The welfare impacts of mechanical and manual broiler catching and of circumstances at loading under field conditions

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ABSTRACT Loading of broilers for transport to the processing plant poses a notable injury risk for broilers. Therefore, the poultry industry has developed mechanical methods as alternatives to manual loading methods. Our objective in the present study was to compare manual loading (**MAN**) of broilers with the mechanical loading (**MECH**). We assessed the injuries of broilers of 12 MAN and 12 MECH flocks on-farm before and immediately after loading, documented the numbers of broilers dead on arrival reported by the processing plant, and assessed the circumstances at loading. A smaller number of broilers with a hematoma (≥0.5 cm in diameter) on the wing were observed after MAN compared with MECH using the examined harvester (MAN vs. MECH odds ratio: 0.16; 95% confidence interval: 0.10, 0.28). The number of broilers with severe wing injuries did not differ between the loading methods. The number of broilers dead on arrival was greater in mechanically loaded flocks (MAN vs. MECH odds ratio: 0.26; 95% confidence interval: 0.10, 0.68), but lower than in comparable studies. We observed a lower average stocking rate than targeted in the drawers of MECH containers, most likely because the used harvester can adapt to short-term changes in weight and adjust the stocking rate during the loading process. A longer total loading duration in MAN was associated with an increase of wing hematomas, and the involvement of more working people per 10,000 broilers during MAN was associated with a lower occurrence of hematomas. The total loading duration in MECH had no notable influence on the occurrence of injuries. Physical conditions of the involved personnel might play a larger role in MAN than in MECH. The harvester that was examined should be further developed to reduce the occurrence of hematomas. Our results indicate that the choice of loading method alone does not determine the injury risk, and multiple factors are associated with broiler welfare during loading. It is important that the chosen method is performed under the most adequate conditions.

Key words: broiler, manual loading, mechanical loading, injury, DOA

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INTRODUCTION

For many decades, agricultural production largely focused on increasing productivity, for example, through increasing growth rates of conventionally fattened broilers (Havenstein et al., 2003; Bessei, 2006). Recently, however, agricultural stakeholders have become aware of the importance to ensure animal welfare in livestock production (Maria, 2006; Vanhonacker et al., 2008; Tuyttens et al., 2014). As part of animal-friendly meat production, the loading of the animals for transport to the processing plant at the end of the fattening period should be as gentle as possible. In principle, 2 options are available for loading broilers. One option is manual loading and the other is mechanical loading.

Manual loading is often performed by commercial catching teams. The catchers usually grab the broilers by the legs, often 3 to 4 broilers per hand, and carry them to the transport containers. Thus, the broilers are carried upside down (Bayliss and Hinton, 1990). It should be considered that manual loading is a physically demanding and unpleasant task (Kettlewell and Turner, 1985; Bayliss and Hinton, 1990). Resulting fatigue and

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individual attributes of the involved personnel can have a negative influence on the handling of the broilers (Langkabel et al., 2015; Lima et al., 2019). An advantage of manual loading is that the worker can directly and positively influence the escape behavior by adapting the way of grabbing the broilers (Lima et al., 2019).

For mechanical loading, various systems have been developed (de Koning et al., 1987; Bayliss and Hinton, 1990; Kettlewell and Mitchell, 1994; Lacy and Czarick, 1998; Knierim and Gocke, 2003; Nijdam et al., 2005). The ways in which the broilers are picked up from the ground can vary greatly between the systems, whereas the passage to the transport containers is similar. Mechanical harvesters of the new generation use conveyor belts for the passage (de Koning et al., 1987; Bayliss and Hinton, 1990; Kettlewell and Mitchell, 1994; Lacy and Czarick, 1998; Knierim and Gocke, 2003; Nijdam et al., 2005). Considering the collection of the broilers from the ground, 2 main types of harvesters are currently used. One type is the Apollo Generation 2, which was examined in the present study. In the front of this machine, there are 6 parallel arranged collection belts by which the broilers are picked up from the ground. Another type of harvester is called "Chicken Cat Harvester" (JTT Conveying A/S, Bredsten, Denmark). For the process of collecting the broilers from the ground, this machine is equipped with a pick-up head that collects the broilers by means of 3 units with rotating rubber fingers (Knierim and Gocke, 2003; Nijdam et al., 2005). The different mechanical loading methods have in common that the broilers have no direct body contact with the personnel and reach the transport containers in an upright body position.

Numerous past studies showed that substantial injuries can occur during loading and transport (Knierim and Gocke, 2003; Nijdam et al., 2005; Lund et al., 2013; Langkabel et al., 2015; Jacobs et al., 2017b; Cockram and Dulal, 2018). Earlier studies showed the average share of broilers with wing hematomas after manual loading to be up to 8.4% (Knierim and Gocke, 2003; Nijdam et al., 2005; Langkabel et al., 2015). The study by Langkabel et al. (2015) showed that on average up to 4.7% of the broilers from precatching and 14.0% of those after heavy-weight fattening had a wing lesion after manual catching; these data were acquired via a camera system at the processing plant. Knierim and Gocke (2003), who compared manual and mechanical loading, reported significantly more broilers with wing fractures after manual loading (on average 0.77%) than after mechanical loading (on average 0.66%). Nijdam et al. (2005) did not observe an influence of the catching method on the injury rate when comparing manual with mechanical loading methods, with an average of 6.7% to 8.4% bruised wings.

In all mentioned studies, as far as indicated by the authors, the data were acquired at the processing plant. Thus, it is difficult to differentiate between injuries that resulted from loading and those that resulted from transport or handling at the processing plant (Cockram and Dulal, 2018). In view of these findings and because injured animals that cannot move without pain are considered not transportable in Europe (Council Regulation [EC], 2004), it is important to reduce the risk of injuries caused by loading to comply with the animal welfare legislative in Europe.

Loading can also influence other welfare parameters of broilers, such as physiological or behavioral stress parameters (Wolff et al., 2019). Lima et al. (2019) observed that the way in which the catcher is handling the broilers during carrying from the ground to the drawer can influence the broilers' behavior. Wolff et al. (2019) observed less wing flapping during mechanical than during manual loading. They furthermore observed that the stress level of broilers was more influenced by the outside temperature, the body weight of the broilers, and the light intensity during manual loading as compared with mechanical loading.

Another animal welfare aspect is the number of broilers that are dead on arrival (**DOA**) at the processing plant. The reported losses by DOA vary between studies and range from an average of 0.09 to 0.46% of loaded broilers (Nijdam et al., 2004; Chauvin et al., 2011; Kittelsen et al., 2015). According to Bayliss and Hinton (1990), the incidence of DOA in broilers is influenced by 3 main factors: health status of the flock, heat stress during transport, and pre-existing injuries, such as traumata experienced during transport. More recent studies discuss various factors that can influence the DOA rates. A study from 2008 identified the cumulative mortality during fattening as a major factor of influence; other mentioned factors were the live weight of the broilers at slaughter, the feeding regimen, vaccination, and genetics (Haslam et al., 2008). The loading process itself can also influence the DOA rate (Chauvin et al., 2011). Chauvin et al. (2011) observed that the DOA risk was higher after mechanical than after manual loading and mentioned that this was an unexpected result. Knierim and Gocke (2003) observed a trend of higher DOA rates after mechanical loading compared with manual loading but did not find significant differences. Similar observations were made by Nijdam et al. (2005). A Dutch study found a trauma in 29.5% of the examined broilers DOA, with liver ruptures being most frequent and likely the cause of death, followed by bone fractures and cranial traumata (Nijdam et al., 2006), which is comparable with the results of the studies by Lund et al. (2013) and Kittelsen et al. (2015).

Two major advantages of mechanical loading are the missing contact with humans and the transport in an upright position, both reducing the stress for the broilers (Lacy and Czarick, 1998). Furthermore, Knierim and Gocke (2003) observed a lower risk of injuries during mechanical than during manual loading. However, because the handling of the broilers during loading can influence their behavior, a human might be better able to adapt to certain characteristics of flocks (Lima et al., 2019). Thus, both methods have advantages and disadvantages in their use.

To reduce the injury risk during loading and thus potentially the DOA risk in the future, it is therefore important to develop an adequate loading method for broilers. The objective of the present study was to assess the occurrence of injuries and the type of injuries for loaded broilers at the end of heavy-weight fattening by comparing 2 loading methods and the conditions during loading. We compared manual loading by commercial catching teams with mechanical loading by the Apollo Generation 2 chicken harvester (CMC Industries–Ciemmecalabria, Cazzago S. Martino, Italy) under field conditions. The results should contribute to the advancement of the 2 loading methods for broilers at the end of their lives.

MATERIALS AND METHODS

Animals, Farms, and Catching Methods

The data collection was restricted to Bavarian broiler farms (southern Germany) and performed from December 2016 to August 2017. We assessed 24 loadings of Ross 308 broilers after conventional heavy-weight fattening (37–42 fattening days) under commercial field conditions. On the day of loading, the assessed broilers had an average live weight ranging from 2,274 to 2,758 g. The selection criteria for the farms were conventional broiler fattening (stocking density of 39 kg/m^2, except 1 flock [mechanical loading 10/F, Table 1] that was raised at a stocking density of 35 kg/m^2), a maximal distance to the processing plant of 130 km, and for the loaded flocks a maximal cumulative mortality of 5% during rearing and no antibiotic treatment during the last 10 d before slaughter. The assessments of mechanical loadings were performed on 6 farms, whereby 1 farm took part once, 4 farms twice, and 1 farm 3 times. Manual loading was assessed on 11 different farms, of which 1 farm was assessed twice during the study (Table 1).

Twelve of the 24 loadings were performed manually by commercial catching teams and 12 were performed mechanically with the Apollo Generation 2 chicken harvester (CMC Industries–Ciemmecalabria). The harvester was operated by the farmer of the respective flock. In manual loading, no family members or friends were involved in the catching to minimize bias. The goal of the study was to compare the 2 catching methods in their regular on-farm use in an exploratory study; therefore, explicit previous training was not performed. The whole staff involved in loading must be instructed by a certified person before loading if they do not have a certification by a veterinary office. "Certified" persons have completed either an agricultural or comparable education with an examination by the veterinary office or schooling by the veterinary office. In our study, the number and certification type of the "certified" people were documented in accordance with the definition in Table 2. All 24 loadings included in the study were examined during loading and in a random sampling for each assessed parameter listed in Table 2. Loading in this study comprises the loading of all broilers of the whole barn. If the barn was divided in several sections, the entire barn (all sections) counted as 1 sample. On average, 34,531 broilers per farm (min 18,500 to max 67,355) were loaded.

For both loading methods, the same transport container systems ("GP live bird container supply system," Marel, Gardabaer, Iceland) were used for loading the trucks. Each container consisted of a metal frame with 8 drawers, arranged in 2 stacks of 4, which must be opened manually in both loading methods. One person driving a forklift brought the containers into the barn. For manual loading, the containers were placed directly onto the litter as close as possible to the animals. The mechanical harvester has a rotating carousel at the rear end that holds 2 containers, which thus do not touch the litter. A photo of the used harvester and containers can be viewed in the article by Wolff et al. (2019).

