JOURNAL OF ANIMAL SCIENCE
The Premier Journal and Leading Source of New Knowledge and Perspective in Animal Science

Minor beak trimming in chickens leads to loss of mechanoreception and magnetoreception

R. Freire, M. A. Eastwood and M. Joyce

J ANIM SCI 2011, 89:1201-1206.
doi: 10.2527/jas.2010-3129 originally published online December 10, 2010

Minor beak trimming in chickens leads to loss of mechanoreception and magnetoreception[1]

R. Freire,[2] M. A. Eastwood, and M. Joyce

EH Graham Centre, School of Animal and Veterinary Sciences, Charles Sturt University, Wagga Wagga, Australia, New South Wales 2650

ABSTRACT: Routine removal of the tip of the beak of chickens within the poultry industry leads to changes in pecking behavior, which have previously been interpreted as being indicative of pain. By analyzing the force of pecks, with and without the topical application of an analgesic to the beak, we investigated if changes in pecking behavior were due to a loss of sensitivity in the beak or were pain related. Pecking behavior was compared between intact-beak and beak-trimmed chicks with or without topical application of lignocaine during a pain-free period (within 24 h of beak trimming) or after this period (d 2 to 9 of age). After pecking behavior tests, chicks were trained to use a magnetic stimulus to locate hidden food in 1 corner of a square arena. In unrewarded magnetic tests, the location of the chick relative to the magnetic stimulus was determined by automatic image recognition. Beak-trimmed chicks pecked harder than intact-beak chicks within 24 h of beak trimming ($P = 0.04$), possibly as a means of compensating for the loss of sensory feedback in beak-trimmed chicks. At 2 to 9 d of age, beak-trimmed chicks took longer to peck the pecking stimulus ($P < 0.001$) and showed fewer pecks in total ($P < 0.001$), suggesting a reduced pecking motivation. The force of pecks, however, did not differ among treatments at 2 to 9 d of age, suggesting that beak-trimmed chicks were not experiencing pain from the beak. In the magnetic tests, hungry intact-beak chicks stayed nearer to the magnetic stimulus ($P = 0.005$) and spent proportionally more time within 125 mm of the magnetic stimulus ($P = 0.02$) that had previously been associated with food than beak-trimmed chicks, which indicated that intact-beak birds were better able to detect the magnetic stimulus than beak-trimmed birds. We concluded that minor beak trimming at a young age did not result in pain in young domestic chicks, but instead led to impaired function of the magnetoreceptors and mechanoreceptors of the beak.

Key words: beak trimming, poultry behavior, welfare

J. Anim. Sci. 2011. 89:1201–1206
doi:10.2527/jas.2010-3129

INTRODUCTION

Beak trimming in chickens is the removal of one-third to one-half of the upper and lower beak. This routine industry practice is usually undertaken at 1 d of age to reduce cannibalism and improve feed conversion (Glatz, 1990). Despite the above benefits, welfare concerns over the practice of beak trimming have been raised, which have generally centered on the possibility of birds experiencing acute and chronic pain after the procedure (Cheng, 2006).

Behavioral evidence of pain after beak trimming has been based on the observed reduction in pecking behavior, reduced activity and social behavior, and increased sleep duration (Gentle et al., 1982, 1991; Duncan et al., 1989; Craig and Lee, 1990). It is, however, unclear if the above changes in behavior arise from pain or from a loss of sensitivity in the beak (Gentle et al., 1991; Hughes and Gentle, 1995). Here, we attempted to differentiate between these alternative possibilities by examining changes in pecking force and magnetoreception.

Pecking force has been found to decrease after beak trimming in adult hens (Freire et al., 2008), possibly indicating that hens are protecting a painful area from further stimulation (Gentle et al., 1991). Additionally, Fe mineral deposits in the dendrites in the upper beak of chickens may be involved in magnetoreception (Falkenberg et al., 2010) and could provide an important

[1]We thank Gary McKenzie [Spatial Data Analysis Network (SPAN), Charles Sturt University, Wagga Wagga, Australia] for assistance with the spatial analysis, Ann Cowling (Charles Sturt University School of Animal and Veterinary Sciences, Wagga Wagga, Australia) for assistance with statistics, the EH Graham Centre for a scholarship to M. Joyce, and Charles Sturt University for funding to R. Freire and M. A. Eastwood.

