137)} = 6.66$, $P = 0.01$; ascites index: $F_{(1,51)} = 6.47$, $P = 0.01$; pericardial fluid: $F_{(1,45)} = 4.78$, $P = 0.04$; Table 2) but there was no difference in vent cleanliness or cardiovascular measures between R and NR chickens in winter flocks (vent score: $P = 0.23$; ascites index: $P = 0.31$; pericardial fluid: $P = 0.85$; Table 2).

In winter flocks there was no interaction between pre- and post-ranging breast plumage cover or overall plumage cleanliness and ranging; however, there was a main effect, indicating that R chickens had greater breast plumage cover and cleaner overall plumage than NR chickens (breast plumage cover: $F_{(3252)} = 3.50$, $P = 0.02$; overall plumage cleanliness: $F_{(1250)} = 5.11$, $P = 0.03$; Table 2), but there was no difference in plumage between R and NR chickens in summer flocks (breast plumage cover $P = 0.46$; overall plumage cleanliness: $P = 0.80$).

After range access, FPD, HB, breast cleanliness scores and overall plumage cover increased in both seasons (all $P < 0.05$; Table 2). However, there was no difference or interaction between R and NR chickens (FPD: winter $P = 0.34$, summer $P = 0.95$; HB: winter $P = 0.26$, summer $P = 0.11$; breast cleanliness: winter $P = 0.23$, summer $P = 0.14$; overall plumage cover: winter $P = 0.311$, summer: $P = 0.64$).

Post-ranging FHN scores did not differ between R and NR chickens in either season (winter $P = 0.79$; summer $P = 0.95$). Breast blisters, tibial dyschondroplasia and abdominal fluid were never observed.

Part 2: Relationships between Welfare Indicators of R Chickens and the Amount of Range Use

Relationships between the amount of ranging behavior (number of range visits and total time on the range) are only reported in summer flocks due to minimal ranging in winter flocks.

Relationships between Pre-Ranging Welfare Indicators of R Chickens and the Amount of Range Use Chickens with lower pre-ranging weight, more normal gait scores and more overall plumage cover subsequently accessed the range more frequently and for a longer time (weight: ranging frequency $F_{(1207)} = 11.0$, $P = 0.001$; ranging duration $F_{(1207)} = 7.63$, $P = 0.01$;

Table 2. Prevalence or mean and SEM (standard error of the mean) and comparisons of welfare indicators measured pre-range access (17 to 19 d of age) and post-range access (winter flocks: 30 to 33 d of age; summer flocks 42 to 46 d of age) on chickens that accessed the range (R) when access was provided and chickens that did not (NR), in winter and summer flocks.