The commercial catching teams consisted of 6 to 10 catchers from a pool of staff of 53 people. It was always the same pool of staff, but the team differed in composition. The catchers grabbed the broilers by both legs, carried them upside down to the container, and placed them into the drawers. By using this method, a catcher could carry on average 3 birds per catch. The 2-leg catching was a requirement of the study.

The Apollo Generation 2 consists of 9 conveyor belts. On the conveyor belts, the broilers move all the way from the ground into the drawers of the containers. Via 4 parallel arranged collection belts, the broilers are picked up from the ground. From those belts, 2 transversal belts run in the opposite direction and take the broilers from the left or right side of the collection head to the first of 3 conveyor belts (small belt, main belt, caging belt) arranged in sequence in the central channel of the harvester. The caging belt, located at the adjustable rear end of the central channel, deposits the broilers into a container drawer. During the whole process, the animals remain in an upright position and have no direct contact with the personnel.

Two persons operated the rear end of the harvester with the caging module. These 2 persons were on the carousel and adjusted the height of the rear end of the central channel so that the broilers on the caging belt would reach the drawer that was to be loaded. The team during mechanical catching was a small group of farmers who use the machine together and support each other during each loading. Thus, the farmers themselves operated the harvester, and each farmer on his own farm would manage the loading. Another 1 or 2 persons (also farmers or helpers of the family) attended the front collection head in the area where the broilers climbed onto one of the first 4 parallel collection belts. They made sure that the broilers would be picked up properly and the density on the collection belts would be appropriate. The speed of the harvesters' forward movement in the barn is approximately 0.02 m/s. There was no preassigned speed of the conveyor belts in the study. The speed of the belts, which was adjusted by the farmers, was measured in accordance with the definition in Table 2.

Table 1. Facts about climatic circumstances, general conditions, and dead on arrival (DOA) rates of the loadings (12 manual and 12 mechanical loadings); n/a = not applicable.

Method	Number of loading/letter of farm	Number of animals loaded	Number of flocks	Number of fattening days	Average weight on day of loading (g)	Cumulative daily mortality rate in fattening period (%)	Number of antibiotic treatments	DOA (%)	Number of working people	Total loading time (h)	Loading speed (animals per h)	Loading per animal (s)	Ambient outside temperature (°C)
Mechanical catching	1/A	26,715	1	39	2,505	3.75	2	0.00	3	4.47	5,981	21.78	−8.00
	2/B	24,700	1	39	2,544	3.48	1	n/a	3	n/a	n/a	22.83	
	3/C	24,000	1	40	2,496	3.46	0	0.29	3	4.25	5,647	20.95	−4.30
	4/D	67,355	2	40	2,527	4.51	1	0.10	3	10.38	6,487	21.04	−1.30
	5/A	24,500	1	41	2,597	3.76	0	0.15	3	6.47	3,789	21.42	21.90
	6/B	25,400	1	40	2,639	3.66	1	0.35	4	3.58	7,088	20.43	6.80
	7/E	47,391	2	40	2,381	3.60	0	0.08	3	7.13	6,644	22.20	n/a
	8/D	66,892	2	39	2,292	4.27	1	0.16	3	10.03	6,667	20.01	n/a
	9/E	47,540	2	40	2,580	4.68	0	0.07	3	7.27	6,542	19.47	26.90
	10/F	26,200	1	37	2,373	2.72	0	0.32	4	3.22	8,145	14.99	17.70
	11/B	49,622	2	39	2,682	3.95	1	0.07	4	7.93	6,255	15.50	13.90
	12/C	24,720	1	41	2,451	4.51	1	0.17	3	3.82	6,477	15.05	18.90
Average		37,920		40	2,506	3.86	0.7	0.16	3	6.23	6,338	19.64	10.30
Manual catching	1/G	23,744	2	40	2,758	3.04	0	0.15	8	4.27	5,565	2.54	8.80
	2/H	21,907	1	39	2,533	2.93	0	0.00	8	4.45	4,923	3.15	9.00
	3/I	26,880	1	38	2,274	2.71	0	0.04	7	4.77	5,639	3.91	−11.30
	4/J	24,000	1	41	2,611	3.19	0	0.11	7	4.22	5,692	5.15	−7.00
	5/K	30,995	5	39	2,324	2.70	0	0.15	10	4.97	6,241	2.87	8.20
	6/L	40,534	4	40	2,540	3.16	0	0.00	6	6.97	5,818	2.82	6.20
	7/M	18,500	2	42	2,732	2.34	0	0.03	8	3.75	4,933	2.98	n/a
	8/N	26,837	1	41	2,640	2.78	0	0.06	8	4.67	5,751	4.21	n/a
	9/O	54,000	4	40	2,734	4.82	1	0.08	7	9.55	5,654	2.91	n/a
	10/P	51,369	2	39	2,560	2.99	0	0.04	8	7.57	6,789	3.59	17.30
	11/O	31,250	3	39	2,606	4.13	1	0.03	7	5.72	5,466	3.59	24.00
	12/Q	23,700	1	41	2,644	3.03	0	0.02	8	4.05	5,852	2.98	18.90
Average		31,143		40	2,580	3.15	0.2	0.06	8	5.41	5,694	3.39	8.20

Table 2. Climatic and general circumstances and conditions with respective definitions assessed at each of the 24 loadings.

Variable	Information or definition
Number of animals	Total number of animals that were loaded during the entire loading time
Antibiotic therapy	No/yes
Therapy recurrence	Number of treatments >1 (no/yes)
Parental flocks	Week of production
Number of working people	Number of persons involved in loading per 10,000 broilers
Expertise of staff	Number of persons in the team with officially certified expertise by a veterinary office (includes agricultural education or education with exam by veterinary office) (§ 17, German Order on the Protection of Animals and the Keeping of Production Animals, 2006); evaluated binomially (yes/no) for each involved person
Loading time	Time in hours for entire loading of barn
Loading speed	Animals per hour
Speed of the conveyor belt	Meter per second (Testo 470 rotation speed control counter, Testo North America, West Chester, PA), measurement of the speed of 4 of the 5 conveyor belts (sequence of collection, transversal, small, main, and caging belts) 3 times during each loading (the small belt was not accessible)
Loading time per animal	Seconds Mechanical catching: t = V/l (t = time in seconds, V = speed of conveyor belt in m/s, l = length of conveyor belt in meters), standstill of the conveyor belt during adjustment of rotary head is not considered Manual catching: time (seconds) from lifting of broiler by catcher till depositing in container, measurement 8 times during each loading
Sound level	dB (Sound Level Meter, PCE 322A, PCE Instruments UK Ltd, UK), 3 times during each loading near the animals on the ground
Light	lux (LMT Pocket-Lux 2B, LMT Lichtmesstechnik GmbH, Berlin, Germany) 3 times during each loading using a 6-sided-measuring system
Climatic data collection:	
Season	4 seasons 1 = December 2016/January 2017 2 = February/March 2017 3 = April/May 2017 4 = June/July/August 2017
Temperature	4 categories, outside temperature 1 = <0°C 2 = 1°C–10°C 3 = 11°C–20°C 4 = >20°C recorded by data logger (LogBox RHT, B + B Thermo-Technik GmbH, Donaueschingen, Germany)
Time of the day	4 categories 1 = loading at night 2 = loading at daytime 3 = loading at twilight (sunrise/sunset) 4 = loading during the night, twilight and daytime

When the loading of one truck was complete, the trucking company "BSG Logistik & Service GmbH, Zweigniederlassung Bogen" delivered the containers to the processing plant "Donautal Geflügelspezialitäten, Zweigniederlassung der Lohmann & Co. AG" in Bogen, Germany, where the broilers were slaughtered. The waiting period from arrival to slaughter was about 1 h.

Methods of Data Acquisition

The 2 catching methods were evaluated for their risk of broiler injuries and the frequency of broilers DOA. Therefore, the broilers were examined on-farm for the presence, severity, and frequency of injuries (listed in Table 3) during the 24 loadings. To assess whether injuries were already present before loading, a pre-examination in the barn was performed on 200 animals, which were randomly selected in dimmed light (66 in the front part of the barn, 67 in the middle, 66 in the back of the barn), representing a sample of the flock. The pre-examination was performed on the same day as the main examination, immediately or at most 24 h before loading began. All animals of the pre-examination were examined considering weight (scale: Mettler Toledo ICS425 scale, Mettler Toledo GmbH, Gießen, Germany), sex, and the injury variables listed in Table 3. In total, 4,800 individual birds were examined during the pre-examination and 11,497 after loading (5,709 after mechanical, 5,788 after manual loading). Four veterinarians, previously trained in 2 sample loadings, performed all examinations. During the pre-examination, head lights were used to ensure adequate conditions for the assessment. Each bird was examined carefully by visual assessment and palpation.

The main examination was carried out during harvesting of the first 2/3 of the barn. Animals in 2 loaded containers were examined. The containers were randomly chosen during the first and second third of the loading of the barn. The animals of the first container (on average 241 after mechanical and 242 after manual loading) were similarly examined (weight, sex, and injuries) to the pre-examination, and animals of the second container (on average 235 after mechanical and 240 after manual loading) were examined for all mentioned variables except for weight. The examinations of the containers after loading took place outside of the barn in daylight conditions or illuminated buildings on site. Injuries were assessed visually or by palpation if necessary. X-ray was not performed. To ensure animal welfare, broilers that were diagnosed with a fracture or luxation

Table 3. Assessed variables before and after loading.

Variable	Severity	Assessment method	Type of injury	Location on body	Type of variable	Explanation
Body weight	n/a	Mettler Toledo ICS425 scale (Mettler Toledo GmbH, Gießen, Germany)	n/a	n/a	Metric	Assessment only of birds of first container
Sex	n/a	Phenotypical characteristics	n/a	n/a	Binomial	Female/male
Injury	Minor injury	Visual assessment	Hematoma (≥0.5 cm in diameter)	Wing (broilers with ≥1 HoWI; including HoWIT and HoWIpWIT)	Binomial	Occurrence yes/no; on either wing, left or right; any location on the wing
				Wing tip (broilers with ≥1 HoWIT)	Binomial	Occurrence yes/no; on either wing, left or right
				Wing proximal to wing tip (broilers with ≥1 HoWIpWIT)	Binomial	Occurrence yes/no; on either wing, left or right
				Torso (broilers with ≥1 HoBODY)	Binomial	Occurrence yes/no
				Leg (broilers with ≥1 HoLEG)	Binomial	Occurrence yes/no; on either leg, left or right
	Severe injury	Visual assessment and palpation; pathologic examination after diagnosis via palpation	Fracture (including epiphysiolysis, EPIoH) or luxation	Wing (broilers with ≥1 SWI)	Binomial	Occurrence yes/no; on either wing, left or right
			Epiphysiolysis (total separation fracture of the distal humeral epiphysis)	Wing (broilers with ≥1 EPIoH)	Binomial	Occurrence yes/no; on either wing, left or right[1]

Number of assessed broilers per loading: 200 before loading, on average 478 after mechanical, on average 482 after manual loading; all broilers were randomly selected, broilers assessed before and after loading were not necessarily the same animals.