[2]Corresponding author: rfreire@csu.edu.au

Received May 2, 2010.
Accepted November 22, 2010.

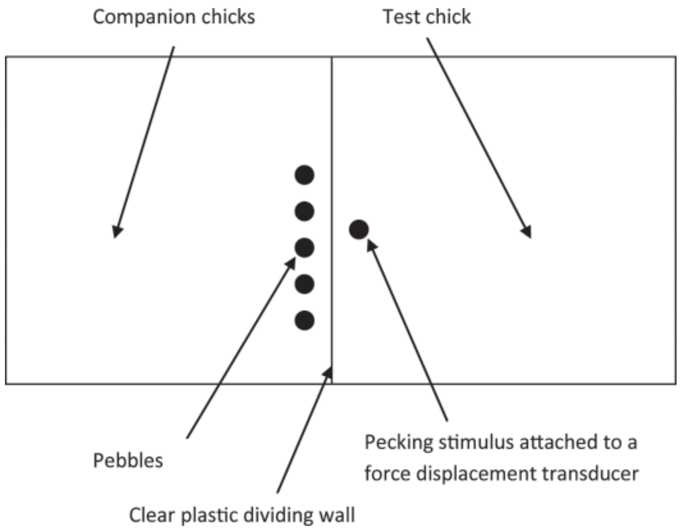

Figure 1. Diagram of the arena used for the pecking behavior test.

cue for spatial orientation in large flocks (Wiltschko et al., 2007).

We were interested in pecking behavior and magnetoreception in 2 distinct periods, the first 24 h (pain-free period; Gentle et al., 1991; Kuenzel, 2007) and d 2 to 9 (increased pain period; Gentle et al., 1997), after minor (one-fifth) trimming, which is under consideration as an alternative to the industry standard. The objectives of the study were to 1) determine if birds experience pain after minor beak trimming, and 2) identify the effect of beak trimming on mechano- and magnetoreception.

MATERIALS AND METHODS

All procedures involving animals were approved by the Animal Care and Ethics Committee (approval number ACEC 08/035).

Subjects and Housing

Seventy-four layer-strain medium-hybrid domestic cockerel chicks were obtained from Nulkaba Hatchery, Cessnock, New South Wales, Australia. Forty-nine of these chicks had been beak-trimmed with a commercial hot blade beak trimming machine within 6 h of hatching to remove about one-fifth of both the top and bottom mandibles (minor beak trimming procedure). The remainder of the chicks had not been beak-trimmed. On arrival at our laboratory at approximately 18 h of age (d 1 of age), chicks were housed in groups of 2 or 3 in metal wire cages measuring 30 × 30 × 30 cm with a solid floor lined with white paper (home cages). Beak-trimmed and intact-beak chicks were housed separately, with group size balanced as far as possible. Chicks had continuous access to water via an externally placed drinker and were fed commercial chick starter crumbs. Fluorescent lights were on a 14-h light and 10-h dark cycle and were supplemented by natural daylight for about 12 h of the light period. Temperature was maintained at 35°C for the first week and between 25 to 30°C thereafter. Chicks were marked with either green or purple livestock marker (Heiniger Aust. Pty. Ltd., Bibra Lake, WA) on the back to allow individual identification.

The chicks were assigned to 1 of 3 treatments: 1) a beak-trimmed group (**BT**, n = 24), 2) a BT group that received 2 applications of 20 mg/mL of lignocaine hydrochloride (Ilium Lignocaine 20, Troy Laboratories Pty. Ltd., Smithfield, New South Wales, Australia) to the tips of the upper and lower mandibles with a saturated swab at 20 and 10 min before the pecking behavior test (**BTL**, n = 25), and 3) an intact-beak group (**IB**, n = 25). The BT and IB chicks received a comparable sham treatment in which a wet swab was applied to the tip of the beak as for the BTL treatment. All 3 treatments underwent a pecking behavior test between d 1 and 9, and all chicks underwent a magnetic intensity test between d 11 and 16.

