A comparison of two manual catching methods of broiler considering injuries and behavior

Jenny Wessel,* Elke Rauch,* Sandrina Hartmannsgruber,* Michael Erhard,* Paul Schmidt,† Benjamin Schade,‡ and Helen Louton[§,1]

*Chair of Animal Welfare, Animal Behavior, Animal Hygiene and Animal Husbandry, Department of Veterinary Sciences, Faculty of Veterinary Medicine, LMU Munich, 80539 Munich, Germany; †Paul Schmidt, Statistical Consulting for Science and Research, 13086 Berlin, Germany; ‡Bavarian Animal Health Service, Department of Pathology, 85586 Poing, Germany; and §Animal Health and Animal Welfare, Faculty of Agricultural and Environmental Sciences, University of Rostock, 18059 Rostock, Germany

ABSTRACT The aim of this study was to compare the 2 manual catching methods in terms of injuries and behavior. Throughout 12 loadings on practical farms with the same standard, 1 container each was caught using the one-legged (**1LCM**) and 1 using the two-legged catching method (**2LCM**). The animals were filmed during loading to evaluate their behavior and subsequently examined regarding injuries. Wing flapping was observed more frequently in broilers caught with the 1LCM than 2 LCM. Carrying animals with neighbors (1 neighbor: $P < 0.001$; 2 neighbors: $P < 0.001$) and a grasping position at or above the tarsal joint ($P < 0.001$; $P < 0.054$) reduced wing flapping in both methods. A short grasping duration ($P = 0.004$), settling the broilers into the crate ($P = 0.005$) and avoiding striking the broilers against the crate ($P < 0.001$) reduced the occurrence of wing flapping. About 1.1% of 1LCM and 0.43% of 2LCM broilers were diagnosed with an epiphysiolysis. Catching with the 1LCM ($P = 0.042$), loading in lower crates (low vs. middle: $P = 0.005$; low vs. high: $P = 0.008$), a longer catching duration (p = 0.025) and female broilers ($P = 0.007$) had a higher chance for epiphysiolysis. Broilers loaded in lower crates ($P = 0.007$) and ones which showed more wing flapping ($P = 0.015$) had a higher chance for hematomas. A higher loading duration led to a higher risk of hematomas (prevalence: 1.5%) and a prevalence of 1.0% of broilers with severe injury in 2LCM in a simultaneously performed study (mechanical loading vs. 2LCM), in which manual loadings of entire barns were evaluated. This may be caused by fatigue of the workers. In summary, the catching method or number of grasped legs is not the decisive factor, but the compliance and implementation of the identified risks and careful handling of the animals are determining factors to reduce wing injuries caused by loading and wing flapping.

Key words: broiler, manual catching, behavior, injury, loading

2022 Poultry Science 101:102127
https://doi.org/10.1016/j.psj.2022.102127

INTRODUCTION

Animal welfare and ethics in livestock husbandry with special attention to the areas of transport and slaughter have become more and more the focus of society in recent years (German Federal Ministry of Food and Agriculture, 2015). Germany is the second largest country in the EU for poultry meat production, with domestic broilers dominating (German Federal Ministry of Food and Agriculture, 2019). The topics injuries and animal behavior are increasingly being included in research programs funded by the German Federal Ministry of Food and Agriculture. In 2021, 625,824,778 broilers, corresponding to 1,081,009,023 tons, were loaded and slaughtered in Germany (Statistisches Bundesamt, 2022). Manual loading of broilers is the predominantly used method of loading in this region (Louton et al., 2022).

Catching broilers represents a critical point in terms of stress (Duncan et al., 1986; Queiroz et al., 2015) and injuries (Knowles and Broom, 1990; Nijdam et al., 2005a; Langkabel et al., 2015; Kittelsen et al., 2018). As early as 1987, de Koning et al. (1987) described manual catching of broilers as an unhealthy work that causes a lot of injuries to the broilers and affects the broilers' welfare. De Koning et al. (1987) observed that broilers carried by 1 leg and inverted during manual catching had

Received May 31, 2022.
Accepted August 3, 2022.

[1]Corresponding author: helen.louton@uni-rostock.de

significantly more injuries than during mechanical catching. In 1995, it was recommended that the catching should take place by grasping 2 legs and in an upright position (European Commission, 1995). In the one-legged catching method (**1LCM**), 3 to 4 broilers per hand are grasped by the leg and carried inverted to the container (Bayliss and Hinton, 1990). In comparison, a maximum of 2 broilers per hand can be caught by the two-legged catching method (**2LCM**) (Langkabel et al., 2015).

Our study was part of a larger project with 2 further subprojects, published by Wolff et al. (2019) and Mönch et al. (2020). Wolff et al. (2019), investigated the stress parameters of broilers comparing the 2LCM and mechanical loading. Mönch et al. (2020) investigated the welfare impacts and circumstances during loading of 2LCM and mechanically loaded broilers. Wolff et al. (2019) observed that 68.6% of the broilers showed wing flapping during the 2 LCM. Further recent studies assessed the behavior of broilers during loading with a detailed focus on wing flapping (Langkabel et al., 2015; Kittelsen et al., 2018; de Lima et al., 2019). De Lima et al. (2019) investigated the agitation of broilers carried around the abdomen in an upright position. The broilers were filmed during manual catching and then evaluated for agitation in the hand of the catcher, striking into the crate entrance and agitation in the crate (De Lima et al., 2019). Kittelsen et al. (2018) compared 2LCM and a manual "upright method" and described the crating of the broilers as a critical point in the catching process. However, these studies were based on general observations of loadings. There are no other detailed studies to date.

In previous studies, it was observed that the majority of injuries resulting from catching and transport were fractures, dislocations and bruises of legs, wings and breast (de Koning et al., 1987; Nicol and Scott, 1990; Gocke, 2000; Nijdam et al., 2005a; Langkabel et al., 2015; Jacobs et al., 2016; Kittelsen et al., 2018; Mönch et al., 2020). Gocke (2000) dealt with the comparison of 1LCM and mechanical catching and observed the majority of injuries on the wing. Hematomas on the wing occurred in 1.3% and fractures of the wing in 0.77% of manually caught broilers (Gocke, 2000). Mönch et al. (2020) found severe wing injuries in 1.0% of the manually caught broilers examined directly after catching on-farm and hematomas of the wings in 1.5%. Already in an earlier study by De Koning et al. (1987), 11.8% of the broilers showed a hematoma on the wing, however, the broilers were examined at the slaughterhouse after plucking. Nijdam et al. (2005a) performed a postmortem examination of broilers after 1LCM at the slaughterhouse and wing bruises occurred in 6.7 to 8.4%. Jacobs et al. (2016) investigated the injuries before catching, after catching, after lairage and postmortem. The authors observed that wing fractures increased significantly after catching and there was only a minor increase of 0.1% after lairage and postmortem. A study by Langkabel et al. (2015) compared 1LCM and 2LCM for light and heavy broilers, the assessment of injuries was performed at the slaughterhouse. The catching methods did not differ regarding the injuries (Langkabel et al., 2015).

The aim of this study was to compare 1LCM and 2LCM in terms of behavior and injuries during loading. A further goal was to identify risk factors of the behavior of broilers which could cause injuries. The examination of the broilers considering loading injuries immediately after loading was linked to the video evaluation of the same broilers. This type of study is unique and could help to improve animal welfare during loading and to develop new guidelines.

MATERIALS AND METHODS

Animals and Barns

The data collection took place from May 2018 to August 2018. The application for an animal experiment and ethical endorsement was approved by the administration of Upper Bavaria, Germany (reference number ROB-55.2Vet-2532.Vet_02-17-55). The 12 loadings were examined at 7 different broiler farms. The farms had a fattening capacity of 20,000 to 50,000 broilers, were all located in Bavaria, Germany and owned by the Brüterei Süd ZN of the BWE-Brüterei Weser-Ems GmbH & Co. KG, Regenstauf, Germany. The tests were carried out in male and female conventional Ross 308 broilers housed in mixed flocks as hatched in the final fattening age of 38 to 40 d with an average live weight of 2.331 kg to 3.114 kg (Table 1). The animals were kept in accordance with the German Order on the Protection of Animals and the Keeping of Production Animals (2006). Furthermore, the flocks had to fulfil the following criteria: an average health status without antibiotic treatment in the last 10 d and a cumulative mortality rate of <6%. All farms were closed barns were equipped with a forced ventilation, 2 floors with 8 compartments on each farm (4 on the ground floor, 4 on the first floor), a maximum stocking density of 35 kg/m^2 and the same standard on equipment and animal welfare, including straw bales and pecking stones (at least 1 item per 150 m^2) and a permanently loose, dry and soft bedding material consisting of straw pellets (Society for the Promotion of the Animal welfare in livestock farming mbH, 2019). For the assessment of the catching methods at loading, 1 of the 8 compartments of each barn with an average of 8,679 broilers was chosen per loading. Details of the flocks included in the study are given in Table 1 (number of loaded animals, production week of the parental flocks, number of fattening days, mortality, average broiler weight, target stocking density in the crate).

Catching Methods

During loading, 2 containers were caught from the same flock, 1 each by the method of "one-legged" catching (1LCM) and 1 by the method of "two-legged" catching (2LCM) immediately one after the other. Before loading the containers, the catchers were instructed with which catching method they should catch. The order of applied methods was chosen randomly and changed within the loadings. The broilers were caught

Table 1. Overview of the flock and the environmental conditions during loading.