		Winter				Summer			
		Pre-range access		Post-range access (I)		Pre-range access		Post-range access (II)	
Welfare indicator % (n)	Score	NR	R	NR	R	NR	R	NR	R
Weight (kg)	Female	0.77 ± 0.01	0.75 ± 0.01	1.77 ± 0.03	1.74 ± 0.05	0.81 ± 0.02^{a}	0.73 ± 0.01^{b}	2.85 ± 0.07^{a}	2.45 ± 0.04^{b}
	Male	0.86 ± 0.01	0.85 ± 0.02	2.09 ± 0.03	1.99 ± 0.06	0.86 ± 0.03^{a}	0.80 ± 0.01^{b}	3.24 ± 0.09^{a}	2.97 ± 0.06^{b}
	Pooled sex	0.80 ± 0.01	0.81 ± 0.01	1.94 ± 0.03	1.88 ± 0.05	0.81 ± 0.01^{a}	0.77 ± 0.01^{a}	3.05 ± 0.07^{b}	2.66 ± 0.04^{c}
Gait score	Normal	76.1 (124)	67.9 (36)	41.7 (35)	58.1 (25)	38.5 (20)^{a}	26.5 (58)^{a}	0.0 (0)^{b}	16.8 (19)^{c}
	Affected	23.9 (39)	32.1 (17)	54.8 (46)	39.5 (17)	61.5 (32)	73.1 (160)	73.9 (17)	76.1 (86)
	Lame	0.0 (0)	0.0 (0)	3.6 (3)	2.3 (1)	0.0 (0)^{a}	0.5 (1)^{a}	26.1 (6)^{b}	7.1 (8)^{c}
Foot pad dermatitis	None	65.9 (139)	64.6 (51)	5.8 (5)	4.5 (2)	79.3 (42)	80.4 (181)	56.5 (13)	49.1 (56)
	Slight	23.7 (50)	24.1 (19)	20.9 (18)	27.3 (12)	7.5 (4)	16.0 (36)	4.3 (1)	14.0 (16)
	Moderate	8.5 (18)	7.6 (6)	43.0 (37)	47.7 (21)	9.4 (5)	3.1 (7)	8.7 (2)	20.2 (23)
	Severe	1.9 (4)	3.8 (3)	30.2 (26)	20.5 (9)	3.8 (2)	0.4 (1)	30.4 (7)	16.7 (19)
Hock burn	Absent	86.7 (182)	88.5 (69)	85.9 (67)	97.7 (42)	98.1 (52)	93.7 (208)	62.2 (15)	69.0 (80)
	Present	13.3 (28)	11.5 (9)	14.1 (11)	2.3 (1)	1.9 (1)	6.3 (14)	34.8 (8)	31.0 (36)
Vent cleanliness	Clean	89.2 (189)	91.1 (72)	12.6 (11)	13.6 (6)	88.7 (47)^{a}	90.7 (205)^{a}	4.3 (1)^{b}	22.8 (26)^{c}
	Soiled	9.0 (19)	8.9 (7)	8.0 (7)	13.6 (6)	7.5 (4)	6.2 (14)	8.7 (2)	21.9 (25)
	Dirty	0.0 (0)	0.0 (0)	79.3 (69)	72.7 (32)	3.8 (2)^{a}	3.1 (7)^{a}	87.0 (20)^{b}	55.3 (63)^{c}
Breast cleanliness	Clean	65.6 (139)	65.8 (52)	1.1 (1)	4.5 (2)	26.4 (14)	37.8 (85)	0.0 (0)	0.9 (2)
	Soiled	32.1 (68)	32.9 (26)	5.7 (5)	15.9 (7)	28.3 (15)	34.2 (77)	4.3 (1)	8.7 (10)
	Dirty	2.4 (5)	1.3 (1)	93.1 (81)	79.5 (35)	45.3 (24)	28.0 (63)	95.7 (22)	90.4 (104)
Overall cleanliness	Clean	69.2 (203)	97.4 (76)	8.4 (7)	28.6 (12)	94.2 (49)	91.6 (196)	4.3 (1)	2.6 (3)
	Soiled	3.3 (7)	1.3 (1)	73.5 (61)	57.1 (24)	5.8 (3)	7.9 (17)	78.3 (18)	81.7 (94)
	Dirty	0.5 (1)	1.3 (1)	18.1 (15)	14.3 (6)	0.0 (0)	0.5 (1)	17.4 (4)	15.7 (18)
Breast plumage cover	1 (most)	0.9 (2)^{a}	3.8 (3)^{b}	1.2 (1)	2.3 (1)	26.4 (14)	23.5 (53)	17.4 (4)	11.2 (13)
	2	10.3 (22)	10.1 (8)	3.5 (3)	4.5 (2)	26.4 (14)	26.4 (53)	17.4 (4)	36.2 (42)
	3	36.2 (77)	39.2 (31)	9.3 (8)	22.7 (10)	15.1 (8)	15.1 (32)	43.5 (10)	30.2 (35)
	4 (least)	52.6 (112)	46.8 (37)	86.0 (74)	70.5 (31)	32.1 (17)	32.1 (31)	21.7 (5)	22.4 (26)
Overall plumage cover	1 (most)	37.1 (79)	40.5 (32)	36.0 (31)	45.5 (20)	73.6 (39)	59.6 (134)	91.3 (21)	95.5 (109)
	2	54.5 (116)	49.4 (39)	60.5 (52)	47.7 (21)	20.8 (11)	27.1 (61)	8.7 (2)	2.7 (3)
	3 (least)	8.5 (18)	10.1 (8)	3.5 (3)	6.8 (3)	5.7 (3)	13.3 (30)	0 (0)	0.9 (1)
Ascites index	Mean ± SE	N/A		0.19 ± 0.01	0.18 ± 0.01	N/A		0.17 ± 0.01^{a}	0.16 ± 0.01^{b}
Pericardial fluid	Absent	N/A		54.1 (53)	50.7 (35)	N/A		21.1 (4)^{a}	52.9 (9)^{b}
	Present			45.9 (45)	49.3 (34)			78.9 (15)	47.1 (8)
Femoral head necrosis score	Normal	N/A		70.1 (68)	71.0 (49)	N/A		25.0 (5)	29.2 (7)
	Separation			15.5 (15)	15.5 (11)			20.0 (4)	38.0 (9)
	Progressive			5.2 (5)	10.1 (7)			30.0 (6)	4.2 (1)
	FHN			9.3 (9)	2.9 (2)			40.0 (8)	29.2 (7)
Sex	Female	46.0 (40)	43.2 (19)			62.3 (33)	55.7 (122)		
	Male	54.0 (47)	56.8 (25)			37.7 (20)	44.3 (97)		