Pecking Behavior Test

Pecking behavior was examined by moving each chick to a test arena that consisted of a solid 30 × 30 × 30-cm cage with a clear plastic front wall to allow viewing of the chick, and a clear plastic back wall (Figure 1). Behind this latter plastic wall were the cage-mates of the chick, also in a 30 × 30 × 30-cm cage, which served as social companions. Pecking force was recorded on a pecking stimulus, which consisted of a black 3-mm diameter stone, which protruded 5 mm above the white paper floor through a hole. The pecking stimulus was glued to a force displacement transducer (FT03, Grass Technologies, West Warwick). The force of pecks at the pecking stimulus was recorded by a PC running LabChart 7.1 (ADI Instruments, Colorado Springs, CO) connected to the transducer by an ADI Powerlab (ADI Instruments). The transducer was calibrated to record forces up to 5 newtons with an accuracy of 0.01 newtons.

Chicks were individually placed in the test arena soon after arrival on d 1 (so that d 1 tests were between 12 to 20 h after beak trimming) and on d 2, 5, 7, and 9. The order of testing was balanced across treatments. To encourage pecking, food was withheld from chicks for 12 h before testing, and chicks were fed immediately after being returned to their home cages. The latency to the first peck at the pecking stimulus was recorded by the observer, and the test was terminated after the chick pecked the pecking stimulus 10 times, or after 10 min, whichever occurred sooner. Chicks were observed to ensure that force recorded at the pecking stimulus corresponded with pecks (i.e., instances when the chick stood on the pecking stimulus were noted and omitted from the analysis).

Magnetic Intensity Test

From 11 to 14 d of age, all chicks were trained to associate a magnetic stimulus with the location of hidden food in a square enclosed arena made of laminated chipboard with sides of 80 cm and 75 cm high. A dark gray substrate of a mixture of peat and wood dust covered the floor. The upper 35 cm of each wall could be opened to introduce and remove the chicks. Lighting was provided by 4 incandescent lamps (40 W) positioned above each corner and above a light diffuser. The use of an enclosed arena ensured that external spatial cues were minimized.

A black plastic feeding dish (15 cm diameter) was placed at each of the 4 corners of the arena. Underneath these dishes (and under the floor of the arena) was fixed a magnetic coil or a control coil. Control coils were fixed beneath 3 of the 4 corners with a magnetic coil fixed below only 1 randomly chosen corner. The magnetic coil was composed of Cu wire wound around a wooden wheel to create a coil of 60 revolutions of wire with a maximum diameter of 15 cm. A DC current of 1 A was run through the coils to produce a magnetic field. A fluxgate magnetometer (MAG-01H, Bartington, UK) was used to measure the strength of the field at 100 mm above the coil (100 mm is approximately the height of the head of the chick). The field was measured at the local maximum (north orientation, 65° inclination), vertical and horizontal (north direction) positions. These 3 measurements were summed and compared with identical measurements with the coil at certain distances from the probe. When the center of the coil was 100, 125, 150, and 200 mm away from the probe, the field was 40, 18, 2, and 0% stronger than the local field, respectively. A control coil involved identical Cu wire wound around 30 times in 1 direction and 30 times in the opposite direction so that the magnetic field generated by the current would be cancelled out.

The training procedure involved the feeding of starter crumbs to pairs of chicks in the arena on d 11 and 12, and individual chicks on d 13 and 14, out of the dish located above the magnetic coil for 10 min. Chicks had been food-deprived for 12 h before being placed in the arena. The remaining dishes had the dark gray substrate. The position of the food dish was changed every day according to a pseudo-random sequence. On each subsequent day, additional dark gray substrate was placed over the food to progressively hide the food and encourage searching for food.