Loading	Examination	Number of loaded animals	Production week of the parental flocks	Mortality %	Average temperature (outdoor) C°	Average humidity (outdoor) %	Target stocking density in the crate	Age (in fattening days)	Average broiler weight g	Average light intensity (inside) lux
1	EPL	10,828	6; 12	3.3	26.13	36.4		39	2,807	
	1LCM						240	40	2,756	1.71
	2LCM								2,794	1.71
2	EPL	8,070	13	4.5	13.50*	85.5*		39	2,689	
	1LCM						240	40	2,729	n/a
	2LCM								2,756	n/a
3	EPL	8,179	34	4.2	24.80	50.2		40	3,076	
	1LCM						240	41	3,114	0.50
	2LCM								3,086	0.50
4	EPL	8,221	1	3.0	26.94	55.8		39	2,662	
	1LCM						240	40	2,580	0.66
	2LCM								2,653	0.50
5	EPL	8,532	0	4.1	26.942	55.8		39	2,616	
	1LCM						224	40	2,567	0.17
	2LCM								2,619	0.17
6	EPL	8,773	1	2.8	34.14	36.1		37	2,356	
	1LCM						240	38	2,407	0.33
	2LCM								2,410	0.66
7	EPL	8,450	3	4.2	17.28	76.9		37	2,453	
	1LCM						240	38	2,415	0.50
	2LCM								2,476	0.33
8	EPL	8,527	4	2.5	24.31	47.5		37	2,471	
	1LCM						240	38	2,631	0.33
	2LCM								2,612	0.33
9	EPL	8,500	7; 18; 24	2.9	26.35	42.2		38	2,569	
	1LCM						224	39	2,621	0.50
	2LCM								2,576	0.33
10	EPL	8,327	8; −1; 18; 7	5.4	25.10	50.0		37	2,365	
	1LCM						208	38	2,331	0.17
	2LCM								2,357	0.17
11	EPL	8,900	1	3.3	23.23*	49.0*		39	2,427	
	1LCM						240	40	2,406	0.33
	2LCM								2,411	0.16
12	EPL	8,844	1	4.7	27.02	42.8		38	2,402	
	1LCM						240	39	2,382	0.66
	2LCM								2,411	0.50
Mean	EPL	8,679	/	3.7	22.40	44.7		38.25	2,395	
	1LCM						234	39.25	2,578	0.53
	2LCM								2,597	0.49

Abbreviations: EPL, examination prior loading; 1LCM, one-legged catching method; 2LCM, two-legged catching method; n/a, not available.
*On the basis of the nearest weather station.

GRASPING	1. **Escape behaviour:** Running or flying away from the catcher 2. **Grasping attempts:** Attempts that a catcher needs to catch a broiler 3. **Re-Grasping:** the catcher has to grab one leg of the same broiler several times to catch it 4. **Dragging along:** the catcher pulls the broiler over the ground during grasping, it can overturn (overturning was not noted separately) 5. **Grasping Position (GP):** Position at the leg where the catcher grabs the broiler (in the area of, or just above, the metatarsophalangeal joint (GP1); just below the tarsal joint (GP2); in the area of, or above, the tarsal joint (GP3) 6. **Wing flapping :** the catcher has already grasped the animal, but it is still on the ground 7. **Neighbor:** simultaneously carried broilers, which are either held in one or two hands against each other
CARRYING	1. **Wing flapping:** from the moment the broiler no longer touches the floor and the way it is carried by the catcher to the crate 2. **Neighbor:** simultaneously carried broilers, which are either held in one or two hands against each other
CRATING	1. **Striking against the container:** the broiler strikes with the wing against a part of the container **Crating Type** **2.1 Settling:** the catcher places the broiler in the crate, broiler is released when touching the ground of the crate **2.2 Dropping:** the catcher drops the broiler in the crate, broiler is released before touching the ground of the crate **2.3 Throwing:** the catcher throws the broiler in the crate, broiler is released with force towards the crate 2. **Position of the crates:** each container consists of 8 crates in total. 4 on each side. **3.1 High:** the two top crates of the container on the right and on the left side **3.2 Middle:** the four middle crates of the container on the right and on the left side **3.3 Low:** the lowest two crate of the container on the right and on the left side 4. **Wing flapping:** from the moment the broiler is crated by the catcher and the catcher releases the broiler 5. **Neighbor:** simultaneously carried broilers, which are either held in one or two hands against each other

Figure 1. Ethogram and definitions of the procedure for evaluating the behavioral observations.

by teams of specialized company-owned catching groups. Four workers, who were randomly selected from a pool of 26 workers, were responsible for loading the 2 containers (2 workers on each side of the container), thus the animals of the containers of each method per sample (loading) were loaded by the same 4 workers. In the 1LCM, the broilers were grasped at 1 leg and carried upside down to the container while holding several broilers against each other and placed in the crate. Using this method, 1 person could carry 2 to 3 animals per hand. In the 2LCM, the broilers were grasped at both legs and carried upside down to the container, using this method 1 person could carry 1 or 2 animals per hand. The broilers were held upside down individually or against each other. The metal containers of the type GP live bird container supply system from the company Marel (Austurhraun 9, Gardabaer, IS-210 Iceland; Figures 1 and 2) were driven into the barn by a forklift driver and placed directly in front of the animals in the bedding. The broilers were loaded with an average density of 29 animals per crate. The specified target stocking density of numbers of broilers per crate was indicated by the abattoir (Table 1) and the corresponding variances were noted during examination.

Interobserver Reliability Test

Before the first loading, training and an interobserver reliability test was performed by 4 veterinarians (3 trained and 1 untrained) in a test loading. This included a careful visual assessment and palpation of 100 broilers (Ross 308) for loading related injuries of the wing and legs (minor injury: hematomas (≥0.5 cm), severe injury: fractures (different types of bone fractures affecting the diaphysis) and epiphysiolysis (injuries involving the epiphyseal plate; Figure 3) and sexing. The assessed variables are shown in detail by Mönch et al. (2020). Three of these 4 veterinarians performed the examinations during the 12 loadings whereby 1 was constantly present whereas the others alternated.

Figure 2. Metal container of the type GP live bird container supply system from the company Marel (Austurhraun 9, Gardabaer, IS-210 Iceland). The container consisted of a metal frame with a total of 8 crates, divided into 2 sides (left and right) with 1 low (green), 2 middle (yellow), and 1 high crate (red) on each side; each crate is opened and closed manually during loading.

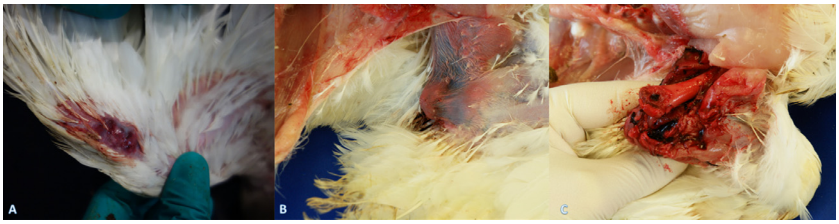

Figure 3. Examples of evaluated minor (A) and severe injuries (B, C). (A) Hematoma of the wing. (B) Closed epiphysiolysis of the right distal humerus with subcutaneous hemorrhages. (C) Open epiphysiolysis of the right distal humerus with subcutaneous hemorrhages.

Examination Prior Loading

The day before loading, 2 behavior tests to evaluate the approach (approach test = stationary person test) and the avoidance (avoidance distance touch test and the avoidance distance) of the broilers were performed to estimate the broiler-human relationship and the fearfulness of the flock. The test procedures were carried out as described by Graml et al. (2008) and Wolff et al. (2019). The performing person was always the same and wore a blue overall. The light was dimmed to an average value of 2.1 lux (measured in a six-side measurement with a testo 545 − Luxmeter, Testo SE & Co. KGaA, Titisee - Neustadt, Germany) for the tests, to minimize the influence of light intensity. In addition, it was not possible to perform the tests at a higher light intensity, as the broilers were not used to the test person within a high light intensity and would thus have been too restless, leading to a high risk of injury.

The approach test evaluates the approach of animals to an observer. The examining person stood quietly against the wall in 3 selected positions with the direction of a view toward the flock. The 3 positions were on the right or left long wall of the barn. The first chosen position was close to the beginning of the long side of the barn, the second position was between the beginning and about half of the wall of the long side of the barn and the third position was about halfway up the long side of the barn. The defined places were kept as equal as possible in all barns approximately at the same distance and approximately with the same light conditions (not directly at the ventilation slots). The examining person filmed at all 3 positions for 2 min with the camera in front of the chest, always at the same height of approximately 130 cm, stood still and the tips of the feet were centered in the camera image. Analogous to the work of Wolff et al. (2019), the videos were evaluated with the help of the program "Kinovea 0.8.15" (Kinovea organization, www.kinovea.org, France). For this purpose, a defined virtual box given by the program was used. This box was centered at the height of the feet of the observer. In each of the 3 videos, the approaching broilers were counted. To exclude a possible influence of the different positions, an average value of the 3 videos was calculated. If a higher number of animals approached the observer and were counted in the defined area, a lower fear of humans was assumed.

The avoidance distance touch test was performed like described by Wolff et al. (2019). The performing person walked slowly (2 steps per second) with a stretched arm through the stable and tried to touch a broiler alternately on the right and left side every 5 steps by bending down to the broilers on the floor. The distance to the randomly selected animal was estimated to be 150 cm. Slowly but surely the animal was approached. If the animal showed an escape or avoidance attempt (both legs lifted from the ground), the distance from the observer to the animal was estimated and noted in centimeters (in increments of 10 cm) (= avoidance distance). Furthermore, all animals that were touched (avoidance distance of 0) were recorded. In total, this test was performed on 40 broilers per loaded flock. The average value of the number of touched broilers was calculated (avoidance distance touch test). Additionally, the avoidance distance, if the broilers escaped was considered (avoidance distance). If a higher mean value of the avoidance distance was observed, a higher stress level of the flock was assumed.

The pre-examination was performed in 200 broilers at 3 places (60 animals in the front of the barn, 80 in the middle and 60 in the back) in the selected flock under dimmed light conditions. A total of 2,400 broilers were carefully examined by visual assessment and palpation for minor and severe injuries (minor injury: hematomas ($\geq$ 0.5 cm), severe injury: fractures and epiphysiolysis of the wings and legs (Figure 3), and severe injuries of the skin. Furthermore, sex determination and recording of weight (with a Mettler Toledo ICS425 scale, Mettler Toledo GmbH, Gießen, Germany) was done. The broilers were carefully lifted upright and placed on the platform of the scale. The assessment methods were carried out as described in detail by Mönch et al. (2020). To examine the individual broilers under appropriate lighting conditions head lights were used. This assessment was done to assure, that observed injuries after loading were caused by the process of catching.

Main Examination

Climatic Circumstances Before the catching of each of the 2 containers, the light intensity in lux (testo 545 − Luxmeter, Testo SE & Co. KGaA, Titisee) was determined and the outside temperature in degree Celsius and humidity in percent (using LogBox RHT, B+B Thermo-Technik GmbH, Donaueschingen, Deutschland) was documented (Table 1). Due to technical problems, the temperature data for 2 loadings were missing. These were reconstructed with the help of the recordings of the weather stations of the German Weather Service.