$^{a-c}$Different superscripts within a row represent a statistical difference ($P < 0.05$) between R and NR chickens and time of data collection (pre-ranging or post-ranging).

gait scores: ranging frequency $F_{(1207)} = 8.45$, $P = 0.01$; ranging duration $F_{(1164)} = 7.26$, $P = 0.01$; overall plumage cover: ranging frequency $F_{(1212)} = 6.10$, $P = 0.01$; ranging duration $F_{(1212)} = 5.02$, $P = 0.03$).

The amount of range use was not associated with FPD, HB, plumage cleanliness, or breast plumage cover (FPD: ranging frequency, $P = 0.98$, ranging duration, $P = 0.62$; HB: ranging frequency, $P = 0.14$, ranging duration, $P = 0.51$; vent cleanliness: ranging frequency, $P = 0.10$, ranging duration, $P = 0.11$; breast cleanliness: ranging frequency, $P = 0.76$, ranging duration, $P = 0.93$; overall cleanliness: ranging frequency $P = 0.76$, ranging duration, $P = 0.94$; breast plumage cover: ranging frequency, $P = 0.41$, ranging duration, $P = 0.34$).

Predicting the Amount of Range Use with Pre-Ranging Welfare Indicators Lower weight and better gait scores before range access were significant predictors of more subsequent range visits (weight: $F_{(1214)} = 16.54$, $B = -2.74$, CI -4.09, -1.39, $P < 0.01$; gait score: $F_{(1214)} = 6.84$, $B = 0.39$, CI 0.11, 0.67, $P = 0.01$). Of note, only 1 lame score was observed at this age (Table 2).

Normal gait score and more overall plumage cover before range access were predictive of more subsequent time spent on the range ($F_{(2212)} = 5.68$, $P \leq 0.01$) but only accounted for 4.2% of the total variance (gait score: $t_{(2212)} = -2.29$, CI: -8.95, -0.67, Exp(B): -0.154, $P = 0.02$; overall plumage cover: $t_{(2212)} = -2.33$, CI: -5.57, -0.47, Exp(B): -0.156, $P = 0.02$).

Relationships between Post-Ranging Welfare Indicators of R Chickens and the Amount of Range Use Lower weight gain from pre- to post-ranging was associated with more range visits and more time spent on the range (interaction between time point (pre- and post-ranging) and amount of range use: total number of range visits $F_{(1226)} = 21.95$, $P < 0.01$; total time spent on the range $F_{(1226)} = 9.67$, $P \leq 0.01$). Greater retention of breast plumage cover from pre- to post-ranging was associated with more range visits (interaction between time point and number of range visits: $F_{(1226)} = 5.71$, $P = 0.02$) but not with total time spent on the range ($P = 0.14$).

There was no interaction between pre- and post-ranging gait score and ranging, however there was a main effect of gait score for range visits and time spent on the range (total number of range visits: $F_{(1219)} = 5.70$, $P = 0.02$; total time spent on the range: $F_{(1215)} = 10.64$, $P < 0.01$). A lower ascites index was associated with more range visits ($F_{(1,53)} = 8.50$, $P = 0.01$) but not total time spent on the range ($F_{(1,53)} = 3.80$, $P = 0.06$). The presence of pericardial fluid was associated with less time spent on the range ($F_{(1,44)} = 4.37$, $P = 0.04$) but not the total number of range visits ($P = 0.10$).

After range access, FPD and HB and plumage cleanliness (vent, breast and overall) scores increased (all $P < 0.05$) and overall plumage cover scores decreased (more plumage cover) ($P < 0.01$) but none of these measures were related to the number of range visits (FPD $P = 0.39$; HB $P = 0.16$; cleanliness: vent $P = 0.60$, breast $P = 0.31$, overall $P = 0.90$; overall plumage cover $P = 0.14$) or total time spent on the range (FPD $P = 0.79$; HB $P = 0.16$; cleanliness: vent $P = 0.17$, breast $P = 0.20$, overall $P = 0.69$; overall plumage cover $P = 0.09$). The amount of range use was not related to FHN scores (ranging frequency: $P = 0.72$; ranging duration: $P = 0.54$).