Testing on d 15 and 16 was unrewarded (no food) with all 4 dishes filled with dark gray substrate. Two days of testing was selected because in an earlier pilot study it was found that searching behavior became extinguished after this time. Chicks had been food-deprived for 12 h before testing. Chicks were tested individually for 2 min, and the position of the magnetic coil was determined by random, with IB and BT chicks tested alternately. An overhead camera was placed above the center of the arena with the lens positioned through a 5-cm-diameter hole and was used to record the behavior of the chick on a laptop computer.

Statistical Analysis

For the pecking behavior test, the latency to the first peck, the number of pecks given, the mean force of pecks, and the maximum force of pecks at the pecking stimulus were analyzed in a generalized linear mixed model with treatment and day as factors, and chick as a random effect. Laying strains of chicks of this age often experience considerable mortality rate, termed starve-out within the industry, and 5 IB, 7 BT, and 4 BTL chicks died during the first 9 d, and these were treated as missing values.

For the magnetic intensity tests, automatic image recognition was used to detect the centroid of the detected area of the chick (light colored) against the dark gray background. Every fifth frame (i.e., every 0.2 s) was processed to yield 600 centroid locations for each chick for each day. Individual chicks were found in all images. The centroid locations were transformed to actual distances from the center of the magnetic coil after correction for the distortion caused by the field of view of the lens and averaged over the 2 test days, and were analyzed in an ANOVA. In addition, the amount of time that the centroid was within 125 mm of the center of the magnetic coil (i.e., the distance at which we could detect the field with our magnetometer) and of the other coils (numbered 2 to 4 clockwise from the magnetic coil) was calculated for each chick, averaged over the 2 test days and log-transformed to meet parametric assumptions. The proportion of time spent in the corner of the magnet was analyzed following a logistic transformation $\{\log[P/(1 - P)]\}$ to take into account variation in the proportion of time spent at all corners. Six chicks (2 BT and 4 IB) failed to approach within 125 mm of any coil on either test day and were removed from the analysis.

RESULTS

Pecking Behavior Test

Within 24 h of Beak Trimming. The majority of chicks spontaneously pecked the pecking stimulus in the first test with the first peck 216 ± 27 s after introduction into the testing arena. No difference in the latency to the first peck was found among treatments (Figure 2; ANOVA, $F_{2,71} = 0.30$, $P = 0.97$). Chicks pecked the pecking stimulus 6.0 ± 0.5 times in the testing arena, and no significant difference in the number of pecks given was shown among treatments (Figure 3; ANOVA, $F_{2,71} = 0.90$, $P = 0.41$). Perhaps unexpectedly, IB chicks pecked more softly than BT or BTL chicks (Figure 4; ANOVA, $F_{2,56} = 3.55$, $P = 0.04$). Maximum pecking force was 0.14 ± 0.01 newtons for all chicks, with no significant difference among treatments (ANOVA, $F_{2,56} = 0.37$, $P = 0.70$).

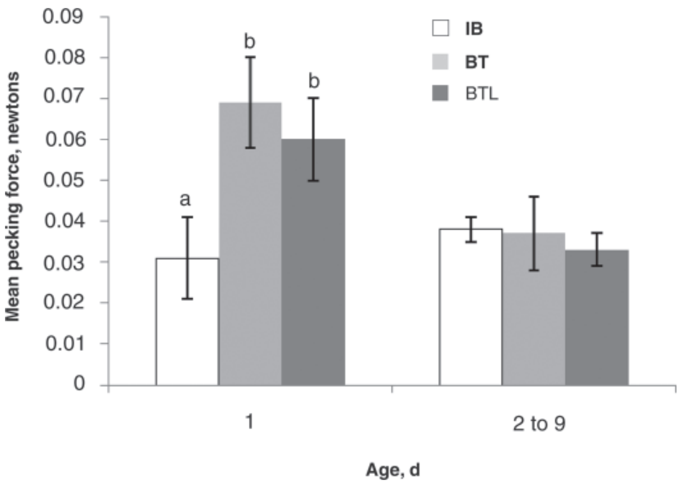

Figure 2. Mean (SE) force (newtons) of pecks at the pecking stimulus in the test arena by intact-beak (IB), beak-trimmed (BT), and BT + lignocaine-treated (BTL) chicks on d 1 and on d 2, 5, 7, and 9 combined. [a,b]Values indicated by different letters differed ($P < 0.05$).