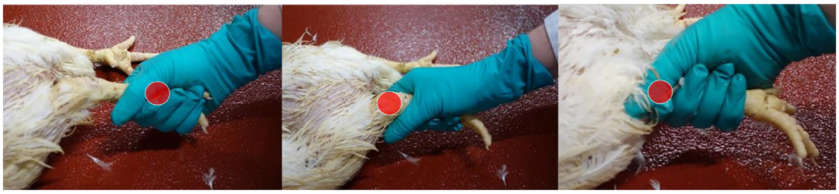

Figure 4. Evaluated grasping positions in the area of the limb, left: in the area of, or just above the metatarsophalangeal joint (Grasping Position 1 = GP1), middle: just below the tarsal joint (Grasping Position 2 = GP2), right: in the area of, or above the tarsal joint (Grasping Position 3 = GP3). The respective joints involved are marked with a red dot.

The distance from the farm to the weather station was measured (www.luftlinie.org) and the closest weather station in Metten, Germany, and Straubing, Germany, was chosen for these measurements. Furthermore, the following parameters were noted: number of loaded animals, production week of the parental flocks, antibiotic treatment, mortality in percent during fattening, age (in fattening days), target stocking density in the crate, and the container density in animals per container (Table 1).

Behavior To record the behavior of the broilers, the loading of the whole container of each loading was filmed with 2 Sony Cyber-shot DSC-RX100 cameras (Sony Europe Limited, Surrey, UK). On each side of the container 1 worker was filmed, the same worker for both catching methods. With the recorded video material, the observation of the behavior of 100 randomly chosen broilers loaded into the respective container (2 during each loading) was possible. During filming of the catching, it was necessary to create an imperceptible light source for the broilers, therefore a Nitecore torch (SYSMAX Innovations Co., Ltd., Guangdong, China) of type Chameleon CB6 (green light) was used. The permission of filming was obtained prior loading and human rights were maintained during filming. All behavioral observations (Figures 1 and 4) were evaluated with the program "Kinovea 0.8.15" (Kinovea organization, www.kinovea.org, France). The videos were viewed at a speed of 25.0% for evaluation and each broiler was closely observed. When evaluating the videos, the broilers always had to be completely visible in the picture for the assessment of the respective parameter. Because the catchers at times turned away from the camera while carrying the broilers, consequently inhibiting the evaluation of the behavior, it was determined that a broiler could be out of the picture section at maximum twice for a maximum of 2 s. Due to technical reasons, it was not possible to evaluate every broiler for all 3 types of wing flapping. This resulted in missing values for wing flapping at grasping and wing flapping in the crate. In the case of wing flapping during carrying in the air, each broiler had to be evaluable. If, for example, a broiler could not be evaluated during grasping or crating, but showed wing flapping when carried in the air, the broiler was entered in the statistics as "wing flapping". If, however, the broiler could not be evaluated during grasping and crating and did not show wing flapping when carried in the air, the broiler was not included in the evaluation and was listed as a missing value. This is the reason for the different percentages in the result section of general wing flapping (compare Table 2).

Injuries After loading, a total of 5,624 broilers were carefully examined with the same methods and by the same veterinarians who performed the pre-examination (1 veterinarian per container). After catching a forklift moved the containers to an empty section of the barn with good light conditions. First the sex was determined, and the weight was recorded (with a Mettler Toledo ICS425 scale, Mettler Toledo GmbH). Then the broilers were examined for loading related minor and severe injuries on wings and legs (Figure 3). The broilers were not x-rayed. All broilers that were diagnosed with severe injuries were not transported to the abattoir but killed on site for animal welfare reasons. They were stunned by concussion and then killed by cervical dislocation. All the culled broilers underwent a pathological examination to rule out other possible diseases that could have influenced the severe injuries.

Statistical Data Analysis

All analyses were performed with the statistical programming language R (R Core Team 2017). The data were first analyzed and summarized descriptively.

The interobserver reliability test was performed for sex, minor injuries, and severe injuries to the prevalence-adjusted and bias-adjusted kappa (**PABAK**) according to Byrt et al. (1993). Both, 2 and multiple categories, were calculated for observer agreement according to Gunnarsson (2000): ((k*p)-1)/(k-1) where k = the number of categories and p = the proportion of matching between observers.

Pearson's correlation coefficient was used for the examination prior loading. The values for avoidance distance touch test, avoidance distance and approach test were calculated for the individual loadings. The correlation between avoidance distance touch test, avoidance distance and approach test with the other parameters (weight, mortality, production week of the parental flocks) was further analyzed using multiple linear regression models.

For the analysis of the target stocking density a generalized additive model for location scale and shape (gamlss, Rigby and Stasinopoulos, 2005) was used for simultaneously analyzing the mean and the standard deviation with respect to differences along the catching methods.

Table 2. Overview of the average results of the 12 loadings considering behavioral observations and injuries.

Examination	Average loading duration Animals per hour	Average catching durations per animal	Average grasping durations per animal	Average container density Animals per Container	General wing flapping %	Wing flapping during grasping %	Wing flapping in the air %	Wing flapping in the crate %	Epiphysiolysis %	Hematomas %	Striking against Container %
EPL									0/2,400 0%	7/2,400 0.29%	
1LCM	8,048	3.25	2.41	234	987/1,121 88.0%	66/1,132 5.8%	970/1,160 83.6%	75/965 7.8%	31/2,819 1.1%	28/2,819 0.99%	78/934 8.4%%
2LCM	3,408	2.79	3.00	234	877/1,088 80.6%	40/1,142 3.5%	866/1,162 74.5%	23/839 2.7%	12/2,805 0.43%	17/2,805 0.60%	14/835 1.7%

Abbreviations: EPL, examination prior loading; 1LCM, one-legged catching method; 2LCM, two-legged catching method.

For the behavior part, the parameters were divided into experimentally controllable variables (catching type, neighbor, grasping position) and other covariates (avoidance distance touch test, approach test, temperature, weight, mortality, catching duration, grasping duration, settling, dropping, throwing, re-grasping). Temperature was not available for all loadings, so a linear regression model was formulated using the fully observed temperature data and using temperature data from nearby weather stations to impute the missing values. General wing flapping is composed of wing flapping at grasping, wing flapping in the air, and wing flapping in the crate. For simplification and due to the many missing values for wing flapping in the crate, the general wing flapping was coded as wing flapping or no wing flapping. If 1 of the wing flapping characteristics had a missing value, but another had a value not equal to 0, it was evaluated as wing flapping. The effects of the experimental variables and covariates on general wing flapping, wing flapping at grasping, wing flapping in the air, wing flapping in the crate, escape behavior, dragging along, striking against the container and re-grasping were estimated using logistic regression models. Results were presented as estimated risks and odds ratios (**OR**) along with their respective 95% uncertainty intervals (**95% CI**). For crating, a regression model for ordinal response variables was used. For the analysis of grasping attempts, a Poisson regression model for count data was chosen. Results for this model were presented as rate ratios.

For the analysis of hematomas and epiphysiolysis, the number of injuries along the crates was analyzed using Poisson regression models. Results for these models were presented as rate ratios. For the analysis based on individual animals with epiphysiolysis, logistic regression models were used.

RESULTS

Interobserver Reliability Test

The PABAK value of the interobserver reliability test for the gender was 0.98. For the minor injuries it was 1.0 and for the severe injuries 0.99.

Examination Prior Loading

Avoidance Distance Touch Test, Avoidance Distance, and Approach Test In the avoidance distance touch test an average of 15.0 to 47.5% of the animals were touched during the 12 loadings. The average avoidance distance varied between 0.36 m and 0.69 m. The average number of animals approaching the observer in the approach test was between 0 and 2. No correlation was confirmed between the avoidance distance touch test and the approach test (correlation coefficient: 0.34; 95% CI: −0.29; 0.76) or between the avoidance distance and the approach test (correlation coefficient: −0.28; 95% CI: −0.73; 0.35). Thus, a correlation between these tests could not be confirmed. None of the factors

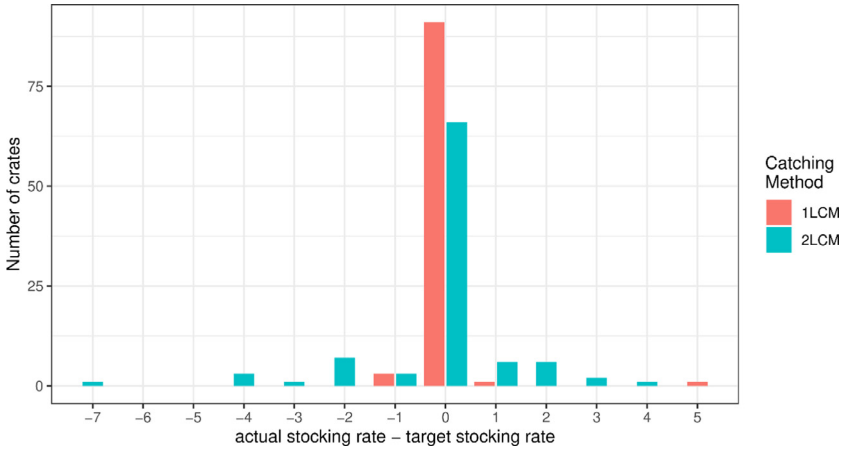

Figure 5. Compliance with and deviation from the target stocking density regarding the number of animals per crate for each catching method. Abbreviations: 1LCM, one-legged catching method; 2LCM, two-legged catching method.

considered (production week of the parental flocks, weight, mortality) had a significant effect on the result of the avoidance distance touch test, the avoidance distance or approach test. The effects of the avoidance distance touch test and approach test values on the other parameters collected during loading are described in the respective sections.

Minor and Severe Injuries There were 0.29% of broilers with hematomas and 0% of broilers with epiphysiolysis in the examination prior loading.

General Data

The catching types differed significantly in loading duration. The average loading duration of the one-legged catching method (1LCM) was less than 50.0% of the two-legged catching method (2LCM) (Table 2). Figure 5 shows the compliance with and deviation from the target stocking density regarding the number of animals per crate for each catching method. It is apparent that most of the deviations were observed in the 2LCM (1LCM: 5.2% deviations, 2LCM: 31.2% deviations). No systematic deviation of the catching method in a positive or negative direction was detected. However, in 1LCM, the deviation was in the range −1 to +1 broiler and in 2LCM it was −4 to +4. The deviations from the target stocking density of 2LCM differed from the 1LCM (SD 1LCM: 0.55; SD 2LCM: 1.45, $P < 0.001$).