Abbreviations: EPIoH, epiphysiolysis on humerus; HoWI, hematoma on wing (including HoWIT and HoWIpWIT); HoWIT, hematoma on wing tip; HoWIpWIT, hematoma on wing proximal to wing tip; HoBODY, hematoma on body; HoLEG, hematoma on leg; n/a = not applicable.; SWI, severe wing injury

[1]During assessment, the occurrence of fractures was separately documented for the left and right wing; for analysis, data were used binomially for both sides.

via palpation by a veterinarian after loading were not further transported to slaughter but stunned by concussion and then killed by cervical dislocation. To exclude other diseases as an influencing factor for fractures and to examine the severe injuries in more detail, these culled broilers were examined at the Department of Pathology of the Bavarian Animal Health Service (Tiergesundheitsdienst Bayern e. V.). A complete pathological and histological examination of the severe injuries was performed on these broilers.

In addition, the actual stocking rate in each drawer of the 2 examined containers was recorded and compared with the target stocking rate prescribed by the processing plant. As basis for calculating the target stocking rate, the processing plant staff used the average weight of the flock measured about 48 h before slaughter, adjusted to the assumed weight on the day of slaughter. Furthermore, the number of broilers DOA assessed at the processing plant was recorded.

To identify possible factors, besides the loading method, that are associated with the occurrence of injuries and the DOA rate, we measured the variables listed in Table 2. These variables were randomly measured throughout the first 2/3 of the loading in accordance with the methods described in Table 2.

Statistical Analysis

Experimental units in the statistical analyses of injuries are the loadings. Therefore, the sample size used here is 24. This sample size in combination with the number of research questions only allows an exploratory and simplified analysis of the data and questions at hand. The differences in the effect of the predictors (Table 2) on each injury variable (response variables) mentioned in Table 3 (HoWI = hematoma on wing [including HoWIT or HoWIpWIT], HoWIT = hematoma on wing tip, HoWIpWIT = hematoma on wing proximal to wing tip, HoBODY = hematoma on body, HoLEG = hematoma on leg, SWI = severe wing injury [fracture or luxation; including epiphysiolysis on humerus], EPIoH = epiphysiolysis on humerus) between the 2 catching methods were estimated by single logistic regression models for binomial responses, that is, 1 model for each predictor.

The modeling setup consisted of an intercept, a main effect of the predictor, a main effect for the catching methods (dummy coded), and the interaction of the latter 2 variables. Owing to the relatively small sample size, no confounding factors were included in the analysis. Farm-specific random intercepts were included in the models to account for multiple observations on some farms. Results of these models include the effects (expressed as odds ratios) of all predictors on the injury variables for the 2 catching methods separately, as well as the differences of these effects between the catching methods (results considering injuries and epiphysiolysis).

The same approach was used for the response variables DOA and compliance with the target stocking rate. However, for the latter, the experimental units are 381 drawers, and a linear mixed model for continuous response variables was used. In this model, the assumptions about identically and normally distributed error terms were violated. Owing to the lack of adequate alternatives and the exploratory character of this analysis, these violations were accepted.

The variables "loading speed (animals per hour)," "catching duration per animal (seconds)," and "total loading duration (hours)" were additionally analyzed in an exploratory manner using Pearson's correlation coefficient. All statistical analyses were carried out with the statistical programming language R (R Core Team, 2018).

RESULTS

Injuries

The results of the pre-examination of the broilers showed that the occurrence of hematomas or fractures during the pre-examination (i.e., before loading) was nearly 0 (Table 4).

Minor Injuries Regardless of the catching method, wing hematomas were among the most frequently observed injuries after loading (Table 4). The average share of assessed broilers with ≥1 wing hematoma per loading was 4.34% (with a maximum of 11.16%). Most of the broilers had the wing hematoma on the wing tip (on average 3.96% per loading). Analyzing the frequency of wing hematomas in accordance with the catching method, we found on average 7.19% (min: 3.83%; max: 11.16%) of the mechanically loaded broilers with ≥1 wing hematoma per loading (Table 4). In manually loaded flocks, we found on average 1.49% (min: 0.00%; max: 4.43%) of the broilers with ≥1 wing hematoma per loading. The higher value for broilers with ≥1 wing hematoma in mechanically loaded flocks was statistically supported (Table 4). Most of the mechanically loaded broilers had the wing hematoma on the wing tip (on average 6.92%). In 1.00% of the manually loaded broilers, ≥1 hematoma on the wing tip were observed per loading, significantly fewer than after mechanical loading. One or more hematomas proximal to the wing tip were observed in 0.49% of the broilers after manual loading and in 0.26% after mechanical loading. This higher value for manual loading was not statistically supported.

Severe Injuries Regardless of the catching method, on average 1.19% (min: 0.39%; max: 3.15%) of the broilers of per loading showed ≥1 severe injury (including fractures or luxations) of the wing after loading (Table 4). Of all diagnosed severe wing injuries, 93.35% were epiphysiolyses, a specific type of fracture in which the fracture line is in the epiphyseal plate. Analyzing the frequency of severe wing injuries in accordance with the catching method, we found an average share of 1.36% (min: 0.56%; max: 3.15%) with ≥1 severe injury in the mechanically loaded broilers. After manual loading, on average 1.02% (min: 0.39%; max: 1.47%) of the broilers showed ≥1 severe wing injury. This lower value for manually loaded broilers was not statistically supported (Table 4).

Dead on Arrival

In addition to the frequency of injuries after loading, we also evaluated the numbers of broilers DOA recorded at the processing plant. Regardless of the catching method, on average 0.11% (SD: 0.10%; min: 0.00%; max: 0.36%) of the delivered broilers were dead. The average DOA rate was 0.16% (SD: 0.12%; min: 0.00%; max: 0.36%) in mechanically loaded flocks and 0.06% (SD: 0.05%; min: 0.00%; max: 0.15%) in manually loaded ones. Statistically, the risk for DOA was lower for manual than mechanical loading (manual vs. mechanical odds ratio: 0.26; 95% confidence interval [CI]: 0.10, 0.68).

Stocking Rate in Container Drawers

On average, the mechanically loaded drawers (61.98%) were understocked more frequently than the manually loaded drawers (34.39%) (Figure 1). In

Table 4. Average percentages of injuries observed at assessments before and after loading and odds ratios (ORs) for manual vs. mechanical catching.

	Injuries total				Mechanical catching				Manual catching				OR manual vs. Mechanical catching		
	Before		After		Before		After		Before		After				
Variable	AV	SD	AV	SD	AV	SD	AV	SD	AV	SD	AV	SD	Coef	2.5% CI	97.5% CI
Broilers with ≥1 HoWI	0.02	0.10	4.34	3.48	0.00	0.00	7.19	2.35	0.04	0.14	1.49	1.46	0.16	0.10	0.28
Broilers with ≥1 HoWIT	0.02	0.10	3.96	3.48	0.00	0.00	6.92	2.30	0.04	0.14	1.00	0.95	0.13	0.08	0.20
Broilers with ≥1 HoWIpWIT	0.00	0.00	0.38	0.51	0.00	0.00	0.26	0.24	0.00	0.00	0.49	0.68	1.53	0.53	3.00
Broilers with ≥1 HoBODY	0.02	0.10	0.06	0.13	0.04	0.14	0.07	0.14	0.00	0.00	0.05	0.13	0.72	0.10	3.00
Broilers with ≥1 HoLEG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	n/a	n/a	n/a
Broilers with ≥1 SWI	0.04	0.14	1.19	0.61	0.04	0.14	1.36	0.77	0.04	0.14	1.02	0.33	0.76	0.52	1.11
Broilers with ≥1 EPIoH	0.04	0.14	1.11	0.58	0.04	0.14	1.22	0.74	0.04	0.14	1.00	0.36	0.83	0.56	1.25

n = 24 loadings, total of 5,788 assessed broilers for manual loading, total of = 5,709 assessed broilers for mechanical loading.

Abbreviations: AV, average; CI, confidence interval; Coef, coefficient; EPIoH, epiphysiolysis on humerus; HoBODY, hematoma on body; HoWI, hematoma on wing (including HoWIT and HoWIpWIT); HoWIT, hematoma on wing tip; HoWIpWIT, hematoma on wing proximal to wing tip; HoLEG, hematoma on leg; SWI, severe wing injury (fracture or luxation; including epiphysiolysis on humerus); n/a, not applicable.

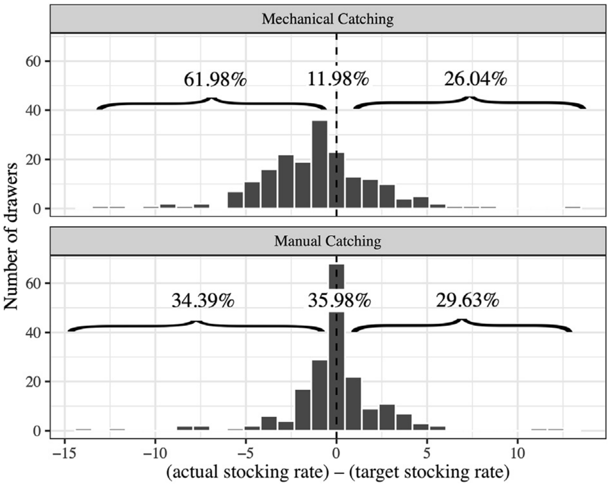

Figure 1. Difference of actual to target stocking rate in loaded container drawers (X-axis) and distribution of the 381 investigated drawers (Y-axis) after mechanical and manual catching.

11.98% of the mechanically loaded drawers, the target stocking rate was met, and in 26.04%, it was exceeded. After manual loading, 35.98% of the drawers met the target stocking rate and 29.63% exceeded it.

The average difference between actual and target stocking rate was −1.16 animals (SD: 3.47) after mechanical loading and −0.11 animals (SD: 2.88) after manual loading. In the linear mixed model, we identified an expected difference of −1.67 animals (95% CI: −2.57, −0.78) for the mechanical harvester. The expected difference between manually and mechanically loaded drawers was 1.54 animals (manual vs. mechanical 95% CI: 0.31, 2.78). Thus, at an average loading speed, the actual stocking rate was higher in manually loaded drawers than in mechanically loaded drawers.

An increase in loading speed by 1,000 animals per hour was tendentially associated with an increase in stocking rate in the mechanically loaded drawers (Pearson correlation coefficient: 1.40 animals; 95% CI: 0.29, 2.52). We did not find this tendency for manual loading. Because both CIs (for manual and mechanical loading) include zero, a statistically supported association of loading speed on the actual stocking rate in the container drawers could not be shown for the 2 loading methods.

General Conditions During Loading

Table 1 gives an overview of the general conditions recorded during loading. We examined, inter alia, possible relationships between loading speed (in animals per hour), total loading duration (in hours), and catching duration per animal (in seconds) within each loading method (Figures 2A–2C). For mechanical loading, we found a longer catching duration per animal tendentially being associated with a slower loading speed and a longer total loading duration. For manual loading, the trend was opposite, with a longer catching duration per animal tendentially being associated with a faster loading speed and a shorter total loading duration. Increasing loading speed during mechanical loading was tendentially associated with decreasing total loading duration. For manual loading, the trend was opposite. Moreover, the total loading duration was associated with the number of animals being loaded (Figure 2D) and the number of working people per 10,000 broilers (Figure 2E) during manual and mechanical loading. Similarly, the loading speed was associated with the number of working people. For mechanical loading, 1 additional person led to an average of 1,133 additional broilers being loaded per hour (95% CI: 51, 2,215). Manual loading showed the same tendency (110 additional broilers per hour; 95% CI: −379, 599).