DISCUSSION

Individual tracking of ranging behavior revealed that ranging chickens in summer flocks had reduced growth, better gait scores, and lower ascites index and presence of pericardial fluid than non-ranging chickens after range access. Furthermore, for summer flocks, higher frequency, or duration of ranging was linked to reduced growth, retention of breast plumage, improved gait score, and better cardiovascular function (reduced ascites index and fewer instances of pericardial fluid) after range access. Weight, plumage cover, and gait score before range access were also associated with the broilers' subsequent ranging behavior in summer flocks, although these welfare indicators only explained a small proportion of the variance in ranging behavior, suggesting that other factors were associated with ranging behavior. Ranging chickens in winter flocks had more breast plumage cover before and after range access and cleaner overall plumage after range access compared to non-ranging chickens but no other differences between ranging and non-ranging birds were identified. It is difficult to determine why there were minimal relationships identified between ranging and welfare in winter flocks, but the variation could be related to seasonal effects, the rarity of severe scores (e.g., gait scores) in winter flocks, the age of data collection or minimal ranging behavior. This represents to date the most comprehensive report of the relationship between ranging behavior and the welfare of free-range broilers at the individual level. We discuss below possible explanations for the relationships identified, although we cannot infer causality.

Pre-Range Access Welfare Indicators

Typically, consumers believe that accessing an outdoor range positively affects the welfare of an animal (de Jonge and van Trijp, 2013; Howell et al., 2016). Notably, we provide evidence that the welfare state of a broiler chicken may also influence ranging behavior when the opportunity is provided. In summer flocks prior to range access, chickens that later accessed the range weighed less than chickens that would never access the range and lower pre-ranging weight predicted the total number of range visits, greater overall plumage cover predicted the total time spent on the range and pre-ranging gait scores predicted both the number of visits and total time spent on the range.

Gait scores prior to range access ranged between normal and affected, and only 1 lame chicken was observed. Thus, the relationship between reduced ranging activity and higher gait scores prior to range access could have different causes. The inability to differentiate painful leg pathologies and impaired walking ability due to unbalanced body conformation limits the interpretation of the gait scoring method (Skinner-Noble and Teeter, 2009; Sandilands et al., 2011; Caplen et al., 2012;2013). However, a self-administering analgesic study by Danbury et al. (2000) provides evidence that gait scores of 3 and above in broiler chickens are painful. As we saw only 1 gait score above 2 prior to range access, the relationship between ranging and gait score is likely a reflection of differences in weight and body confirmation, rather than painful leg pathologies. Furthermore, we observed no clinical signs of TD and no relationships between ranging and FHN scores. However, despite measuring TD and FHN, the most common leg pathologies in broilers (McNamee et al., 1999; SCAHAW, 2000), chickens may have been suffering from other leg pathologies.

Previous studies have shown a relationship between the provision of range access and broiler chicken weight (Castellini et al., 2002; Durali et al., 2012) and specifically more time spent on the range and lower post-ranging weight (Durali et al., 2014). However, this is the first report of weight difference prior to range access and associations with subsequent ranging behavior. Increased body weight can negatively impact activity levels in broiler chickens (Rutten et al., 2002; Bokkers et al., 2007). However, the relationship between pre-ranging weight and subsequent ranging frequency observed in the current study may reflect other variables that were not measured, such as motivation to explore and forage. It is possible for instance that ranging individuals are more active in early life and thus have lower body weight, while being simultaneously more likely to use the range.

In summer flocks, pre-ranging plumage cover (overall) was predictive of more time spent on the range. Feathers contribute to heat loss resistance (Deschutter and Leeson, 1986) and therefore it is plausible that the degree of plumage cover may protect chickens from extreme wind speeds and temperatures on the range. However, this effect was not seen in winter, when theoretically it would be more pronounced, although it may not have been evident due to minimal ranging and the shorter period of time the chickens were tracked. Alternatively, it could be a seasonal effect on plumage growth, as Yalcin et al. (1997) showed that 4- to 7-week-old broilers have greater plumage cover in summer compared to winter, despite relatively small differences in temperature (20 to 27°C). This seasonal effect was apparent in the current study as summer flocks had higher plumage scores compared to winter flocks prior to range access. Our results indicate that the likelihood of accessing the range in summer is *not* related to plumage cover, as we found no difference between ranging and non-ranging chickens, but individuals may choose to spend less time on the range if plumage cover is reduced. A greater understanding of these relationships is required before practical recommendations can be made on ranging opportunities relative to plumage cover.