Behavior

General wing flapping includes the wing flapping at grasping, wing flapping in the air and wing flapping in the crate. About 84.4% of the observed broilers show general wing flapping. Wing flapping in the air was the most observed behavior, 79.1% of the broilers showed this behavior. Wing flapping at grasping was observed in 4.7% and wing flapping in the crate in 5.4% of the crated broilers. Due to technical reasons, it was not possible to evaluate every grasping and crating process. Thus, the parameter wing flapping at grasping (2.1%) and wing flapping in the crate (28.7%) has missing values. It was also possible that a broiler showed wing flapping several times for the different parameters. Due to these aspects, the results do not sum up to 100% when adding the 3 wing flapping parameters.

General Wing Flapping Broilers caught with the 1LCM showed more wing flapping than broilers caught with the 2 LCM (Table 2). In both catching methods the risk for wing flapping decreased as more broilers were carried and with a more proximal grasping position (Figure 6). When carried without a neighbor the risk was comparable between the 2 catching methods (1LCM: 89.2%, 95% CI: 76.7−95.4; 2LCM: 84.2%, 95% CI: 71.5 −91.9; OR: 0.64, 95% CI: 0.32−1.3, $P = 0.218$). Carried with 1 neighbor the risk decreased for both methods (1LCM: 80.1%, 2LCM: 36.5%), however, the decline was more pronounced for 2LCM (OR = 0.14, $P < 0.001$), and was likewise observed for 2 neighbors (1LCM: 66.2%, 2LCM: 5.9%, OR = 0.03, $P < 0.001$). It should be noticed that in the 2LCM it is not possible to carry more than 2 broilers per hand. Broilers grasped in the area of, or above the tarsal joint (GP3) (Risk: 33.1%, 95% CI: 10.3 −68.1) had the least risk of wing flapping compared to broilers grasped just below the tarsal joint (GP2) (Risk: 71,1%, 95% CI: 56.7−82.2, OR: 0.20, 95% CI: 0.04−1.02, $P = 0.054$) or broilers grasped in the area of, or just above the metatarsophalangeal joint (GP1) (Risk: 88.7%, 95% CI: 80.5−93.6, OR: 0.06, 95% CI: 0.01−0.33, $P < 0.001$). An increase of the approach test (OR: 0.57, $P < 0.001$) and the grasping duration (OR: 0.82, $P = 0.004$), (more broilers approaching the human and a longer duration at grasping the broiler at catching) led to a reduction of the risk for wing flapping.

Wing Flapping at Grasping Since wing flapping at grasping was observed only very rarely (Table 2), an effect of catching methods with respect to grasping position was not observed at grasping. Positive effects were estimated for grasping duration (OR: 1.28, $P = 0.002$), dragging along (OR: 3.65, $P < 0.001$) and re-grasping (OR: 2.72, $P = 0.006$). However, due to the rare occurrence of this behavior all of these results need to be interpreted with caution.

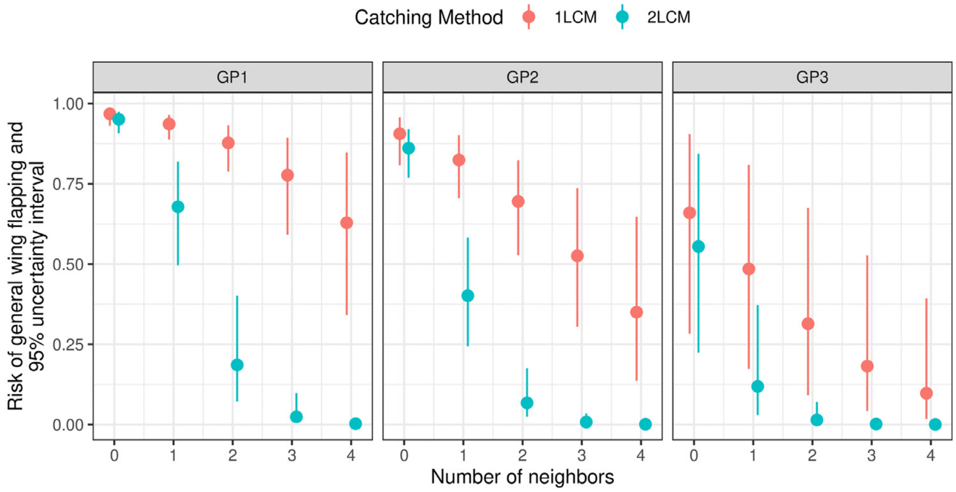

Figure 6. Risk of wing flapping and the 95% uncertainty interval of animals showing general wing flapping along the two catching methods (one-legged catching method [1LCM], two-legged catching method [2LCM]), the three grasping positions (GP) and the number of neighbouring animals. Abbreviations: GP1, in the area of, or just above, the metatarsophalangeal joint; GP2, just below the tarsal joint; GP3, in the area of, or above, the tarsal joint.

Wing Flapping in the Air Wing flapping in the air during carrying was observed frequently (79.1%) and more often in 1LCM (Table 2). Similar to general wing flapping, the risk for this behavior decreased in both catching methods with the number of broilers carried and with a more proximal grasping position (Figure 7). However, in contrast to general wing flapping, wing flapping in the air was also observed more frequently for 1LCM when carried without a neighbor (1LCM: 81.4%, 2LCM: 68.9%, OR: 0.51, $P = 0.016$). For 1 (1LCM: 67.8%, 2LCM: 19.3%, OR: 0.11, $P < 0.001$) and 2 (1LCM: 50.3%, 2LCM: 2.5%, OR: 0.03, $P < 0.001$) neighbors the difference between the 2 catching methods became more pronounced. The GP3 reduces the chance of wing flapping in the air compared to the GP2 or the GP1 (GP3 vs. GP1: OR 0.07, $P < 0.001$; GP3 vs. GP2: OR 0.18, $P = 0.04$). The grasping just below the tarsal joint (GP2) was also associated with less wing flapping in the air in contrast to the GP1 (GP2 vs. GP1: OR 0.39, $P < 0.001$). With increasing grasping duration, the chance of wing flapping in the air also increases (OR: 0.88, $P = 0.017$).

Wing Flapping in the Crate The rare occurrence of wing flapping in the crate was observed on average in 5.4% (98 broilers) of crated broilers (1,804 assessed broilers). Within the 1LCM the animals flapped their wings more frequently after being crated than with the 2LCM (Table 2), this difference was however not significant (OR: 0.36, $P = 0.464$). Neither an effect of the number of the simultaneously carried broilers nor an effect of the catching method could be confirmed (carried without a neighbor: 1LCM: 25.7%, 2LCM: 11.0%, OR: 0.36, $P = 0.464$; 1 neighbor: 1LCM: 14.2%, 2LCM: 9.1.3%, OR: 0.61, $P = 0.409$; 2 neighbors: 1LCM: 18.0%, 2LCM: 0%, OR: 0.00, $P = 0.984$). Furthermore, the grasping position had no influence on wing flapping in the crate

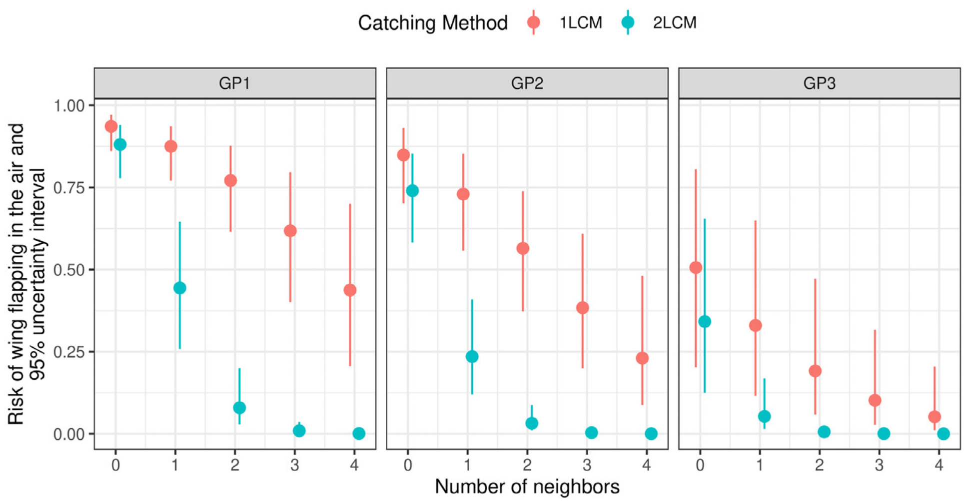

Figure 7. Risk of wing flapping and the 95% uncertainty interval of animals showing wing flapping at carrying in the air along the two catching methods (one-legged catching method [1LCM], two-legged catching method [2LCM]), the three grasping positions and the number of neighbouring animals. Abbreviations: GP1, in the area of, or just above, the metatarsophalangeal joint; GP2, just below the tarsal joint; GP3, in the area of, or above, the tarsal joint.

(GP2 vs. GP1: OR: 0.77, $P = 0.727$; GP3 vs. GP1: OR: 1.47, $P = 0.938$). However, considering the crating methods (settling, dropping, throwing), an increased chance of wing flapping in the crate was observed for the crating methods dropping (OR: 2.66, $P = 0.002$) and throwing (OR: 3.53, $P = 0.046$) compared to the crating method settling. Striking against the crate or parts of the container also led to an increased chance of wing flapping in the crate (OR: 3.65, $P < 0.001$).

Escape Behavior The escape behavior (running or flying away from the catcher) was observed in 0.80% of the animals of the 1LCM and in 0.40% of the 2LCM and was therefore not investigated in further detail.

Dragging Along The dragging along (catcher pulls the broiler over the ground during grasping, it can overturn) during grasping was rather rare and only observed in 6.9% of the caught broilers. There was no difference in the frequency of dragging along between the 2 catching methods (1LCM 6.9%, 2LCM 7.1%). However, a slight difference was observed between the individual grasping positions, broilers which were grasped with the GP1 were more frequently dragged along than broilers grasped with the GP3 (GP1 7.2%, GP2 5.5%, GP3 0%). Furthermore, the effect of the catching methods changed slightly along the grasping positions (1LCM and GP1 6.7%, 2LCM and GP1 8.3%, 1LCM and GP2 5.7%, 2LCM and GP2 5.5%, 1LCM/ 2LCM and GP3 0%). These descriptive analyses showed only slight differences and were not statistically significant. Also, the difference between the catching methods was not significant (2LCM vs. 1LCM: OR: 1.14, $P = 0.595$). The grasping duration had a significant effect (OR: 1.35, $P < 0.001$). The longer the grasping process took, the higher the chance of dragging the broilers along.