The average sound level was 82.95 dB (SD: 3.09 dB; min: 78.40 dB; max: 87.00 dB) during mechanical loading and 75.25 dB (SD: 2.60 dB; min: 70.10 dB; max: 80.80 dB) during manual loading. The average difference in sound level between manual and mechanical loading was −7.70 dB (95% CI: −10.12 dB, −5.28 dB). Thus, the average sound level was significantly lower during manual than mechanical loading.

The measurement of illumination in the barn during loading showed an average light intensity of 1.13 lux (SD: 2.08 lux; min: 0.05 lux; max: 6.98 lux) during mechanical loading and 1.85 lux (SD: 2.75 lux; min: 0.06 lux; max: 7.93 lux) during manual loading. The difference in the average values between manual and mechanical loading was 0.72 lux (95% CI: −1.43 lux, 2.87 lux), and thus the light intensity was tendentially lower during mechanical than manual loading.

Determining Factors for Injuries and DOA Rates

Figure 3 illustrates factors associated with the occurrence of injuries. Relevant associations included catching duration per animal (i.e., how long it took to move an animal from the ground to the container drawer; in seconds), total loading duration (hours), and loading speed (animals per hour). During mechanical loading, a longer catching duration per animal was associated with a greater number of broilers with ≥1 hematoma on the wing tip. This result was statistically supported. When the broilers were loaded manually, the number of broilers with ≥1 hematoma on the wing tip tendentially decreased with increasing catching duration per animal (Figure 3). This difference between the loading methods was statistically supported. An increasing total loading duration during mechanical loading was not associated with the number of broilers with ≥1 wing tip hematoma. During manual loading, an increasing total loading duration was associated with a greater number of broilers with ≥1 wing tip hematoma (Figure 3). This difference between the loading methods was statistically supported.

An increase in loading speed by 1,000 broilers per hour during mechanical loading was associated with a smaller number of broilers with ≥1 wing tip hematoma. During

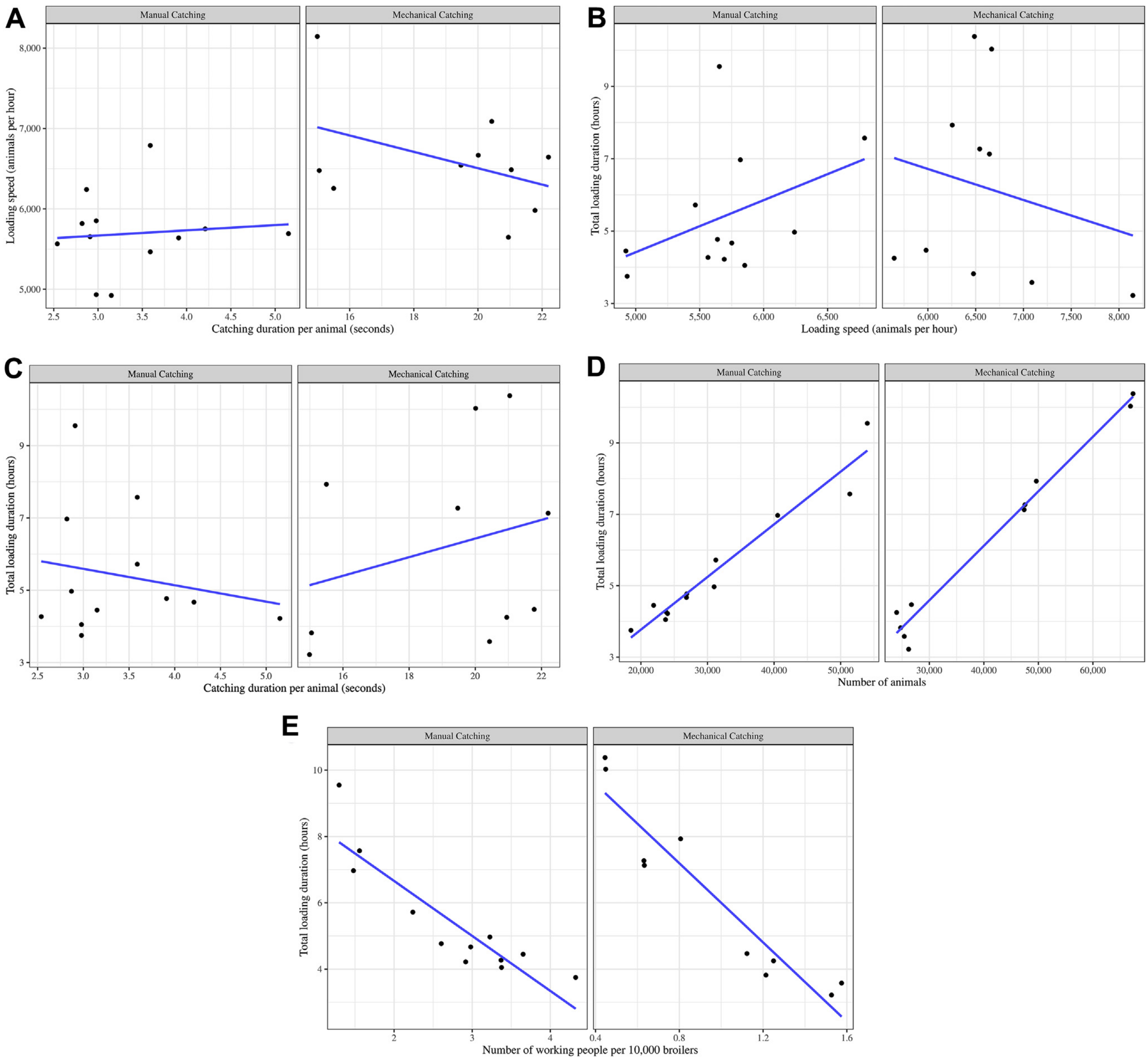

Figure 2. A. Relationship of loading speed (animals per hour) to catching duration per animal (seconds) ($r = 0.10$ [-0.51; 0.63] for manual catching and $r = -0.43$ [-0.83; 0.27] for mechanical catching). B. Relationship of total loading duration (hours) to loading speed (animals per hour) ($r = 0.41$ [-0.21; 0.80] for manual catching and $r = -0.21$ [-0.74; 0.48] for mechanical catching). C. Relationship of total loading duration (hours) to catching duration per animal (seconds) ($r = -0.19$ [-0.69; 0.43] for manual catching and $r = 0.27$ [-0.43; 0.77] for mechanical catching). D. Relationship of total loading duration (hours) to number of animals being loaded ($r = 0.97$ [0.90; 0.99] for manual catching and $r = 0.99$ [0.95; 1.00] for mechanical catching). E. Relationship of total loading duration (hours) to number of working people per 10,000 broilers ($r = -0.89$ [-0.97; -0.66] for manual catching and $r = -0.95$ [-0.99; -0.78] for mechanical catching).

manual loading, this increase in loading speed was tendentially associated with a greater number of broilers with ≥1 wing tip hematoma. Considering the association of increasing loading speed by 1,000 animals per hour with the total number of broilers with ≥1 hematoma on the wing (regardless of the location on the wing), we found a similar picture; during mechanical loading, the number of broilers with these injuries decreased, during manual loading, the number increased. This difference between the loading methods was statistically supported (Figure 3). An association of the deviation from the target stocking rate with the occurrence of injuries was not observed.

Other factors that were associated with the occurrence of injuries included the sound level and the light intensity in the barn. An increase in sound level was associated with an increase in the number of broilers with ≥1 wing tip hematoma during mechanical loading and manual loading. This increase in the occurrence of the mentioned injuries was higher during manual than during mechanical loading, and the difference between the loading methods was statistically supported. In addition, higher light intensity in the barn was associated with an increased number of broilers with ≥1 wing tip hematoma during mechanical loading and manual loading. This increase in the occurrence of wing tip

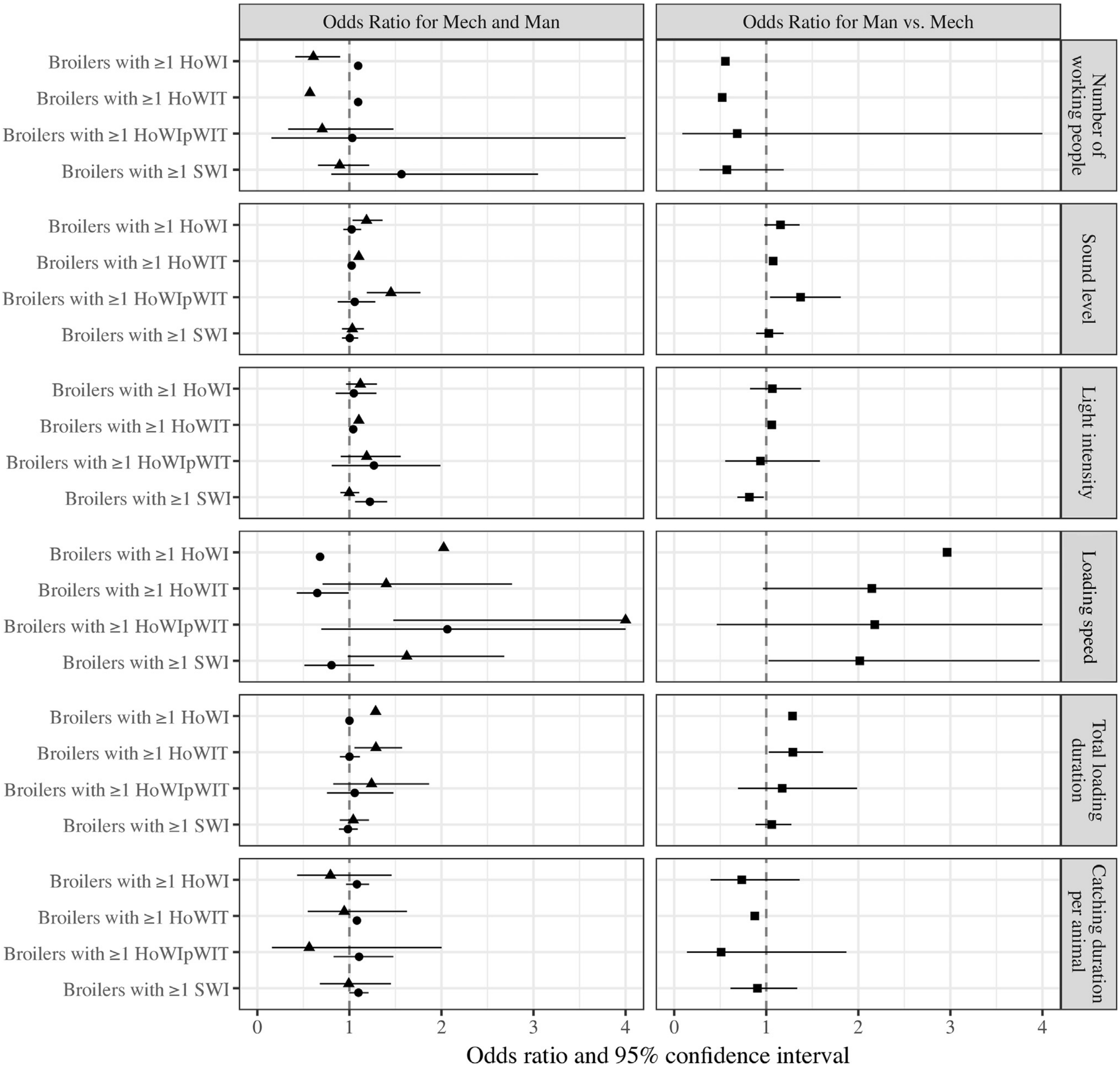

Figure 3. Odds ratios and estimated effects with 95% confidence intervals (bars) for the occurrence of injuries during loading for the mechanical (Mech, circles) and the manual (Man, triangles) catching method (total $n = 24$ loadings). Abbreviations: HoWI, hematoma on wing (including HoWIT and HoWIpWIT); HoWIT, hematoma on wing tip; HoWIpWIT, hematoma on wing proximal to wing tip; EPIoH, epiphysiolysis on humerus; SWI, severe wing injury (fracture or luxation; including epiphysiolysis on humerus).

hematomas was higher during manual than during mechanical loading, and the difference between the loading methods was statistically supported. The barn illumination furthermore showed an association with the occurrence of severe wing injuries (Figure 3). Severe wing injuries increased with increasing light intensity for both loading methods, but with a lower value for manual than for mechanical loading. This difference between the loading methods was statistically supported.