Days 2 to 9 After Beak Trimming. Beak-trimmed and BTL chicks pecked the pecking stimulus later after introduction into the testing arena than IB chicks (Figure 2; ANOVA, $F_{2,39.8} = 12.4$, $P < 0.001$). No difference in the latency to the first peck was found for day (ANOVA, $F_{3,63.5} = 1.9$, $P = 0.13$) or day × treatment interaction (ANOVA, $F_{6,109} = 1.3$, $P = 0.27$). Beak-trimmed and BTL chicks also pecked the pecking stimulus less than IB chicks (Figure 3; ANOVA, $F_{2,44.2} = 13.5$, $P < 0.001$). The number of pecks differed significantly among days (Figure 3; ANOVA, $F_{3,67} = 3.48$, $P = 0.02$), although no day × treatment interaction was found (ANOVA, $F_{6,109} = 1.39$, $P = 0.23$). No difference in mean pecking force was found among the 3 treatments (Figure 4; ANOVA, $F_{2,36.5} = 0.31$, $P = 0.73$), or among days (ANOVA, $F_{3,44.4} = 2.57$, $P = 0.07$) or in the day × treatment interaction (ANOVA, $F_{6,38} = 1.70$, $P = 0.15$). Similarly, no difference in maximum pecking force was found among the 3 treatments (ANOVA, $F_{2,29.9} = 0.19$, $P = 0.83$) or among days (ANOVA, $F_{3,48.1} = 0.25$, $P = 0.86$) or in the day × treatment interaction (ANOVA, $F_{6,38} = 0.58$, $P = 0.74$).

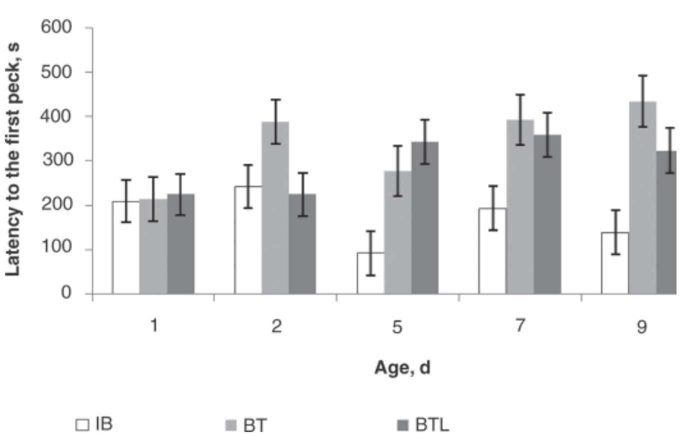

Figure 3. Mean (SE) latency (s) to the first peck in the test arena by intact-beak (IB), beak-trimmed (BT), and BT + lignocaine-treated (BTL) chicks on each of the 5 test days.

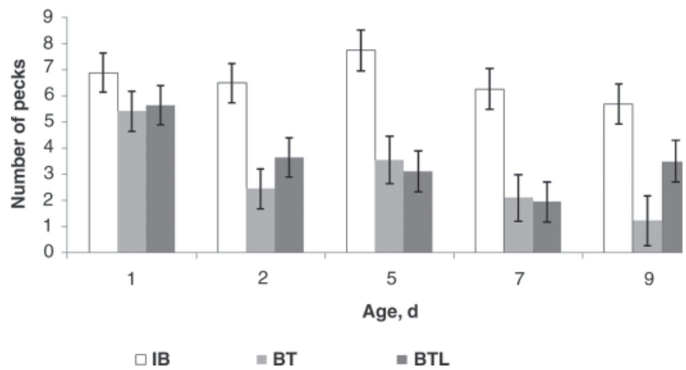

Figure 4. Mean (SE) number of pecks at the pecking stimulus in 10 min in the test arena by intact-beak (IB), beak-trimmed (BT), and BT + lignocaine-treated (BTL) chicks on each of the 5 test days.