Striking Against Container About 8.4% of the 1LCM and 1.7% of the 2LCM were struck against the container (Table 2). A reduced chance for striking against the container was detected for 2LCM (2LCM vs. 1LCM: OR: 0.18, $P < 0.001$). Noteworthy is the effect of the weight: broilers with a lower body weight (average weight ranged from 2.331 kg to 3.114 kg) tended to have a higher chance of striking against the container (OR: 0.35, $P = 0.076$). No influence of the position of the crate was identified (crate position: middle vs. low: OR: 0.81, $P = 0.498$; high vs. low: OR: 0.77, $P = 0.624$).

Crating Crating was divided into 3 methods (settling, dropping, throwing). Overall, 80.2% of the broilers were settled, 17.3% dropped and 2.5% thrown. In the 1LCM 76.7% were settled, 19.5% dropped and 3.8% thrown, in the 2LCM 84.2% were settled, 14.8% dropped and 1.0% thrown. Broilers caught with the 2LCM had a higher chance of being settled than those caught by the 1LCM (OR: 2.69, $P < 0.001$). Broilers of the 1LCM were dropped or thrown more frequently (Dropping: 2LCM vs. 1LCM: OR: 0.41, $P < 0.001$; Throwing: Type: 2LCM vs. 1LCM: OR: 0.30, $P = 0.005$). A higher catching duration (Settling: OR: 1.82, $P < 0.001$; Dropping: OR: 0.51, $P < 0.001$), a higher weight of the broilers (Settling: OR: 9.86, $P < 0.001$; Dropping: OR: 0.10, $P < 0.001$) and being placed in high (Settling: high vs. low: OR: 8.66, $P < 0.001$) and middle crates (Settling: middle vs. low: OR: 2.23, $P < 0.001$; Dropping: middle vs. low: OR: 0.43, $P < 0.001$) favor settling and decrease the chance of dropping.

Grasping Attempts Additional grasping attempts were more frequently observed for 2 LCM (1 additional grasping attempt: 1LCM: 1.0%; 2LCM: 5.9%; 2 additional grasping attempts: 1LCM: 0%, 2LCM: 1.0%; 3 additional grasping attempts: 1LCM: 0%, 2LCM: 0.40%; 5 additional grasping attempts: 1LCM: 0%, 2LCM: 0.10%). More grasping attempts were required for 2LCM than for 1LCM (1LCM vs. 2LCM: Rate Ratio 8.68, $P < 0.001$) and thus led to a longer grasping duration (Rate Ratio: 1.15, $P = 0.024$).

Re-Grasping On average, the 2LCM (9.1%) required more re-grasping attempts than 1LCM (1.9%) (2LCM vs. 1LCM.: OR: 4.36, $P < 0.001$). With a longer grasping duration, the chance of re-grasping increased (OR: 1.23, $P = 0.001$)

Injuries

Minor Injuries In total, 0.80% of the broilers examined were diagnosed with a hematoma. Hematomas occurred slightly more frequently in broilers with 1LCM than with 2LCM (Table 2), this difference was not significant (Table 3). Of these, 60.7% of broilers with a hematoma in 1LCM were female and 39.3% were male. In 2LCM, 35.3% of the broilers with a hematoma were female and 64.7% male. The crate position had an influence on the occurrence of hematoma (Table 3). Broilers from lower crates had an increased chance of hematoma compared to broilers from middle crates. Similarly, a higher uniformity and increased wing flapping led to a higher chance of hematoma (Table 3).

Severe Injuries About 97.7% of the observed fractures were diagnosed as epiphysiolysis of the distal humerus. On average 0.76% of the broilers caught were diagnosed with an epiphysiolysis of the humerus after loading. Epiphysiolysis occurred more frequently in broilers caught with the 1LCM than in broilers caught with the 2LCM (Table 2). At 1LCM, 77.4% of the broilers with an epiphysiolysis were female and 22.6% were male, in 2LCM, 58.3% of the broilers with an epiphysiolysis were female and 41.7% were male. All broilers with a fracture had a Salter-Harris-Fracture Type I of the distal humeral epiphyseal plate (according to the results of the pathological examination). No signs of a predisposing disease were observed in the pathologic examination of these broilers. In both catching methods, the proportion of animals with epiphysiolysis varied between loadings. When considering the occurrence of epiphysiolysis along the 2 catching methods and the number of neighbors (simultaneously carried broilers), no association was observed, the same applies to the comparison of the grasping positions. A significantly higher chance for epiphysiolysis was observed in broilers caught by 1 leg (2LCM vs. 1LCM: OR: 0.39, $P = 0.006$), female broilers (female vs. male: OR: 3.04, $P = 0.007$), broilers loaded

Table 3. Factors influencing the occurrence of hematomas and epipysiolysis.

	Hematomas			Epiphysiolysis		
Factor	Rate ratio	95% CI	*P*-value	Rate ratio	95% CI	*P*-value
2LCM vs. 1LCM	1.034	0.320−3.335	0.956	0.228	0.055−0.950	0.042
Crate position: middle vs. low	0.179	0.052−0.618	0.007	0.101	0.020−0.496	0.005
Crate position: high vs. low	0.539	0.092−3.166	0.494	0.038	0.003−0.428	0.008
Sex	15.094	0.176−1291.105	0.232	1.111	0.010−122.816	0.965
Weight	1.000	0.996−1.004	0.987	0.997	0.994−1.001	0.176
Uniformity	42.884	1.063−1729.691	0.046	25.343	0.277−2317.940	0.161
Settling	0.987	0.966−1.008	0.216	0.988	0.968−1.009	0.257
Dropping	0.994	0.961−1.029	0.750	1.009	0.987−1.032	0.428
Striking against Container	1.011	0.956−1.069	0.700	0.988	0.931−1.048	0.680
Mortality	1.007	0.556−1.825	0.982	0.701	0.334−1.470	0.347
Avoidance distance touch test	1.030	0.967−1.097	0.363	1.084	1.000−1.176	0.050
Approach test	0.756	0.298−1.916	0.555	0.633	0.235−1.705	0.365
Wing flapping	1.047	1.009−1.087	0.015	0.997	0.966−1.028	0.827
Escape behavior	0.985	0.828−1.172	0.864	0.971	0.824−1.145	0.726
Dragging along	1.003	0.967−1.041	0.877	1.031	0.981−1.084	0.226
Re-grasping	0.950	0.884−1.021	0.160	1.038	0.976−1.103	0.233
Grasping duration	0.951	0.640−1.415	0.805	0.651	0.383−1.106	0.112
Catching duration	1.046	0.490−2.235	0.908	2.655	1.134−6.217	0.025
Parent animal production week	1.026	0.944−1.116	0.540	1.129	1.001−1.273	0.048
Difference of the target stocking density	1.023	0.699−1.497	0.908	0.996	0.626−1.585	0.986

Abbreviations: 1LCM, one-legged catching method; 2LCM, two-legged catching method.
Rate ratio and limits of the corresponding 95% uncertainty interval (= 95% CI).

in lower crates, broilers with a higher avoidance distance touch test, broilers with a longer catching duration and broilers with a higher production week of the parental flocks (Table 3).

DISCUSSION

Interobserver Reliability Test

Values for PABAK above 0.75 are considered as “excellent” agreement (Fleiss et al., 1981). In our interobserver-reliability test all values for kappa were between 0.98 and 1.0.

Examination Prior Loading

The avoidance distance touch test with the avoidance distance and approach test were used to assess the human-animal relationship and have already been validated for the use in laying hens (Graml et al., 2008). For the use in broilers, the avoidance distance test is recommended by Welfare Quality ® (2009) for the assessment of the human-animal relationship. Animals with frequent positive contact with humans show less fear of humans in these tests (Graml et al., 2008). Fear can be a powerful and potentially harmful stressor and can affect animal welfare (Jones, 1996). Certain fear responses can lead to injury and pain in intensive care systems (Jones, 1996). The combination of a touch test is suitable for testing the human-animal relationship (Johansson et al., 2015). Furthermore, these tests were already used in other studies to assess the human-animal relationship, in broilers (Keppler et al., 2009; Hakansson, 2015; Wolff et al., 2019) and in other animal species (Windschnurer et al., 2009). In the presented study, the tests were carried out to find out whether there was a correlation between the animal-human relationship or the stress level of the flock and the behavior of the broilers during loading, assuming a corresponding influence on loading injuries due to more wing flapping as avoidance behavior.

Wolff et al. (2019) showed an even wider range of broilers that could be touched and likewise a wider range in average avoidance distance than in our study. In our study, fewer broilers had approached the observer than in the study by Wolff et al. (2019). In our study, the barns always had the same structure, this was different in the study by Wolff et al. (2019), which would explain the different results despite the same genetics of the broilers. The structure of the housing could have an influence on the self-confidence of the broilers and thus on the animal-human relationship.

To detect injuries that had already occurred before loading, the broilers were examined for severe and minor injuries 1 day before loading. None of the broilers had an epiphysiolysis before loading and only 0.29% of broilers had a hematoma. Thus, it can be concluded that the observed injuries after loading were due to the loading of the broilers.

General Data

In this study, like in the study by Langkabel et al. (2015), 2LCM took approximately twice as long as 1LCM. 2LCM seems to be an even slower catching method compared to the “upright method” in which 1 or 2 broilers are grasped under the abdomen and carried in an upright position (Kittelsen et al., 2018). As an alternative to manual catching, mechanical catching with various types of catching machines is available (Duncan et al., 1986; de Koning et al., 1987; Gocke, 2000; Nijdam et al., 2005a; Wolff et al. 2019; Mönch et al, 2020). Catching and transporting broilers poses an increased risk of dehydration (Vanderhasselt et al., 2013) and feed deprivation, this is stressful for broilers and can have a negative effect on animal welfare (Nijdam et al., 2005b). Therefore, to keep the catching process as short as possible and thereby maintain animal welfare, it is important that catching personnel is well trained and available in an adequate number allowing a smooth catching process.