A further factor associated with the number of injured broilers was the number of overall involved working people during loading per 10,000 broilers (Figure 3). During manual loading, an increasing number of involved workers significantly reduced the occurrence of hematoma; during mechanical loading, this effect was opposite, albeit weaker. In addition, the number of personnel with certified expertise in accordance with § 17 of the German Order on the Protection of Animals and the Keeping of Production Animals (2006) or with comparable expertise was documented. The results considering the expertise of the workers during manual loading are based on only 2 loadings because in all of the other manual loadings, the whole team was certified by our definition. During mechanical loadings, the whole staff was always certified. Owing to the lack of variance, the presence of certification was not further considered in analysis.

For the manual loadings, we found a greater number of broilers DOA in flocks with a higher cumulative mortality as compared with flocks with a lower cumulative mortality during the rearing period (Table 5). This association was statistically supported. A higher deviation from the target stocking rate was associated with a higher chance of DOA after mechanical loading (Table 5). The number of broilers DOA after manual loading was furthermore tendentially greater in flocks that had received ≥1 antibiotic treatment during rearing as compared with untreated flocks (Table 5). Another factor that was associated with the number of broilers DOA was the barn illumination during loading (Table 5), with an increase in light intensity increasing the number of broilers DOA. This influence was statistically supported for mechanical loading and was tendential for manual loading (Table 5).

Determining Factors for Epiphysiolyses

The diagnosed severe wing injuries were almost exclusively humeral epiphysiolyses, prompting us to analyze possible factors influencing the occurrence of epiphysiolyses (Figure 4). We found a tendentially greater number of broilers with ≥1 humeral epiphysiolysis in female than male broilers for both loading methods (Figure 4). Flocks that had received several antibiotic treatments during rearing had tendentially fewer broilers with ≥1 humeral epiphysiolysis than untreated flocks or flocks with only 1 treatment during rearing. Flocks with comparably higher mortality during rearing showed tendentially smaller numbers of broilers with ≥1 humeral epiphysiolysis during mechanical loading and manual loading. The association of body weight and flock uniformity with the number of broilers with ≥1 humeral epiphysiolysis was marginal and showed opposite tendencies between the 2 catching methods (Figure 4).

DISCUSSION

Injuries

In the presented study, wing tip hematomas were more frequent in mechanically loaded broilers. The occurrence of severe wing injuries was observed in both catching methods and a difference between the 2 catching methods was not observed. The German Animal Welfare Act (2006) prohibits the infliction of evitable pain, suffering, or injuries to an animal. Thus, physical integrity is an essential element of animal welfare (Botreau et al., 2007; Farm Animal Welfare Council, 2009). In this study, we therefore compared the 2 catching methods by considering the induced injury risk in broilers. To do so, we examined the living broilers on-farm before and immediately after a loading was complete. The examination before loading was used as the baseline. By this examination, we ensured that the broilers of the investigated flocks were not injured before loading. The results of this pre-examination showed that the occurrence of hematomas or fractures during the pre-examination was nearly 0. Thus, we conclude that the minor or severe injuries diagnosed immediately after loading had occurred during the loading process. The results of previous studies on loading-induced injury risk in broilers at slaughter age are often based on the evaluation of injuries assessed on the carcass (de Koning et al., 1987; Lacy and Czarick, 1998; Knierim and Gocke, 2003; Nijdam et al., 2005; Musilová et al., 2013; Langkabel et al., 2015). This could be a problem because the assessed injuries could also have occurred during transport (Cockram and Dulal, 2018) and not only been caused by loading. Therefore, we examined the broilers immediately after loading to make sure that the observed injuries indeed resulted from the loading and not from the following processes, as also stated by Langkabel et al. (2015). This approach is an advantage of our study, although it hampers direct comparisons with the results from the mentioned studies. Because no confounding factors were included in the regression models, the results of this work can only provide directions for future research and may be further analyzed within a more controlled setup.

In the present study, we observed a significantly higher occurrence of hematomas on the wing tip in mechanically loaded broilers than in manually loaded broilers. Our results differ markedly from those of previous studies, although other authors comparing catching methods observed a similar tendency, the differences between the methods were much smaller (Lacy and Czarick, 1998; Nijdam et al., 2005). Knierim and

Table 5. Determining factors for the dead on arrival (DOA) rate.

	DOA					
	Mechanical catching			Manual catching		
Variable	OR	2.5% CI	97.5% CI	OR	2.5% CI	97.5% CI
Cumulative mortality (%)	0.65	0.50	0.85	2.04	1.00	4.17
Antibiotic therapy during rearing (yes/no)	0.40	0.28	0.56	1.73	0.20	5.00
Number of antibiotic treatments during rearing	0.40	0.30	0.54	1.72	0.21	5.00
Deviation from the target stocking rate (number of broilers per drawer)	1.03	1.01	1.05	1.00	0.99	1.00
Total time of loading (hours)	1.05	0.99	1.12	0.70	0.35	1.37
Illumination during loading (lux)	1.39	1.19	1.61	1.26	0.97	1.62
Sound level during loading (dB)	0.97	0.91	1.03	0.89	0.81	0.98

$n = 24$ loadings.
Abbreviations: CI, confidence interval; OR, odds ratio.

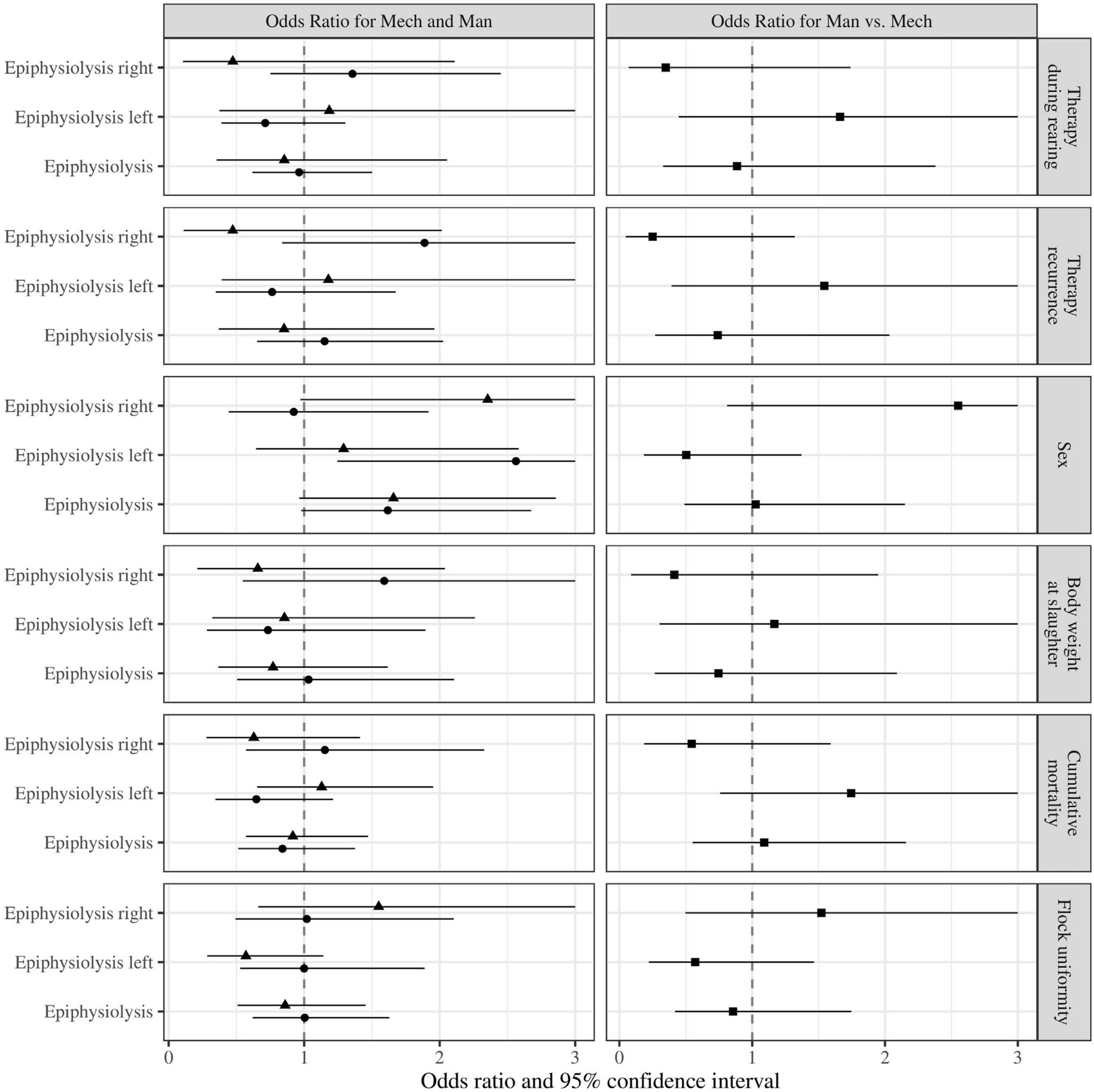

Figure 4. Odds ratios and estimated effects with 95% confidence intervals (bars) for the occurrence of epiphysiolysis on either side of the body during loading with the mechanical (Mech, circles) and the manual (Man, triangles) catching method (total $n = 24$ loadings).

Gocke (2003) observed a larger share of broilers with hematomas during manual loading. One possible explanation for this discrepancy could be that we investigated feathered wings. Hematomas on the underside of feathered wings could be identified easily because this part of the body is only sparsely feathered. Wing flapping or startling reflexes of the broilers during mechanical loading could cause the broilers to hit the conveyer belt with the ventral part of the wings (Wolff et al., 2019). This could explain the higher share of broilers with hematomas on the wing tip during mechanical loading in our study. Other authors suggested that during manual loading by the 2-leg catching method, higher pressure is put on the legs by which the broilers are caught than on the wings (Langkabel et al., 2015). The legs of the broilers, as well as the rest of the body, were still covered by feathers when examined in our study. Thus, owing to the feather cover, the assessment methods or the fact that it was not possible to perform the presented study in a blinded setting, the lesions caused by the manual method might have been underestimated in our study. Comparability with results from other studies is furthermore limited because the previous studies did not all use the same type of chicken harvester. In addition, hematomas in our study were counted as such when they exceeded a size of 0.5 cm (in diameter). This is very small compared with the size thresholds in other studies and might explain the higher overall occurrence of hematomas (Knierim and Gocke, 2003; Nijdam et al., 2005). Other authors concluded that the risk of injuries during manual loading increases when the personnel is exhausted (Lima et al., 2019). This fact could cause more injuries in broilers being caught toward the end of loading. Owing to technical reasons in doing this examination under field conditions, it was only possible to examine the broilers of the first 2/3 of the barns. This restriction could have caused an underestimation of injuries, especially during manual loading.