Magnetic Intensity Test

Chicks readily approached the food during training, and all chicks successfully found the food under the substrate in the last few days of training, indicating that chicks were motivated to find the food. In tests, average distance to the center of the magnetic coil was shorter for IB than BT chicks (443 ± 12 and 487 ± 8 mm, respectively; ANOVA, $F_{1,51} = 8.58$, $P = 0.005$). Beak-trimmed chicks spent significantly more time within 125 mm of all coils than IB chicks (Figure 5; ANOVA, $F_{1,50} = 9.69$, $P = 0.003$). Analysis of the logistically transformed proportions of time spent in the magnetic corner as opposed to other corners showed that IB chicks spent proportionally more time within 125 mm of the magnetic coil than BT chicks (Figure 5; ANOVA, $F_{1,40} = 5.71$, $P = 0.02$).

DISCUSSION

In summary, BT chicks pecked harder than IB chicks within 24 h of beak trimming, but otherwise showed no difference in their willingness to peck the pecking stimulus. In the following days, however, BT chicks took longer to peck the pecking stimulus after introduction into the testing arena and gave fewer pecks in total, suggesting a reduced motivation to peck compared with IB birds. Pecking force, however, did not differ between IB and BT chicks, and was not affected by the application of lignocaine, indicating that birds were not experiencing pain during this time. In a magnetic intensity test, hungry IB chicks were on average nearer and spent proportionally more time within 125 mm of the magnetic stimulus that had previously been associated with food than BT chicks, indicating that IB birds were better able to detect the magnetic stimulus than BT birds.

Changes in pecking behavior after beak trimming have previously been interpreted as indicative of guarding behavior, a term that originated in the human pain literature to describe the protection of painful areas from further stimulation seen in pain patients (Gentle et al., 1991). However, a limitation of this interpretation is that changes in pecking behavior can also arise from a loss of sensitivity in the beak (Hughes and Gentle, 1995). The beak of the chicken is a complex functional organ with an extensive nerve supply that is used for food manipulation, exploration of the environment, preening, and social interaction (Kuenzel, 2007). Because beak trimming severs the nerves of the beak, pecking with a trimmed beak will not provide the sensory reward that an intact beak provides (Kuenzel, 2007). The loss of sensitivity after beak trimming could, therefore, account for the above-mentioned changes in pecking behavior after beak trimming. There are 3 main lines of evidence to suggest that minor beak trimming causes loss of sensitivity, rather than pain, during the early life of chicks.

First, the finding that chicks within 24 h of being beak trimmed pecked harder than IB birds was unexpected because we expected BT birds to be mostly pain-free during this period and, therefore, show no difference in pecking force when compared with IB chicks. The current findings could be related to the reduced function of mechanoreceptors because beak trimming is known to cause damage to the mechanoreceptors (Hughes and Gentle, 1995; Kuenzel, 2007). The finding that BT chicks pecked harder than IB birds in our study may therefore indicate attempts by the former chicks to enhance stimulation of the mechanoreceptors and receive feedback from pecking. Interestingly, high-speed video filming of feeding chickens has shown that beak trimming affects the ability to pick up food (Prescott and Bonser, 2004), and another possibility was that BT birds pecked harder in the current study to compensate for reduced pecking success. In either case, it appears that our finding that BT birds peck harder, even when treated with analgesic, is related to damage to the mechanoreceptors in the beak. An alternative explanation is that the removal of the tip of the beak affects the mechanics of pecking. With a slightly shorter beak, BT chicks may have a slightly longer acceleration motion before making contact with the pecking stimulus. Although plausible, this latter explanation seems unlikely given that only a small length of the beak was removed, but nonetheless could be tested by examining pecking behavior in BT birds with and without a prosthesis.