Stocking density in a crate was given by the slaughterhouse in our study. To avoid asphyxiation or heat stroke during hot weather, the number of broilers is reduced (Bayliss and Hinton, 1990). Bayliss and Hinton (1990) described that there should be enough broilers in the crate, however, to prevent lateral movement and resulting injury. Overstocking of crates can result in economic losses and stress to broilers in transport to the slaughterhouse (Delezie et al., 2007). Delezie et al. (2007) concluded that the effect of stress on broilers from increased stocking density is greater than from feed deprivation. Therefore, it is important to maintain an adequate stocking density in the transport crates. Our study (31.2% deviations) as well as Mönch et al. (2020) (64.0% deviations) showed that the 2LCM had a much larger variance in the stocking density of the crates. 1LCM on the other hand, showed only 5.2% deviations in our study. The larger deviation by Mönch et al. (2020) could possibly be explained by the fact that not only 1 container was loaded by the catching teams with the 2LCM as in our study, but the entire barn. Catchers become exhausted after a certain time (Delezie et al., 2006) and are no longer able to do their job with the necessary concentration and caution (Kettlewell and Mitchell, 1994; Nijdam et al., 2004). In addition, 2LCM places an even greater burden on the catching staff (Langkabel et al., 2015). In order to ensure efficient and animal welfare oriented loading, it would be necessary to increase the size of the catching teams, which would entail a greater financial effort (Nijdam et al., 2004). In our study 2 catchers placed the broilers in 1 crate. A good agreement between the catchers is necessary to maintain the previously determined target stocking density specified by the abattoir. It was noticeable that the catching was much easier for the catching staff using the 1LCM in terms of counting the number of broilers per catch. The slower loading duration and the greater variance in the stocking density suggests that the catching personnel had little practice in the 2LCM and therefore had to concentrate fully on the grasping technique. The counting of the broilers was probably neglected when using the 2LCM. Kittelsen et al. (2018) also found variation in stocking density. To solve these, Kittelsen et al (2018) also suggested training the catching personnel or hiring a catcher only for counting the broilers.

Behavioral Part

General Wing Flapping 88.0% of the broilers caught with the 1LCM showed wing flapping, this was significantly more frequent than in broilers caught by the 2LCM (80.6%). This is in contrast to observations by Langkabel et al. (2015) who observed more restless behavior with more wing flapping during 2LCM, especially at grasping. However, the authors did not provide detailed values for the different catching method and based their statement on general observations. Wolff et al. (2019) observed that flocks that showed a higher value of broilers that could be touched in the avoidance distance touch test showed significantly more escape behavior during manual catching. We could not confirm this in our study. Perhaps it is as Wolff et al. (2019) hypothesized, that broilers have little chance to escape when grasping and holding during manual catching. Additionally, the light intensity was kept low in our study and the broilers most likely did not see the approaching catchers. In our study, like in the study by Wolff et al. (2019), flocks of which more broilers approached the observer showed less general wing flapping during manual catching. The wing flapping at grasping, wing flapping in the air and wing flapping in the crate were analyzed separately in our study. To our knowledge, no studies on these behavioral observations during catching are yet available in literature.

Wing Flapping at Grasping Wing Flapping at grasping was observed rather seldom in the present study and did not show any significant differences between the catching methods. However, a longer grasping duration, dragging along and re-grasping led to a significant chance of wing flapping. Langkabel et al. (2015) observed that wing flapping occurred more frequently when broilers were held in the catcher's hand on the ground in order to grasp the second leg and second broiler. Similarly, in our study, more time was needed in the 2LCM and grasping the broilers in the 2LCM was more difficult for the catchers than in the 1LCM. Accordingly, a rapid and precise grasping of the broilers should take place to reduce wing flapping at grasping.

Wing Flapping in the Air Broilers of the 1LCM showed 83.6% wing flapping in the air and 74.5% of the 2LCM. It is possible that wing flapping is a natural righting mechanism in relation to being carried in an inverted position, but the present study clearly shows that it would be possible to reduce the chance of wing flapping by increasing the number of neighboring broilers and a proximal grasping position for both catching methods. Our observations were in line with the study by Wolff et al. (2019). Broilers carried with several other broilers at the same time showed less wing flapping. This effect was significantly more pronounced for the 2LCM in our study. It is possible that broilers feel more comfortable with neighboring broilers, are calmer as a result, and have less space available for wing flapping (Wolff et al.; 2019). It should be noticed however, that in the 2LCM it is not possible to carry more than 2 broilers per hand, thus 1 broiler having a maximum of 2 neighbors. In contrast to wing flapping at grasping, a shorter grasping duration led to increased wing flapping in the air. Probably the broilers were not securely fixed during the faster grasping and therefore the broilers showed more wing flapping in the air.

Wing Flapping in the Crate Like the wing flapping at grasping, the rarely observed wing flapping in the crate was also not affected by the catching method. The grasping position and the number of neighbors also had no effect. Broilers that were thrown, dropped, or struck against the container showed a significantly increased chance of wing flapping. As early as 1990, Knowles and Broom (1990) observed that mechanically caught broilers which dropped a few centimeters showed more wing flapping and were therefore more susceptible to injuries. De Lima et al. (2019) observed that broilers that were settled showed less agitation but struck the container more often than broilers that were dropped or thrown. This result was not expected and the authors assume that settling broilers is more difficult if broilers show agitation in the hand of the catchers and therefore increase the risk of dropping or throwing (de Lima et al., 2019). Similarly, in our study, broilers that were dropped or thrown and broilers that struck against the container showed more wing flapping in the crate. Langkabel et al. (2015) stated that the containers should be placed as close as possible to the broilers to minimize the chance of wing flapping. This seems especially necessary to improve the working conditions of the employees. In the presented study, catchers filling low crates tended to stay in a "bent" position and let the broilers drop during a shorter catching process and shorter distance, this led to more wing flapping. This may be improved by more intense training of catching personnel and frequent control of the quality of loading. It should also be noted that it may be possible that the broilers flap their wings when placing in the crate to maintain balance. The crating process is an important factor, however, due to technical reasons it is only rarely considered and evaluated. Further studies are useful to analyze this critical point.

Other Behavioral Observations The escape behavior was only rarely observed in the present study and was therefore not investigated further. This contrasts with the observations of Langkabel et al. (2015). In the 2LCM, the broilers showed more restless behavior overall and attempted to escape from the catching team and crowded into the back of the barn (Langkabel et al., 2015). During the catching process, escape behaviors occur and broilers may injure themselves (Knowles and Broom, 1990). Rough handling of broilers increases their fear behavior (Jones, 1992). Therefore, it can be assumed that a gentle and calm handling of the broilers will cause less escaping behavior and thus also reduces the risk of injuries.

Dragging along during grasping was found to be the same for both types of catching method. A proximal grasping position and a shorter grasping duration led to less dragging along, whereby interestingly the effect of the catching method seems to change along the grasping position. Again, better training of catchers could have a positive impact.

Kittelsen et al. (2018) described the crating process as a critical point. 2LCM resulted in significantly fewer striking against the container than 1LCM. Broilers caught by the 2LCM were significantly more frequently settled than broilers caught by the 1LCM. 23.3% of the 1LCM caught broilers were dropped or thrown into the crate. Kittelsen et al. (2018) observed that broilers loaded by the manual "upright method" were more carefully placed in the crates than broilers caught by the 2LCM. Like in the study of de Lima et al. (2019), in our study we assumed that the settling of the broilers in the 1LCM is more difficult due to the increased wing flapping. Also, broilers from lower crates were significantly more frequently affected. By results of interviews with the catchers, Millman et al. (2017) stated that manual catching of broilers is one of the most physically demanding jobs and because of the working conditions the workers try to do their job as fast as possible. This time pressure may lead to a more hectic handling of broilers and could result in mistakes such as striking against the container, dropping, or throwing broilers, imprecise grasping and faulty counting of the stocking density. Therefore, it seems necessary to improve the working conditions of the employees. This may be improved by more intense training of catching personnel and frequent control of the quality of loading. It was observed that more experienced catching teams caused fewer injuries (Taylor and Helbacka, 1968) as well as training and education of personnel (Pilecco et al. 2013). A shorter catching duration as well as a lower weight additionally favored dropping in our study. This can probably be explained by a more hectic and imprecise handling of light broilers, which could lead to an increased number of droppings. It should be noted again, that the 1LCM corresponded to a faster loading, therefore the lower rate of dropping or throwing in 2LCM could be explained by a more careful handling overall, rather than the number of grasped legs. It is unclear why broilers with a lower weight were less frequently dropped than the heavier ones. The idea that lighter broilers show more wing flapping than heavier broilers could not be confirmed in our study.

If a catcher could not grasp the selected bird and reached for the next one, this was noted as a grasping attempt. It was obvious that the catchers needed more grasping attempts for the 2LCM. On the one hand this could be because it is more difficult to grasp the "matching" second leg of the same broiler in a dark stable or due to the lack of practice of the 2LCM. Observations from other studies showed that the catchers took longer time to catch both legs of a broiler during 2LCM (Langkabel et al., 2015; Kittelsen et al., 2018).

Several grasping attempts resulted in a significantly longer grasping duration. A similar explanation would also be possible for the re-grasping. Re-grasping was noted if the catcher had to grasp the leg of the same broiler more than once. A longer grasping duration increased the chance of re-grasping. It seems logical that due to a longer grasping duration catchers become more hectic and want to get out of the uncomfortable bent position more quickly, which could result in an increased chance of re-grasping.

Injuries

In the German Animal Welfare Act (2006) it is stated that the welfare of the animal as a co-creature is to be protected. According to this, no animal may be harmed without reasonable cause (German Animal Welfare Act, 2006). Therefore, it is important to find out how injuries during catching can be avoided to protect the broilers' welfare.

Minor Injuries Hematoma is defined as an injury to tissue caused by a blunt object that does not result in an external rupture (Hamdy et al., 1957). An interruption of the vascular supply, with blood and fluid accumulating beneath the tissue occurs (Hamdy et al., 1957). In the first 2 min after trauma, there is no swelling or discoloration of the tissue in broilers (Hamdy et al., 1961). Hamdy et al. (1961) described discoloration of the tissue to red after 2 min. After 12 h it changed to diffused dark red-purple and after 24 h to diffused light green-purple, similar changes are described by Northcutt et al. (2000). In our study the broilers were examined directly (within about 10 min) after catching. Therefore, it can be assumed that at the time of the examination hematoma that happened during the catching were visible. Older hematomas (green) were distinguishable in color from fresh hematomas. Hematomas on the wing were rarely found on individual animals (on average 0.80%). In literature the proportion of animals with hematomas is cited from 0 to 0.48% (Langkabel et al., 2015), 3% ± 0.28 (Gocke, 2000), 8.4% (Nijdam et al., 2005a) up to 28.4% (Taylor and Helbacka, 1968). As in our study, hematomas commonly affect the wing (Gocke, 2000; Nijdam et al., 2005a). The catching method showed no significant influence in our study, like the observations by Langkabel et al. (2015). A significant influence of the crate position was observed considering the hematoma in the presented study. In broilers from lower crates, there was a higher chance for the occurrence of hematomas. This aspect coincides with the results for severe injuries. The crating process has already been discussed in the behavior sections. Wing flapping increased the chance for the occurrence of hematomas in our study. In the study by Kittelsen et al. (2018), broilers were not examined for hematomas because it is difficult to detect hematomas among feathered broilers. This could also be a reason why in the present study only few, and mostly animals with hematoma on the less feathered ventral wing were observed.