Severe wing injuries such as fractures and luxations are a very important welfare indicator because they induce pain in loaded broilers, and therefore care should be taken to avoid these severe injuries (Knierim and Gocke, 2003). In our study, the occurrence of severe injuries (fractures and luxations) did not differ between the 2 loading methods. Knierim and Gocke (2003) found significantly fewer wing fractures (on average 0.66%) in mechanically loaded broilers than in manually loaded broilers (on average 0.77%). By contrast, Musilová et al. (2013) observed a frequency of 0.15% of broilers with broken wings after mechanical loading and 0.03% after manual loading. Because both studies investigated the same harvester as a mechanical loading method, these contrasting results indicate that multiple factors (such as weight and age of the broilers) can influence the occurrence of injuries.

Although mechanical loading with the chicken harvester Apollo Generation 2 is a mostly automated production step, this loading method includes work steps that must be performed manually. For example, the herein used harvester model requires manual height adjustment of the rear end of the caging belt to the container drawer being loaded. During data acquisition, we observed a higher occurrence of severe injuries in mechanically loaded broilers once, namely, when the person adjusting the height was distracted. If the height adjustment is inaccurate, the broilers will bump against the upper, closed drawer before they land in the targeted one. Thus, inaccurate adjustment could be associated with an increased injury risk for the animals. Further automation in this part of the Apollo Generation 2 might reduce the occurrence of injuries. Moreover, Wolff et al. (2019) found an increased risk for wing flapping in this part of the mechanical loading process. The bumping against the upper container drawers must be prevented because it is associated with an increased risk for hematomas (Wolff et al., 2019). In a new version of the Apollo Generation 2, the adjustment of the rear end of the caging belt is automated, and whether this automation can reduce the occurrence of injuries is currently investigated in a further study.

Compared with our study, the numbers of wing bruises after manual loading were much greater in the study by Nijdam et al. (2005). A possible explanation could be differences in the practiced procedure. In our study, the catchers had to grab the broilers by both legs. This requirement may have helped to keep the rate of injuries during manual loading lower than under common conditions of practice (i.e., 1-leg catching). However, the difference between 1-leg and 2-leg catching during manual loading seems to have much less influence on the injury risk than presumed because Langkabel et al. (2015) did not observe significant differences between these 2 catching methods. Furthermore, it is possible that the catchers in our study knew that the broilers would be examined and thus handled them more carefully than commonly practiced. During 1 loading, we observed that 1 person used the upright method in which broilers are carried by the abdomen as described by Kittelsen et al. (2018). The broilers caught by this person showed less wing flapping (Wolff et al., 2019). However, because this was only a single observation of 1 of the catchers, no association concerning the injuries could be identified. The upright catching and missing human contact during mechanical harvesting are assumed to be among the advantages of mechanical loading (Lacy and Czarick, 1998; Knierim and Gocke, 2003; Wolff et al., 2019).

Injuries occurring during loading are considered a risk factor for higher losses in terms of animals arriving dead at the processing plant (Bayliss and Hinton, 1990; Nijdam et al., 2006; Kittelsen et al., 2015; Jacobs et al., 2017a). Our study showed an average total DOA rate of 0.11% as registered at the processing plant. Other studies reported DOA rates with on average 0.12 to 0.54% (Knierim and Gocke, 2003; Nijdam et al., 2004; Drain et al., 2007; Haslam et al., 2008; Chauvin et al., 2011; Freitas et al., 2016; Jacobs et al., 2017a).

Considering each catching method separately, we found an average DOA rate of 0.16% for mechanical loading and 0.06% for manual loading. These results agree with Chauvin et al. (2011), who also found a significantly higher DOA rate in mechanically than in manually loaded flocks. Other authors observed a similar trend, but without consistent statistical differences between mechanical and manual loading (Knierim and Gocke, 2003; Nijdam et al., 2005). The DOA rates reported by Nijdam et al. (2005) after mechanical loading were about twice as high and the DOA rates after manual loading also much higher than those in our study.

One explanation for the greater number of broilers DOA after mechanical loading than after manual loading could be that the harvester, in contrast to the catchers, cannot differentiate between living and dead animals in the barn. Thus, it is possible that the harvester collects and loads dead animals that later are recorded as DOA at the processing plant. In the examined mechanically loaded containers after loading, 1 dead broiler was found. By contrast, the catchers would leave dead animals in the barn.

Stocking Rate in Container Drawers

Previous studies showed that the stocking rate in the container drawers during transport can have a significant influence on the number of broilers DOA at the processing plant (Nijdam et al., 2004; Whiting et al., 2007;

Chauvin et al., 2011; Caffrey et al., 2017). Therefore, it is important that the stocking rate in the container drawers can be controlled precisely (in accordance with kilograms per drawer) and adjusted during the loading process. In the present study, the average stocking rate in the manually loaded drawers was significantly higher than in the mechanically loaded ones. After mechanical loading, a drawer contained on average 1.16 fewer animals than required in accordance with the target stocking rate prescribed by the processing plant. During manual loading, the catchers control the stocking rate by counting the loaded animals. The loading of the drawers is based on animals per drawer as prescribed by the processing plant after extrapolation of the expected average weight of the flock on the day of slaughter. Thus, an adjustment due to higher or lower actual weight is hardly possible during the manual loading process. By contrast, during mechanical loading, the harvesting machine controls the stocking rate per drawer and per container in accordance with the actual loaded weight. Thus, the loading is performed based on kilograms per drawer, and the number of broilers per drawer can be adjusted anytime to the actual loaded animal weight. Possibly, the flocks on the day of slaughter were heavier than expected based on the weight data that had been used for extrapolation by the processing plant. This assumption is supported by our finding that only 12% of the mechanically loaded drawers met the target stocking rate, whereas almost 62% contained fewer animals than required. In addition, the average body weight can vary between the different areas of the barn. This weight variance within the barn and differing broiler densities on the conveyor belts of the harvester can influence the stocking rate in the containers. Consequently, the number of broilers can vary much more than during manual loading.

Overstocking of the drawers can influence the losses during transport to the processing plant (Nijdam et al., 2004; Whiting et al., 2007; Chauvin et al., 2011). However, understocking can also lead to an increased DOA risk (Caffrey et al., 2017). The influence of understocking on the number of broilers DOA seemed to be most significant at extreme temperatures below freezing.

General Conditions During Loading

In the present study, we analyzed relationships between the variables catching duration per animal, loading speed, and total loading duration. For mechanical loading, we found a tendentially positive correlation between a longer catching duration per animal and a longer total loading duration. At the same time, the loading speed decreased with longer catching duration per animal. Because we calculated the variable catching duration per animal based on the speed and length of the conveyor belts, a longer catching duration per animal practically corresponds to a slower speed of the conveyor belts. Therefore, the detected trend could indicate that the speed of the conveyor belts can influence the loading speed and the total loading duration during mechanical loading. However, the assumption that a slower speed of the conveyor belts causes a slower loading speed and thus a longer total loading duration contradicts previous observations that revealed no detectable relationship between speed of the conveyor belts and total loading duration, as concluded by observations of a speed of conveyer belts ranging from 1.4 to 1.6 m/s to 0.8 to 1.2 m/s (Knierim and Gocke, 2003). Furthermore, the detected trend should be interpreted with caution because the sample size in the present study was very small, resulting in relatively wide CIs and small effect sizes. Further studies would be necessary to allow more precise statements. For manual loading, we did not find a comparable trend. Here, multiple factors possibly influence the loading speed and total loading duration. The catching duration per animal during manual loading shows how many seconds a catcher needs on average to deposit the broilers in a drawer. Another critical factor for the loading speed expressed as animals per hour is the communication between the catchers and the forklift driver, who removes the full containers and brings empty ones, and this factor is relevant for both loading methods. If this container exchange takes long, it will likely slow down the loading speed and prolong the total loading duration.

Determining Factors for Injuries and DOA Rates

Besides the loading method itself, we focused on examining external circumstances during loading as possible factors influencing the occurrence of injuries in the presented study. We assessed, inter alia, the influence of catching duration per animal on the occurrence of wing tip hematomas. While a longer catching duration per animal was associated with a greater number of broilers with $\geq$1 wing tip hematoma during mechanical loading, it tended to reduce this number during manual loading. The difference between the loading methods was statistically supported. It possibly can be attributed to the differing circumstances for the broilers during handling. For mechanical loading, a longer catching duration per animal means a longer time being on the conveyor belts. When the broilers flap their wings in response to the moving belt, the wing tips hit the belt. This impact can cause hematomas, especially on the wing tips. By contrast, during manual loading, a longer catching duration per animal could be associated with a greater distance of the catchers to the container. This greater distance might lead to a less forceful arm movement during deposition of the broilers in the drawers, thus possibly lowering the injury risk. Another explanation for lowering the injury risk could be that a longer catching duration per animal during manual loading is caused by a slower and more careful handling of the broilers.

The loading speed was also associated with the occurrence of injuries in the present study. An increase in loading speed during mechanical loading was associated with a smaller number of broilers with ≥1 wing hematoma. Multiple factors can influence the loading speed calculated as animals per hour. In general, temporary interruptions for technical reasons, lack of arrangement between involved personnel, short breaks, or waiting for the next truck can reduce the loading speed. For mechanical loading, the loading speed may also depend on the speed of the conveyor belts. However, a previous study showed that more practice in operating the machine can lead to an increase in the loading speed in spite of a constant speed of the conveyer belts (Knierim and Gocke, 2003). In the same study, Knierim and Gocke (2003) observed that a decrease in belt speed from 1.4 to 1.6 m/s to 0.8 to 1.2 m/s did not necessarily lead to an increase in loading duration. Therefore, we conclude that other factors besides the speed of the conveyor belts can influence the loading speed. If the loading time per animal (speed of conveyer belt) is not the main factor determining the loading speed (animals per hour), frequent interruptions of the loading process are possibly responsible for a reduced loading speed. Thus, a slower loading speed may be explained by more stops of the conveyor belts during mechanical loading. The starting of the belts after a stop can provoke wing flapping, likely explaining the increased injury risk in case of frequent stops and starts. Thus, the injury risk may decrease with increasing loading speed because the belts less often stop and start. By contrast, during manual loading, we found an increased loading speed to be associated with an increased injury risk in terms of wing hematomas. The faster loading speed may have been associated with a less careful and more hectic handling of the broilers by the catchers (Cockram and Dulal, 2018).