Second, adult hens have been shown to peck more softly in the days and weeks after beak trimming than IB hens (Freire et al., 2008), which has been suggested to be indicative of guarding behavior. As outlined in the introduction, we similarly expected BT chicks to peck more softly than IB chicks at 2 to 9 d of age, yet this was not found. Instead, we found that BT chicks during this period took more time before first pecking the pecking stimulus and pecked it less often than IB birds. These changes in pecking behavior do not appear to be due to BT birds being in pain because the topical

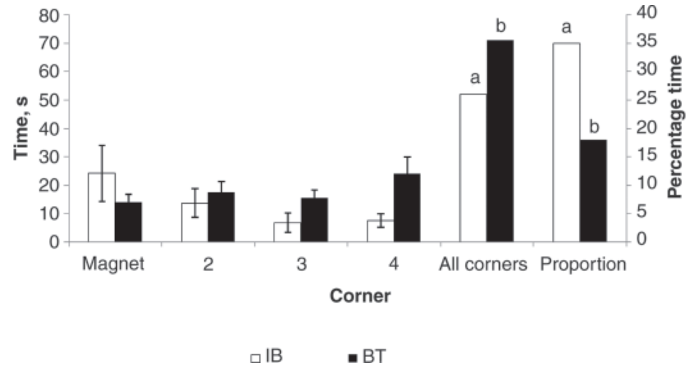

Figure 5. Mean (SE) latency (s) spent within 125 mm of each coil (i.e., each corner) in the 2-min tests for intact-beak (IB) and beak-trimmed (BT) chicks. [a,b]Back-transformed means of the total time spent in all corners ($P = 0.003$) and back-transformed percentage of time spent within 125 mm of the magnet ($P = 0.02$) are also shown and indicated by different letters.

application of lignocaine did not reverse these behavioral changes. Topical application of bupivacaine and lignocaine are effective in relieving avian pain (Machin, 2005), and application of bupivacaine to the trimmed beak has been shown to relieve pain arising from beak trimming at 6 wk of age (Glatz et al., 1992). It has been known for some time that beak trimming at a young age (i.e., d 1) is preferable because it is less stressful, has better production outcomes, and results in the formation of fewer neuromas in the beak (Hughes and Gentle, 1995; Glatz, 2000; Kuenzel, 2007). Although we have followed similar procedures (i.e., Glatz, 1990; Freire et al., 2008) that have previously indicated pain after beak trimming in older chickens, we suggest that the absence of evidence of pain in the present study indicates that minor beak trimming within 24 h of hatching does not lead to acute pain. It should be noted that the issue of whether beak trimming at any age causes chronic pain is still hotly debated (Kuenzel, 2007).

Third, hungry IB chicks showed a stronger preference for a magnetic stimulus previously associated with the presence of hidden food than BT birds, indicating that beak trimming led to a loss in magnetoreception. In pigeons, anaesthetizing the beak or severing the trigeminal nerve to the tip of the upper beak disrupted magnetoreception (Mora et al., 2004) and our findings indicate that chickens may have a similar mechanism of magnetoreception in the beak. The findings presented here provide the first indication of the role of the recently discovered magnetite particles in the upper beak of chickens (Falkenberg et al., 2010). Chickens have been shown to use directional information from the magnetic field of the earth to orient in relatively small areas (Wiltschko et al., 2007), and the present findings raise the possibility that beak trimming impairs the ability of the domestic chicken to orient in extensive systems, or move in and out of buildings in free-range systems. Curiously, BT birds spent less time in the corners of the arena than IB birds. Chicks have been shown to be less active in the weeks after beak trimming (Gentle et al., 1991; Sandilands and Savory, 2002), but because all but 2 BT birds and 4 IB birds approached at least 1 corner, this does not seem to have been the case in these tests. Instead, the difference in the amount of time spent in corners may indicate that the conditioned food-searching behavior in IB chicks was extinguished in the tests because no food was found (i.e., the association is unlearned in the absence of a reward). Beak-trimmed chicks, in contrast, would not have detected the magnetic stimulus and thus extinction of the previously formed magnetic stimulus and food association would not have occurred, offering an explanation of why these chicks continued to search for food in the corners.