Severe Injuries Injuries involving the epiphyseal plate can be divided in 3 main types as follows: transection of the epiphysis by the epiphyseal plate, fractures crossing the epiphyseal plate and crushing of the plate itself (Salter and Harris, 1963). These injuries were divided into Type I-V epiphyseal-plate injury (Salter and Harris, 1963). The injuries observed in this study were predominantly (97.7%) epiphysiolysis of the Salter-Harris-Fracture Type I of the distal humeral epiphyseal plate (according to the results of the pathological examination). In this type, the epiphysis is completely separated from the metaphysis without fracturing of the long bone (Salter and Harris, 1963). In human medicine, this type is frequently found in birth injuries, where pull-off and shear forces play a role (Salter and Harris, 1963). After 190 d, ossification is largely complete in a bird (Martin and Ritchie, 1994). Therefore, a complete ossification of the epiphysis at slaughter of the broilers at an age of approx. 40 d is not expected. Like assumed by Mönch et al. (2020) it is therefore probable that mechanical forces play a major role in the genesis of epiphysiolysis. On the one hand, wing flapping could play a role, since enormous forces are exerted on the humerus by the pronounced chest muscles during this process, which can lead to a fracture of the epiphysis in this area of the body (Mönch et al., 2020). On the other hand, a mechanical effect, for example, striking an object (container), would also be conceivable. No correlation between wing flapping and the occurrence of injuries was observed by other authors (Langkabel et al., 2015; Kittelsen et al., 2018) which is in accordance with our study. It should be noticed though, that the results and conclusion of behavioral observations were drawn to the crates of containers. It was not possible to identify the individual animals on the videos and thus injuries were not tracked to single animals but to crates of a container. This is considered as one limitation of the study.

In the literature, epiphysiolysis is described in broilers at the proximal femur, which are caused by bacteriological chondritis and osteomyelitis (Thorp et al., 1993) and is often classified as femoral head necrosis (Bradshaw et al., 2002). Many different factors lead to disorders of the leg limbs (Bradshaw et al., 2002), including the rapid growth of broilers (Olkowski et al., 2011), which leads to reduced mineralization and maturation of the proximal femur and thus promotes lameness through mechanical irritation and subsequent bacterial colonization (Prisby et al., 2014). Changes in the bone matrix with increased proliferation of pathologically altered osteoclasts were observed by Olkowski et al. (2011). There may be an increased chance of epiphysiolysis due to a skeletal maturation disorder and this hypothesis may also be applicable to epiphysiolysis of the humerus. Mönch et al. (2020) also considered whether the rapid growth led to abnormal development in the epiphysial plate and thus to instability of the humerus. However, this could not be confirmed by the histological examinations by Mönch et al. (2020) or by our study. There was also no evidence of increased femoral head necrosis in either study. Female broilers showed a higher chance for the occurrence of epiphysiolysis in our study as well as in the study by Mönch et al. (2020). Also, Weeks (2007) described that 74.0% of the broilers with broken wings were females. However, faster growth and more leg limb abnormalities were more often seen in male broilers in previous studies (Classen and Riddell, 1989; Bradshaw et al., 2002). One explanation for a higher chance of epiphysiolysis in female broilers could be that females are lighter overall and thus may be loaded more hectically and carelessly by catching personnel. In our study, broilers with a lower weight were more likely to be dropped, which may lead to increased striking against the container. However, this contrasts with the observations of Langkabel et al. (2015), who observed fewer fractures in lighter broilers. In our study a significant influence of the weight was not revealed and there was no evidence suggesting a pathological alteration prior loading. Also, it was not possible to differentiate the sex in the video evaluation for technical reasons. Here it would be necessary to conduct further studies regarding the sex. Mönch et al. (2020) assumed that hormonal differences of female broilers could affect the occurrence of epiphysiolysis. Müsse et al. (2022) investigated the sexual dimorphism of broilers (Ross 308) with regard to the bone quality and found that female broilers had shorter and lighter tibiotarsi with a lower minimum diameter and a lower breaking strength of the bones (Müsse et al., 2022). The lower breaking strength of the bones would be an explanation for the frequent occurrence of epiphysiolysis in female broilers. To clarify the cause and pathology of the epiphysiolysis of the distal humerus, further studies should be carried out.

Our study as well as the study by Wolff et al. (2019) concluded that more research is needed on the influence of the human-animal relationship in terms of the occurrence of minor and severe injuries during loading.

In contrast to Langkabel et al. (2015), in the present study broilers caught by the 1LCM showed a significantly increased chance for the occurrence of epiphysiolysis. However, this result should be evaluated carefully, as the catchers were very cautious and slow in 2LCM, as they were apparently untrained in it. Therefore, the loading method is equivalent to the loading duration, assuming that the slow and careful loading is more important than the number of grasped legs. Also due to the small size of loaded broilers by the 2LCM in the present study within a flock, it is questionable whether the same result can be achieved when loading the whole barn. In the study by Mönch et al. (2020), complete barns were caught with the 2LCM and the results showed that 1.0% of the 2LCM broilers had a severe injury. Thus, their results of catching a whole barn by 2 legs were similar to our results of the broilers caught by 1 leg (1.1%). Because the presented study was defined as an animal experiment, it was decided to only load and examine single containers as a sample size to reduce the number of used broilers for testing. Kittelsen et al. (2018) observed that broilers caught in the manual "upright position" had fewer fractures than broilers caught with the 2LCM. However, this method is also a very slow catching method. Therefore, it is questionable whether 2LCM and "upright" method are economically implementable (Kittelsen et al., 2018) and in addition, whether the catching methods themselves are really the decisive factor.

CONCLUSIONS

Overall, this study showed that for safe and animal-friendly loading several factors must be considered besides the catching method. The catching method or number of grasped legs does not seem to be the decisive factor here. Due to the test design, it is unclear whether the 2LCM would lead to the same result if a whole barn would be loaded. The loading method is equivalent to the factor loading duration. Animal welfare can be significantly improved by minimizing the observed risk factors, regardless of the catching method or number of grasped legs. The following recommendations are suggested:

1. Broilers should be caught and held at or above the hock (tarsal joint) taking care to avoid squeezing the thigh and cause bruises.
2. Broilers should be lifted and carried in pairs.
3. When grasping, the broilers should be fixed quickly, but gently and securely.
4. The broilers should be carried quickly but carefully to the container.
5. The broilers should not be struck against the container (particular care should be taken to ensure that broilers are lifted over the edge of crates).
6. The broilers should be carefully placed in the container and settled and not dropped nor thrown.
7. It should be considered that female broilers have an increased chance of epiphysiolysis (although difficult to implement in practice).
8. The catching staff should be well trained and educated in the implementation of the catching method and animal welfare recommendations.
9. It should be ensured that a specified stocking density is maintained in the crate.

The applicability of these recommendations is suitable for broilers and cannot be unrestrictedly transferred to other animal species.

ACKNOWLEDGMENTS

Foundation of this study by the Bavarian State Ministry of the Environment and Consumer Protection through the Bavarian Health and Food Safety Authority (K3-2533-PN 16-24). We thank Dr. Josef Bachmeier, Ferdinand Hoday, all catchers, and farm managers involved for their support in the performed study.

The project was financially supported by the Bavarian State Ministry of the Environment and Consumer Protection through the Bavarian Health and Food Safety Authority (K3-2533-PN 16-24)

ETHICAL STATEMENT

The work described in this article with research on live animals was conducted in accordance with the principles and specific guidelines presented by the institutional animal care and use committee (IACUC). All animals examined in this study were housed under conditions that comply with all governmental requirements. An animal experiment application was approved for this project with the reference ROB-55.2Vet-2532.Vet_02-17-55.

DISCLOSURES

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

REFERENCES

Bayliss, P. A., and M. H. Hinton. 1990. Transportation of broilers with special reference to mortality rates. Appl. Anim. Behav. Sci. 28:93–118.

Bradshaw, R. H., R. D. Kirkden, and D. Broom. 2002. A review of the aetiology and pathology of leg weakness in broilers in relation to welfare. Avian Biol. Res. 13:45–103.

Byrt, T., J. Bishop, and J. B. Carlin. 1993. Bias, prevalence and kappa. J. Clin. Epidemiol. 46:423–429.

Classen, H. L., and C. Riddell. 1989. Photoperiodic effects on performance and leg abnormalities in broiler-chickens. Poult. Sci. 68:873–879.

de Koning, K., A. R. Gerrits, and A. Migchels. 1987. Mechanized harvesting and transport of broilers. J. Agric. Eng. Res. 38:105–111.

de Lima, V. A., M. C. Ceballos, N. G. Gregory, and M. J. R. P. Da Costa. 2019. Effect of different catching practices during manual upright handling on broiler welfare and behavior. Poult. Sci. 98:4282–4289.

Delezie, E., Q. Swennen, J. Buyse, and E. Decuypere. 2007. The effect of feed withdrawal and crating density in transit on metabolism and meat quality of broilers at slaughter weight. Poult. Sci. 86:1414–1423.

Delezie, E., W. Verbeke, J. De Tavernier, and E. Decuypere. 2006. Consumers' preferences toward techniques for improving manual catching of poultry. Poult. Sci. 85:2019–2027.

Duncan, I. J. H., G. S. Slee, P. Kettlewell, P. Berry, and A. J. Carlisle. 1986. Comparison of the stressfulness of harvesting broiler chickens by machine and by hand. Bri. Poult. Sci. 27:109–114.

European Commission. 1995. Empfehlung in Bezug auf Haushühner der Art. Gallus gallus. Accessed Apr. 2022. https://www.bmel.de/SharedDocs/Downloads/DE/_Tiere/Tierschutz/Gutachten-Leitlinien/eu-haltung-huehner.html.

Fleiss, J. L., B. Levin, and M. C. Paik. 1981. The measurement of interrater agreement. Pages 598−626 in Statistical Methods for Rates and Proportions.. 2nd ed. John Wiley and Sons, New York, NY.