Jacobs et al. (2017b), who examined manual and mechanical loading, could demonstrate a relationship between longer total loading duration and increase in injury risk. They found a positive correlation between increase in wing fractures and increase in loading duration. In our study, there was no association between the total loading duration during mechanical loading and the injury risk. By contrast, during manual loading, the risk for the occurrence of wing hematomas and tendentially for the occurrence of fractures increased when the loading duration increased. This finding might be explained by fatigue of the catchers, which can result in less careful handling of the animals (Kettlewell and Mitchell, 1994; Lacy and Czarick, 1998; Cockram and Dulal, 2018).

Further factors that influenced the occurrence of injuries in our study included the exposure to high sound levels and light intensities in the barn during loading. It is possible that these stimuli trigger a flight response in the animals, leading to more defense movements. However, higher sound levels were observed in mechanically loaded flocks, which had larger flock sizes than the manually loaded flocks in our study. The greater number of birds could also have caused the higher sound level compared with the smaller flocks of the manual loadings. A previous study on the behavior of broilers at various light intensities showed that the broilers were calmed down by low light intensities compared with high light intensities (Kristensen et al., 2006). Other authors also found light intensity to determine the level of activity in broilers and, furthermore, to influence the intensity of defense movements (Jones et al., 1998; Cockram and Dulal, 2018). In the study by Jones et al. (1998), the observed broilers on a processing line struggled much more when the illumination was higher compared with lower light intensities. Nijdam et al. (2004) observed a higher incidence of injuries during daytime loadings than during nighttime loadings. The higher injury risk during daytime loadings agrees with findings from other studies (Taylor and Helbacka, 1968; Cockram and Dulal, 2018). A possible reason could be the higher light intensity during the day. However, Jacobs et al. (2017b) reported contrasting results, with a lower injury risk during daytime transports than during nighttime transports. In our study, the difference of actual to target stocking rate in the drawer was not associated with the prevalence of injuries. This could be a consequence of the fact that we investigated the broilers directly after loading and the influence would only be present if the broilers were examined after transport.

Besides the mentioned factors, we found that a greater number of overall involved working people per 10,000 broilers during manual loading was strongly associated with a lower occurrence of hematomas on the wing. The effect during mechanical loading was opposite, albeit weaker. We additionally evaluated how many persons involved in the loading process had officially certified expertise by a veterinary office (includes agricultural education or schooling with exam by veterinary office) (§ 17, German Order on the Protection of Animals and the Keeping of Production Animals, 2006). If farm staff is loading the broilers, the mentioned certification is not required, and an instruction by legitimated persons (e.g., the farmer or another person with a certification comparable with the expertise of the farmer) is sufficient. The chicken harvester was operated by the farmers; thus, all persons involved in the mechanical loadings had been certified in accordance with § 17 of the German Order on the Protection of Animals and the Keeping of Production Animals (2006). During manual loading, only in 2 loadings not all involved staff had a certification. Therefore, we focus on the number of working people per 10,000 broilers. The association of a greater number of workers per 10,000 broilers with a lower occurrence of hematomas during manual loading should be considered in combination with the association of the total loading duration with the number of injuries and the association of the total loading duration with the number of workers per 10,000 broilers. Thus, the occurrence of hematomas could probably be reduced by involving more personnel or by reducing the number of loaded broilers. During mechanical loading, overall less personnel is needed than manual loading. If the farmers own and operate a mechanical harvester themselves, they can control and affect the way of loading more, than if a commercial catching crew is payed for manual loading.

The number of broilers DOA is not only an important indicator of the welfare of broilers on their way from the farm to the processing plant (Jacobs et al., 2017a; Cockram and Dulal, 2018) but also it represents economic loss (Aral et al., 2014; Ramakrishnan et al., 2018). Numerous previous studies dealt with the possible causes of broilers DOA and identified various factors of influence (Nijdam et al., 2004; Haslam et al., 2008; Chauvin et al., 2011; Kittelsen et al., 2015; Jacobs et al., 2017a). The most frequently mentioned risk factors for broilers DOA include the body weight of the animals at slaughter (Nijdam et al., 2004; Haslam et al., 2008; Chauvin et al., 2011; Caffrey et al., 2017), the weather, certain outside temperature ranges, and the season (Nijdam et al., 2004; Warriss et al., 2005; Petracci et al., 2006; Whiting et al., 2007; Haslam et al., 2008; Chauvin et al., 2011; Elsayed, 2014; Freitas et al., 2016; Caffrey et al., 2017). Furthermore, the management of procedures before slaughter and transport, such as duration of feed withdrawal before loading, duration of transport, and duration of lairage at the processing plant, can significantly influence losses caused by broilers DOA (Nijdam et al., 2004; Vecerek et al., 2006; Oba et al., 2009; Chauvin et al., 2011; Aral et al., 2014; Elsayed, 2014; Caffrey et al., 2017; Kittelsen et al., 2017; Ramakrishnan et al., 2018). Other reported factors that influence DOA rates include flock size (Nijdam et al., 2004; Chauvin et al., 2011; Kittelsen et al., 2017) and cumulative mortality during rearing (Whiting et al., 2007; Haslam et al., 2008; Chauvin et al., 2011). In our study, higher cumulative mortality during rearing led to an increased risk for broilers DOA after manual loading. Furthermore, manually loaded flocks that had received $\geq$1 antibiotic treatment during rearing tended to show a higher DOA rate than the untreated ones. A possible explanation is that the necessity for antibiotic therapy and the higher mortality can indicate poor flock health. Nijdam et al. (2006) found that 90% of the examined broilers DOA had preexisting conditions such as laryngitis, tracheitis, fibrinous polyserositis or purulent arthritis. An association of deviation from the target stocking rate with the number of broilers DOA was observed in mechanical loading. This influence of overstocking or understocking of container drawers on the DOA rate was also observed by other authors (Nijdam et al., 2004; Whiting et al., 2007; Chauvin et al., 2011; Caffrey et al., 2017).

Higher light intensity during loading in the present study was associated with greater numbers of broilers DOA, tendentially for manual and statistically supported for mechanical loading. Nijdam et al. (2004) found a greater number of broilers DOA for daytime loadings than for nighttime loadings. Besides differences in temperature between day and night (Nijdam et al., 2004), differences in light intensity could also explain the influence of the time of day at loading on DOA rates. During loadings at high light intensity, the broilers might suffer injuries resulting from high levels of defense behavior. These injuries, in turn, would increase the mortality risk during transport.

Determining Factors for Epiphysiolyses

In the present study, epiphysiolysis of the distal humerus was the most frequently diagnosed type of wing fracture. All broilers with a fracture or luxation (diagnosed by palpation) were subjected to a complete pathological examination and histology after death. From human medicine, we know that different forms of humeral epiphysiolysis exist (Peterson, 2007). All herein diagnosed cases of epiphysiolysis showed complete separation in accordance with "Salter–Harris type I″ in the classification scheme of Peterson (2007). A comparable form of epiphysiolysis in broilers frequently occurs on the femoral head of the pelvic extremity (Julian, 1998; McNamee and Smyth, 2000; Julian, 2005; Wideman Jr. et al., 2012; Prisby et al., 2014). The broilers examined in the present study were Ross 308 broilers, a fast-growing breed. Authors previously pointed out a possible relationship between frequent occurrence of abnormal skeletal development and the use of fast-growing broiler hybrids with high rates of daily weight gain (Bradshaw et al., 2002; Wideman and Prisby, 2013). Olkowski et al. (2011) showed that abnormal skeletal development occurs especially in fast-growing broiler hybrids. Possibly, abnormal development of the epiphyseal plate caused by fast growth could result in reduced humeral stability. Such instability would be without consequences due to low mechanical stress during rearing. However, our histological findings did not reveal abnormal signs of development of the epiphyseal plates in the examined broilers or frequent occurrences of femoral head necrosis. Furthermore, body weight and flock uniformity were not notably associated with the occurrence of epiphysiolyses in the present study. A possible cause for the herein observed humeral epiphysiolyses could be that the epiphyseal plate in broilers at slaughter age is not yet physiologically closed. It is mentioned in the literature that the ossification of bones in birds is finished 190 d after hatching (Martin and Ritchie, 1994). During loading, the increased mechanical stress caused by contractions of the strong chest muscles during wing flapping could therefore lead to a fracture at the locus minoris resistentiae, which represents the still unossified epiphyseal plate.

A tendentially reduced occurrence of epiphysiolyses during loading in the flocks that had received antibiotic treatment(s) more than once during rearing was observed in our study. For the growth plate of the femur, researchers have suggested that pre-existing pathological alterations, caused for example by mechanical damage, can promote local bacterial colonization (Bradshaw et al., 2002; Dinev, 2012; Wideman and Prisby, 2013; Prisby et al., 2014). Bacterial colonization implies additional weakening of the tissue in the growth plate and could explain our results. In addition, regardless of the loading method, the flocks with higher on-farm mortality rates tendentially had a smaller share of broilers with epiphysiolysis after loading. The recorded higher on-farm mortality rates could be the result of more deliberate selective culling before loading (Jacobs et al., 2017a). This, in turn, could lead to a smaller share of sick broilers with a potential predisposition for epiphysiolysis during loading and transport. After mechanical loading, we furthermore found female broilers to be tendentially at higher risk than male broilers for epiphysiolysis. Possibly, hormonal differences between female and male broilers cause differences in skeletal development, along with an increased risk for epiphyseal rupture in female broilers. However, this assumption contrasts with previous findings on the incidence of abnormal skeletal development, showing male broilers to be much more affected than female broilers (Bradshaw et al., 2002).

CONCLUSION

In our study, a significantly smaller number of broilers with hematomas (≥0.5 cm in diameter) on the wing were observed after manual loading than after mechanical loading using the Apollo Generation 2. The number of broilers with severe wing injuries, such as fractures, was not significantly different between the 2 loading methods. Furthermore, the number of broilers DOA was greater in mechanically than in manually loaded flocks, but lower than in comparable studies. One advantage of the manual loading, compared with mechanical loading, might be that dead broilers in the barn are recognized and removed during loading and therefore not loaded with the living birds. Although the incidence of wing hematomas was higher in mechanically than in manually loaded flocks, our results indicate that the choice of loading method alone does not determine the injury risk. During our study, an increased injury risk in both methods was associated with higher sound level and higher light intensity during loading. By contrast, catching duration per animal, total loading duration, and loading speed tendentially had opposite effects on injury risk in the 2 loading methods. In both loading methods, the total loading duration was strongly correlated with the number of working people per 10,000 broilers and the number of loaded broilers. A longer total loading duration in manual loadings was associated with a significant increase in injury risk in terms of wing hematomas. Furthermore, the involvement of more working people per 10,000 broilers during manual loading was associated with a lower occurrence of hematomas. This finding indicates increasing fatigue of the catchers and thus a less careful handling of the animals. The total loading duration in mechanical loadings had no notable influence on the injury risk. Therefore, it could be concluded that physical conditions of the involved personnel might play a larger role in manual than in mechanical loading. However, our study also indicated aspects that should be optimized in the tested Apollo Generation 2 chicken harvester. The transition of the animals from the caging belt into the transport container might represent a critical point and a crucial risk area for the occurrence of injuries. This risk arises because the rear end of the caging belt of the harvester must be adjusted manually to the height of the container drawer that is to be loaded. Inaccurate adjustment by, for example, distracted personnel can bear injury risk to the broilers, which was observed once during our investigation. Further development regarding the height adjustment of the rear end of the caging belt to the level of the targeted container drawer would mitigate a crucial risk area. One advantage of the examined chicken harvester is that it can control the stocking rate in the drawers in accordance with the body weight of the loaded broilers. Therefore, compared with manual loading, there is a better possibility to adapt the stocking rate in the drawers to changes in body weight before slaughter. Furthermore, loading with the mechanical harvester is less influenced by the physical condition (fatigue) of the working staff, which may result in less careful handling of the broilers during manual loading. In overall view of our results, we conclude that multiple factors besides the loading method are associated with broiler welfare during loading.