In conclusion, analysis of pecking behavior and force with or without the topical application of an analgesic indicates that day-old chicks experienced a loss of sensitivity and reduction in pecking motivation, rather than pain, in the 9 d after minor beak trimming. The changes in pecking behavior and inability to detect a magnetic stimulus in BT chickens indicate that magnetoreception and mechanoreception were impaired by minor beak trimming.

LITERATURE CITED

Cheng, H. W. 2006. Morphopathological changes and pain in beak trimmed laying hens. World's Poult. Sci. J. 62:41–52.

Craig, J. V., and H.-Y. Lee. 1990. Beak trimming and genetic stock effects on behaviour and mortality from cannibalism in White Leghorn-type pullets. Appl. Anim. Behav. Sci. 25:107–123.

Duncan, I. J. H., G. S. Slee, E. Seawright, and J. Breward. 1989. Behavioural consequences of partial beak amputation (beak trimming) in poultry. Br. Poult. Sci. 30:479–488.

Falkenberg, G., G. Fleissner, K. Schuchardt, M. Kuehbacher, P. Thalau, H. Mouritsen, D. Heyers, G. Wellenreuther, and G. Fleissner. 2010. Avian magnetoreception: Elaborate iron mineral containing dendrites in the upper beak seem to be a common feature of birds. PLoS ONE 5:e9231.

Freire, R., P. Glatz, and G. Hinch. 2008. Self-administration of an analgesic does not alleviate pain in beak-trimmed chickens. Asian-australas. J. Anim. Sci. 21:443–448.

Gentle, M. J., B. O. Hughes, A. Fox, and D. Waddington. 1997. Behavioural and anatomical consequences of two beak trimming methods in 1- and 10-d-old domestic chicks. Br. Poult. Sci. 38:453–463.

Gentle, M. J., B. O. Hughes, and R. C. Hubrecht. 1982. The effect of beak-trimming on food-intake, feeding behaviour and body weight in adult hens. Appl. Anim. Ethol. 8:147–157.

Gentle, M. J., L. N. Hunter, and D. Waddington. 1991. The onset of pain related behaviours following partial beak amputation in the chicken. Neurosci. Lett. 128:113–116.

Glatz, P. C. 1990. Effect of age of beak-trimming production performance of hens. Aust. J. Exp. Agric. 30:349–355.

Glatz, P. C. 2000. Beak trimming methods. Asian-australas. J. Anim. Sci. 13:1619–1637.

Glatz, P. C., L. B. Murphy, and A. P. Preston. 1992. Analgesic therapy of beak-trimmed chickens. Aust. Vet. J. 69:18.

Hughes, B. O., and M. J. Gentle. 1995. Beak trimming in poultry: Its implications for welfare. World's Poult. Sci. J. 51:51–61.

Kuenzel, W. J. 2007. Neurobiological basis of sensory perception: Welfare implications of beak trimming. Poult. Sci. 86:1273–1282.

Machin, K. L. 2005. Controlling avian pain. Compend. Contin. Educ. Pract. Vet. 27:299–309.

Mora, C. V., M. Davison, J. M. Wild, and M. M. Walker. 2004. Magnetoreception and its trigeminal mediation in the homing pigeon. Nature 432:508–511.

Prescott, N. B., and R. H. C. Bonser. 2004. Beak trimming reduces feeding efficiency of hens. J. Appl. Poult. Res. 13:463–471.

Sandilands, V., and C. J. Savory. 2002. Ontogeny of behaviour in intact and beak trimmed layer pullets, with special reference to preening. Br. Poult. Sci. 43:182–189.

Wiltschko, W., R. Freire, U. Munro, T. Ritz, L. J. Rogers, P. Thalau, and R. Wiltschko. 2007. The magnetic compass of domestic chicken, *Gallus gallus*. J. Exp. Biol. 210:2300–2310.