German Animal Welfare Act. 2006. Amended and promulgated on May 18th, Last Changed on August 10th, 2021,. Accessed Apr. 2022 http://www.gesetze-im-internet.de/tierschg/BJNR012770972.html.

German Federal Ministry of Food and Agriculture. 2015. Wege zu einer gesellschaftlich akzeptierten Nutztierhaltung - Gutachten. Wissenschaftlicher Beirat für Agrarpolitik beim Bundesministerium für Ernährung und Landwirtschaft. Accessed Apr. 2022. https://www.bmel.de/SharedDocs/Downloads/Ministerium/Beiraete/Agrarpolitik/GutachtenNutztierhaltung.pdf%3F__blob%3DpublicationFile.

German Federal Ministry of Food and Agriculture. 2019. Poultry,. Accessed Apr. 2022. https://www.bmel.de/DE/themen/tiere/nutztiere/gefluegel/gefluegel.html.

German Order on the Protection of Animals and the Keeping of Production Animals. 2006. Amended and promulgated on August 22, 2006,. Last Changed on January 29th, 2021. Accessed Apr. 2022. https://www.gesetze-im-internet.de/tierschnutztv/BJNR275800001.html.

Gocke, A. 2000. Untersuchung über den einsatz einer hähnchenfangmaschine in mastbetrieben in norddeutschland. Diss. TiHo Hannover, Germany.

Graml, C., S. Waiblinger, and K. Niebuhr. 2008. Validation of tests for on-farm assessment of the hen−human relationship in non-cage systems. Appl. Anim. Behav. Sci. 111:301–310.

Gunnarsson, S. 2000. Laying hens in loose housing systems: clinical, ethological and epidemiological aspects. Doctoral Thesis, Swedish University of Agricultural Sciences, Uppsala.

Hakansson, F. 2015. Effect of daytime and age on the avoidance and approach behaviour of commercial Danish broiler chicken. Master Thesis, Linköpings univeritet, Sweden.

Hamdy, M. K., F. E. Deatherage, and G. Y. Shinowara. 1957. Bruised tissue. I. Biochemical changes resulting from blunt injury. Proc. Soc. Exp. Biol. Med. 95:255–258.

Hamdy, M. K., K. N. May, W. P. Flanagan, and J. J. Powers. 1961. Determination of the age of bruises in chicken broilers. Poult. Sci. 40:787–789.

Jacobs, L., E. Delezie, L. Duchateau, K. Goethals, and F. A. M. Tuyttens. 2016. Impact of the separate pre-slaughter stages on broiler chicken welfare. Poult. Sci. 96:266–273.

Johansson, A., H. Blokhuis, D. Berckmans, and A. Butterworth. 2015. Development of an automated method to assess human-animal relationship in broilers at the flock level. Pages 195−201 in 7th European Conference on Precision Livestock Farming. M. Guarino and D. Berckmans, eds. .

Jones, R. B. 1992. The nature of handling immediately prior to test affects tonic immobility fear reactions in laying hens and broilers. Appl. Anim. Behav. Sci. 34:247–254.

Jones, R. B. 1996. Fear and adaptability in poultry: insights, implications and imperatives. Worlds Poult. Sci. J. 52:131–174.

Keppler, C., C. Brenninkmeyer, W. Vogt-Kaute, S. Döring, M. Günther, M. Thiede, T. Gorniak, and U. Knierim. 2009. Eignung unterschiedlicher Herkünfte für die ökologische Haltung von Masthähnchen - Feldprüfung. Report, Universität Kassel, Germany.

Kettlewell, P. J., and M. A. Mitchell. 1994. Catching, handling and loading of poultry for road transportation. Worlds Poult. Sci. J. 50:54–56.

Kittelsen, K. E., E. G. Granquist, A. L. Aunsmo, R. O. Moe, and E. Tolo. 2018. An evaluation of two different broiler catching methods. Animals 8:141.

Knowles, T. G., and D. M. Broom. 1990. The handling and transport of broilers and spent hens. Appl. Anim. Behav. Sci. 28:75–91.

Langkabel, N., M. P. Baumann, A. Feiler, A. Sanguankiat, and R. Fries. 2015. Influence of two catching methods on the occurrence of lesions in broilers. Poult. Sci. 94:1735–1741.

Louton, H., M. Erhard, J. Moench, and E. Rauch. 2022. Tierschutzgerechtes Fangen von Mastgeflügel. Proc. 22. Fachtagung für Fleisch und Geflügelfleischhygiene Online.

Martin, H., and B. W. Ritchie. 1994. Orthopedic surgical techniques. Pages 1137−1170 in Avian Medicine: Principles and Application. B. W. Ritchie, G. J. Harrison and L. R. Harrison, eds. Wingers Pub, Lake Worth, FL.

Millman, C., R. Christley, D. Rigby, D. Dennis, S. J. O'Brien, and N. Williams. 2017. Catch 22": Biosecurity awareness, interpretation and practice amongst poultry catchers. Prev. Vet. Med. 141:22–32.

Mönch, J., E. Rauch, S. Hartmannsgruber, M. Erhard, I. Wolff, P. Schmidt, A. R. Schug, and H. Louton. 2020. The welfare impacts of mechanical and manual broiler catching and of circumstances at loading under field conditions. Poult. Sci. 99:5233–5251.

Müsse, J., H. Louton, B. Spindler, and J. Stracke. 2022. Sexual dimorphism in bone health and performance of conventional broilers at different growth phases. Agriculture 12:1109.

Nicol, C. J., and G. B. Scott. 1990. Pre-slaughter handling and transport of broiler chickens. Appl. Anim. Behav. Sci. 28:57–73.

Nijdam, E., P. Arens, E. Lambooij, E. Decuypere, and A. Stegeman. 2004. Factors influencing bruises and mortality of broilers during catching, transport, and lairage. Poult. Sci. 83:1610–1615.

Nijdam, E., E. Delezie, E. Lambooij, M. J. Nabuurs, E. Decuypere, and J. A. Stegeman. 2005a. Comparison of bruises and mortality, stress parameters, and meat quality in manually and mechanically caught broilers. Poult. Sci. 84:467–474.

Nijdam, E., E. Delezie, E. Lambooij, M. J. Nabuurs, E. Decuypere, and J. A. Stegeman. 2005b. Feed withdrawal of broilers before transport changes plasma hormone and metabolite concentrations. Poult. Sci. 84:1146–1152.

Northcutt, J. K., R. J. Buhr, and G. N. Rowland. 2000. Relationship of broiler bruise age to appearance and tissue histological characteristics. J Appl. Poult. Res. 9:13–20, doi:10.1093/japr/9.1.13.

Olkowski, A., B. Laarveld, C. Wojnarowicz, M. Chirino-Trejo, D. Chapman, T. Wysokinski, and L. Quaroni. 2011. Biochemical and

physiological weaknesses associated with the pathogenesis of femoral bone degeneration in broiler chickens. Avian Pathol 40:639–650.
Pilecco, M., I. Almeida Paz, L. Tabaldi, I. Nääs, R. Garcia, F. Caldara, and N. Francisco. 2013. Training of catching teams and reduction of back scratches in broilers. Rev. Bras. Cienc. Avic. 15:283–286.
Prisby, R., T. Menezes, J. Campbell, T. Benson, E. Samraj, I. Pevzner, and R. Wideman. 2014. Kinetic examination of femoral bone modeling in broilers. Poult. Sci. 93:1122–1129.
Queiroz, M.d. V., J. Barbosa Filho, L. Duarte, D. d. F. Brasil, and C. Gadelha. 2015. Environmental and physiological variables during the catching of broilers. Rev. Bras. Cienc. Avic. 17:37–44.
R Core Team. 2017. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. Accessed June 2021. https://www.R-project.org/.
Rigby, R. A., and D. M. Stasinopoulos. 2005. Generalized additive models for location, scale and shape, (with Discussion). J. R Stat. Soc. Ser. C Appl. Stat. 54:507–554.
Salter, R. B., and W. R. Harris. 1963. Injuries involving the epiphyseal plate. J. Bone Joint Surg. Am. 45:587–622.
Society for the Promotion of the Animal welfare in livestock farming mbH. 2019. Manual agriculture, criteria catalog poultry fattening, program 2018-2020,. Accessed Apr. 2022. https://initiative-tierwohl.de/wp-content/uploads/2019/01/20170101_Version1.1rev01_ITW_Handbuch_Kriterienkatalog_Gefl%C3%BCgelmast.pdf.
Statistisches Bundesamt. 2022. Geflügelstatistik: Erhebung in Geflügelschlachtereien. Federal Statistical Office, Destatis. Accessed Apr. 2022. https://www-genesis.destatis.de/genesis/online?sequenz=tabelleErgebnis&selectionname=41322-0002&leerzeilen=false#abreadcrumb.
Taylor, M. H., and N. V. L. Helbacka. 1968. Field studies of bruised poultry. Poult. Sci. 47:1166–1169.
Thorp, B. H., C. C. Whitehead, L. Dick, J. M. Bradbury, R. C. Jones, and A. Wood. 1993. Proximal femoral degeneration in growing broiler fowl. Avian Pathol 22:325–342.
Vanderhasselt, R. F., S. Buijs, M. Sprenger, K. Goethals, H. Willemsen, L. Duchateau, and F. A. M. Tuyttens. 2013. Dehydration indicators for broiler chickens at slaughter. Poult. Sci. 92:612–619.
Weeks, C. 2007. Poultry handling and transport. Pages 295−311 in Livestock Handling and Transport.. 3rd ed. T. Grandin, CO.
Welfare Quality® assessment protocol for poultry (broiler and laying hens). Welfare Quality® Consortium, Lelystad, The Netherlands: Presented on October 9th, 2009, at the Animal Welfare Conference in Uppsala, Sweden.
Windschnurer, I., X. Boivin, and S. Waiblinger. 2009. Reliability of an avoidance distance test for the assessment of animals' responsiveness to humans and a preliminary investigation of its association with farmers' attitudes on bull fattening farms. Appl. Anim. Behav. Sci. 117:117–127.
Wolff, I., S. Klein, E. Rauch, M. Erhard, J. Mönch, S. Härtle, P. Schmidt, and H. Louton. 2019. Harvesting-induced stress in broilers: Comparison of a manual and a mechanical harvesting method under field conditions. Appl. Anim. Behav. Sci. 221:104877.