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Ethical Approval: 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; the loadings examined were performed within standard procedures used in conventional housing and loading of broilers.

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REFERENCES

Aral, Y., M. S. Arikan, A. C. Akin, C. Y. Kaya Kuyululu, S. C. Güloglu, and E. Sakarya. 2014. Economic losses due to live weight shrinkage and mortality during the broiler transport. Vet. Fak. Derg. 61:205–210.

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

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

Botreau, R., I. Veissier, A. Butterworth, M. B. M. Bracke, and L. J. Keeling. 2007. Definition of criteria for overall assessment of animal welfare. Anim. Welf. 16:225–228.

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

Caffrey, N. P., I. R. Dohoo, and M. S. Cockram. 2017. Factors affecting mortality risk during transportation of broiler chickens for slaughter in Atlantic Canada. Prev. Vet. Med. 147:199–208.

Chauvin, C., S. Hillion, L. Balaine, V. Michel, J. Peraste, I. Petetin, C. Lupo, and S. Le Bouquin. 2011. Factors associated with mortality of broilers during transport to processing plant. Animal 5:287–293.

Cockram, M. S., and K. J. Dulal. 2018. Injury and mortality in broilers during handling and transport to slaughter. Can. J. Anim. Sci. 98:416–432.

Council Regulation (EC). 2004. Council Regulation (EC). Pages 1–44 in No 1/2005 of 22 December 2004 on the protection of animals during transport and related operations and amending Directives 64/432/EEC and 93/119/EC and Regulation (EC) No 1255/97, OJ L 3, 5.1.2005. Accessed Aug. 2020. https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32005R0001&from=EN.

Dinev, I. 2012. Leg weakness pathology in broiler chickens. J. Poult. Sci. 49:63–67.

Drain, M. E., T. L. Whiting, D. P. Rasali, and V. A. D'Angiolo. 2007. Warm weather transport of broiler chickens in Manitoba. I. Farm management factors associated with death loss in transit to slaughter. Can. Vet. J. 48:76–80.

Elsayed, M. A. 2014. Effects of length of shipping distance and season of the year temperature stress on death rates and physiological condition of broilers on arrival to processing plant. J. Nucl. Tech. Appl. Sci. 2:453–463.

Farm Animal Welfare Council. 2009. Farm animal welfare in Great Britain: past, present and future. Farm animal welfare Council report explaining farm animal welfare assessment and proposing future policy priorities. Accessed March 2020. https://www.gov.uk/government/publications/fawc-report-on-farm-animal-welfare-in-great-britain-past-present-and-future.

Freitas, A. S., L. M. Carvalho, A. L. Soares, A. C. de S. Neto, M. S. Madruga, R. H. Carvalho, E. I. Ida, and M. Shimokomaki. 2016. Simultaneous occurrence of broiler chicken hyper and hypothermia in-transit and lairage and dead on arrival (DOA) index under tropical climate. Int. J. Poult. Sci. 15:459–466.

German Animal Welfare Act. 2006. Amended and Promulgated on May 18th, 2006, Last Changed on December 17th, 2018. Accessed Aug. 2020. http://www.gesetze-im-internet.de/tierschg/BJNR012770972.html.

German Order on the Protection of Animals and the Keeping of Production Animals. 2006. Amended and Promulgated on August 22nd, 2006, Last Changed on June 30th, 2017. Accessed Aug. 2020. https://www.gesetze-im-internet.de/tierschnutztv/BJNR275800001.html.

Haslam, S. M., T. G. Knowles, S. N. Brown, L. J. Wilkins, S. C. Kestin, P. D. Warriss, and C. J. Nicol. 2008. Prevalence and factors associated with it, of birds dead on arrival at the processing plant and other rejection conditions in broiler chickens. Br. Poult. Sci. 49:685–696.

Havenstein, G. B., P. R. Ferket, and M. A. Qureshi. 2003. Growth, livability, and feed conversion of 1957 versus 2001 broilers when fed representative 1957 and 2001 broiler diets. Poult. Sci. 82:1500–1508.

Jacobs, L., E. Delezie, L. Duchateau, K. Goethals, and F. A. M. Tuyttens. 2017a. Broiler chickens dead on arrival: associated risk factors and welfare indicators. Poult. Sci. 96:259–265.

Jacobs, L., E. Delezie, L. Duchateau, K. Goethals, and F. A. M. Tuyttens. 2017b. Impact of the separate pre-slaughter stages on broiler chicken welfare. Poult. Sci. 96:266–273.

Jones, R. B., D. G. Satterlee, and G. G. Cadd. 1998. Struggling responses of broiler chickens shackled in groups on a moving line: effects of light intensity, hoods, and 'curtains'. Appl. Anim. Behav. Sci. 58:341–352.

Julian, R. J. 1998. Rapid growth problems: ascites and skeletal deformities in broilers. Poult. Sci. 77:1773–1780.

Julian, R. J. 2005. Production and growth related disorders and other metabolic diseases of poultry – a review. Vet. J. 169:350–369.

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

Kettlewell, P. J., and M. J. B. Turner. 1985. A review of broiler chicken catching and transport systems. J. Agr. Eng. Res. 31:93–114.

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 8:1–9.

Kittelsen, K. E., E. G. Granquist, Ø. Kolbjørnsen, O. Nafstad, and R. O. Moe. 2015. A comparison of post-mortem findings in broilers dead-on-farm and broilers dead-on-arrival at the abattoir. Poult. Sci. 94:2622–2629.

Kittelsen, K. E., R. O. Moe, K. Hoel, Ø. Kolbjørnsen, O. Nafstad, and E. G. Granquist. 2017. Comparison of flock characteristics, journey duration and pathology between flocks with a normal and a high percentage of broilers 'dead-on-arrival' at abattoirs. Animal 11:2301–2308.

Knierim, U., and A. Gocke. 2003. Effect of catching broilers by hand or machine on rates of injuries and dead-on-arrivals. Anim. Welf. 12:63–73.

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

Kristensen, H. H., J. M. Aerts, T. Leroy, C. M. Wathes, and D. Berckmans. 2006. Modelling the dynamic activity of broiler chickens in response to step-wise changes in light intensity. Appl. Anim. Behav. Sci. 101:125–143.

Lacy, M. P., and M. Czarick. 1998. Mechanical harvesting of broilers. Poult. Sci. 77:1794–1797.

Langkabel, N., M. P. O. 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.

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

Lund, V. P., N. C. Kyvsgaard, J. P. Christensen, and M. Bisgaard. 2013. Pathological manifestations observed in dead-on-arrival broilers at a Danish abattoir. Br. Poult. Sci. 54:430–440.

Maria, G. A. 2006. Public perception of farm animal welfare in Spain. Livest. Sci. 103:250–256.

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.

McNamee, P. T., and J. A. Smyth. 2000. Bacterial chondronecrosis with osteomyelitis ('femoral head necrosis') of broiler chickens: a review. Avian Pathol. 29:477–495.

Musilová, A., V. Kadlčáková, and M. Lichovníková. 2013. The effect of broiler catching method on quality of carcasses. Mendel Net 2013:251–255.

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

Nijdam, E., A. R. M. Zailan, J. H. H. van Eck, E. Decuypere, and J. A. Stegeman. 2006. Pathological features in dead on arrival broilers with special reference to heart disorders. Poult. Sci. 85:1303–1308.

Olkowski, A. A., B. Laarveld, C. Wojnarowicz, M. Chirino-Trejo, D. Chapman, T. W. 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.

Oba, A., M. de Almeida, J. W. Pinheiro, E. I. Ida, D. F. Marchi, A. L. Soares, and M. Shimokomaki. 2009. The effect of management of transport and lairage conditions on broiler chicken breast meat quality and DOA (death on arrival). Braz. Arch. Biol. Techn. 52:205–211.

Peterson, H. A. 2007. Distal humerus. Pages 422–518 in Epiphyseal Growth Plate Fractures. H. A. Peterson, ed. Springer, Berlin, Heidelberg, Germany.

Petracci, M., M. Bianchi, C. Cavani, P. Gaspari, and A. Lavazza. 2006. Preslaughter mortality in broiler chickens, turkeys, and spent hens under commercial slaughtering. Poult. Sci. 85:1660–1664.

Prisby, R., T. Menezes, J. Campbell, T. Benson, E. Samraj, I. Pevzner, and R.F. Wideman, Jr. 2014. Kinetic examination of femoral bone modeling in broilers. Poult. Sci. 93:1122–1129.

Ramakrishnan, C., R. N. Babu, V. Appa Rao, R. J. J. Abraham, P. T. Gnanaraj, S. W. Ruban, and K. Bhaskar. 2018. Economic loss due to live weight shrinkage and mortality during broiler transport in summer and winter season in Chennai city. Int. J. Chem. Stud. 6:816–819.

R Core Team. 2018. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. Accessed Oct. 2018. https://www.R-project.org/.

Taylor, M. H., and N. V. L. Helbacka. 1968. Field studies of bruised poultry. Poult. Sci. 47:1166–1169.

Tuyttens, F., F. Vanhonacker, and W. Verbeke. 2014. Broiler production in Flanders, Belgium: current situation and producers' opinions about animal welfare. World Poult. Sci. J. 70:343–354.

Vanhonacker, F., W. Verbeke, E. Van Poucke, and F. A. M. Tuyttens. 2008. Do citizens and farmers interpret the concept of farm animal welfare differently? Livest. Sci. 116:126–136.

Vecerek, V., E. Grbalova, E. Voslarova, B. Janackova, and M. Malena. 2006. Effects of travel distance and the season of the year on death rates of broilers transported to poultry processing plants. Poult. Sci. 85:1881–1884.

Warriss, P. D., A. Pagazaurtundua, and S. N. Brown. 2005. Relationship between maximum daily temperature and mortality of broiler chickens during transport and lairage. Br. Poult. Sci. 46:647–651.

Whiting, T. L., M. E. Drain, and D. P. Rasali. 2007. Warm weather transport of broiler chickens in Manitoba. II. Truck management factors associated with death loss in transit to slaughter. Can. Vet. J. 48:148–154.

Wideman, Jr, R.F., K. R. Hamal, J. M. Stark, J. Blankenship, H. Lester, K. N. Mitchell, G. Lorenzoni, and I. Pevzner. 2012. A wire-flooring model for inducing lameness in broilers: evaluation of probiotics as a prophylactic treatment. Poult. Sci. 91:870–883.

Wideman, R. F., and R. D. Prisby. 2013. Bone circulatory disturbances in the development of spontaneous bacterial chondronecrosis with osteomyelitis: a translational model for the pathogenesis of femoral head necrosis. Front. Endocrinol. (Lausanne) 3:183.

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.