Post-Ranging Welfare Indicators

The differences in post-ranging body weight in relation to range use could be a sustained effect of pre-ranging lower body weight rather than an effect of range use *per se*, even though pre-ranging weight was controlled for in our analysis. Previous studies report conflicting results regarding the relationships between body weight and ranging behavior, which may reflect variation in strains (growth rate) or ranging behavior (Weeks et al., 1994; Jones et al., 2007; Durali et al., 2014; Tong et al., 2015; Stadig et al., 2016). However, our results are in agreement with Durali et al. (2014), who individually tracked ranging behavior of faster-growing broiler chickens and reported a reduction in body weight in relation to more time spent on the range on a commercial farm. Weight reduction related to ranging behavior could be due to redirected energy towards thermoregulation, stress responses, activity levels, consuming alternate feed, or a combination of factors and further research is required to clarify the mechanism involved.

Lower (better) gait scores after range access were more prevalent in ranging chickens. Such relationships suggest that accessing the outdoor range may improve leg health, in agreement with previous studies using scan sampling methods (Jones et al., 2007; Fanatico et al., 2008). As foraging and active behaviors are observed more frequently on the range compared to the indoor shed (Weeks et al., 1994; Jones et al., 2007; Fanatico et al., 2016), accessing an outdoor range has the potential to improve muscle and bone strength through increased activity (Thorp and Duff, 1988; Reiter and Bessei, 1996). We did not monitor activity or muscle and bone characteristics and thus cannot identify the potential mechanism of the relationships identified. As we did not find any association with FHN or TD, we find no evidence that ranging behavior is related to predominant broiler chicken leg pathologies. Furthermore, we cannot infer causation; although we statistically controlled for pre-ranging gait scores, we cannot reliably rule out that good leg health encourages ranging or that relationships with gait scores are a reflection of morphological differences (see previous discussion of gait scoring methodology). Nonetheless, we further highlight an important relationship between gait scores and range use that warrants further investigation.

In summer flocks, the ascites index and presence of pericardial fluid was lower in chickens that accessed the range compared to chickens that never accessed the range and was related to the amount of range use. Such results may indicate that better cardiovascular function enables chickens to be more active and subsequently increase range use, alternatively these relationships may indicate improvements to cardiovascular function in response to ranging, although scores remained below the suggested index indicative of subclinical ascites of 0.29 (Wideman, 2001). Herenda and Jakel (1994) indicated that conventionally housed chickens had higher instances of ascites at slaughter age than free-range chickens, but they did not monitor individual ranging behavior or other causes for it. An alternative measure of cardiovascular function that does not require euthanasia should be investigated to infer a causal relationship.

This study highlights the importance of monitoring individual ranging behavior, rather than flock ranging behavior. Tracking the frequency of range use permitted a clearer understanding of relationships between individual ranging behavior and welfare states. However, our findings were only relationships. Evidence of causality would require controlled experiments. Nevertheless, this study provides guidance for future controlled research with outcomes applicable to commercial situations. We observed the welfare implications on 4 flocks across 2 seasons, but all trials were completed on only 1 farm and 1 broiler chicken strain and thus the extrapolation of these results as they relate to other farms should be carefully considered, especially as a number of factors influence ranging behavior. Post-ranging welfare parameters reported in the current study were measured between 30 and 33 d of age in winter flocks and 42 and 46 d of age in summer flocks, therefore it is not surprising to find disparity in the presence and severity of some measures as many of the welfare measures are affected by age and growth; ascites (Julian, 1993), leg health (Vestergaard and Sanotra, 1999), dermatitis (Kjaer et al., 2006), plumage scores and body weight (Gous et al., 1999).

CONCLUSIONS

We identified a number of relationships between ranging behavior and welfare, such as improvements in breast plumage cover, gait scores and cardiovascular function, and a reduction in weight which require further research to understand causation and the mechanisms involved. A greater understanding of these relationships will allow for science-based improvements in the welfare of commercial free-range broiler chickens.

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