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Effects of stray voltage on the physiology of stress, growth performance and carcass parameters in Romane male lambs

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ABSTRACT

The effects of permanent or random exposure to stray voltage on a water trough were evaluated in growing–finishing Romane male lambs between the age of 13 and 19 weeks. Ninety lambs were assigned during two 6-week experimental periods to one of three treatments, with 30 animals in each treatment (15 per experimental period). The treatments were permanent exposure to voltage (PERM, 3.5 V) on the water trough, random exposure to voltage (RAND, 3.5 V, 34 h/week) and no voltage exposure for the control group (CONT). No effects of voltage exposure were observed on production parameters: growth, average daily gain and water intake. The stress physiology seemed to be slightly modified with a lower plasma cortisol concentration at slaughter in PERM lambs compared to CONT lambs ($P < 0.05$) and a higher adrenal medulla weight in PERM lambs compared to CONT lambs ($P < 0.05$). However, no differences were observed between treatments in heart-rate, basal plasma cortisol concentration and tyrosine hydroxylase and phenylethanolamine-N-methyl transferase activities. Carcass yield, temperature and the pH of the *M. longissimus dorsi* were not modified by voltage exposure during rearing. In the good carcass conformation class (R class in EUROP grading scheme), there were fewer fat carcasses (grade 4 of 5) in the PERM and RAND compared to the CONT group ($P < 0.05$). In conclusion, no major effects of voltage exposure were observed in male lambs on production, carcass parameters and stress physiology. Stray voltage could be considered as a mild stressor in growing–finishing lambs.

1. Introduction

Electricity is essential to modern farming techniques and many electrically powered machines are used such as milking machines, automatic feed dispensers, electrically heated watering devices, etc. Leakage of current from this type of equipment, electric and magnetic induction, faulty connections between the electrical circuits and the earth can lead to the undesirable electrical phenomenon called stray voltage (review by Deschamps, 2002). Stray voltage, usually less than 10 V, can produce a low current flowing through farm animals (USDA, 1991; Gustafson, 2003).

In the last few decades, stray voltage has been considered as a possible factor impairing performance in dairy farms and in swine production. Producers and veterinarians have reported impaired animal performance as well as increased health problems and behavioural modifications

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in cows and pigs housed in buildings where stray voltage was detected (review by Hultgren, 1990). So far, studies on stray voltage have been performed primarily in dairy cows and secondarily in pigs (review by Hultgren, 1990). Almost no scientific data are available on the effects of stray voltage in sheep. Moreover, on farms, stray voltage can occur in a random manner and can be unpredictable for the animals (Hultgren, 1990). Predictability of a stimulus or a stressor is important in relation to animal welfare (Désiré et al., 2002; Bassett and Buchanan-Smith, 2007). Indeed, when a stressor occurs in an unpredictable way, it is more stressful for the animal than if the stressor occurs in a predictable way (Quirce et al., 1981) that allows the animal to expect its occurrence and eventually to adapt.

The aim of this experiment was to investigate how random or permanent exposure to voltage on a water trough, during the growing–finishing period, affects stress physiology, growth performance and carcass parameters of male lambs.

2. Materials and methods

This study was conducted during two consecutive years from December to January, in two identical repetitions. Each repetition included a 1-week habituation to pens and to analysis procedures (blood sampling, cardiac strap wearing, weighing) and a 6-week experimental period.

2.1. Animals, feeding and housing

For each repetition, 45 Romane (INRA 401) male lambs, a crossbreed line between Romanov and Berrichon du Cher, progressively weaned from 49- to 67-day-old, were allocated to one of three groups according to age, weight and litter size (averages were, respectively, 90 ± 4.5 days, 28.3 ± 4.71 kg of BW and 2.6 ± 0.73 lambs, mean ± SD, n = 90). The lambs were housed in three similar pens (3.5 m × 4 m, width × length, 15 lambs of the same treatment in each pen) containing a metallic water trough without enamel coating at the end of a stall (only one lamb could drink at any one time), a trough for concentrate and a straw rack. A fourth pen with non-experimental lambs was used as a buffer pen at the entrance of the building. The pens were bedded with straw. A plain wooden barrier 1.5 m high separated each pen from the others. Animals were fed twice daily at 09:00 and 17:00 h (0.7 kg of concentrate per lamb and per meal), and straw was available *ad libitum*. Water and a mineral block were available at all times.

During repetition 1, one lamb of the control group was excluded from the experiment due to health problems (diarrhea and loss of appetite).

2.2. Experimental treatments

The water troughs were electrically insulated from all the metallic parts of the pen. An aluminium plate (0.4 m × 1.2 m, width × length), isolated from the ground, was placed on the floor of the stall. EDF R&D (Electricité de France Research & Development) provided the electricity exposition system allowing application of the chosen alternating (50 Hz) voltage. A voltage of 3.5 V was applied to the water trough to obtain a voltage pathway through the lamb from the muzzle to the four hooves (Fig. 1). The voltage level was determined in a preliminary experiment in order to obtain a current intensity through the animal in the same range as the threshold leading to aversion obtained in a previous experiment in lambs (Duvaux-Ponter et al., 2005).

During 6 weeks, lambs were exposed to a voltage of 3.5 V, either permanently (PERM; n = 30; 15 animals per repetition), or randomly 34 h a week with the duration of exposition varying from 4 to 16 h (RAND; n = 30; 15 animals per repetition). Thirty lambs (15 animals per repetition) were used as the control and were not exposed to voltage (CONT). Pens were randomly allocated to the treatments for each repetition.

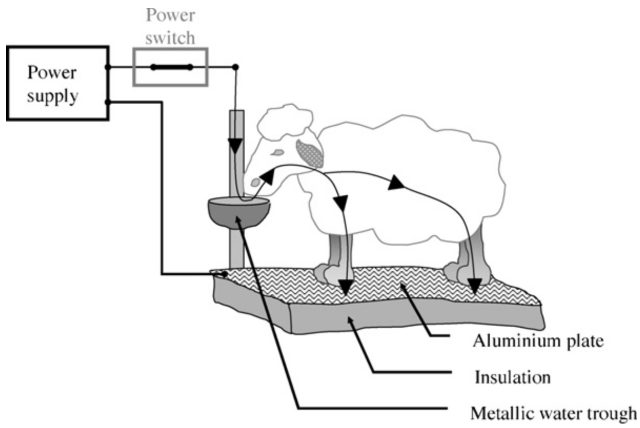

Fig. 1. Simplified diagram of the electrical apparatus used to apply voltage from the muzzle to all hooves of Romane male lambs through a water trough placed at the end of a stall in the rearing pen.

2.3. Production measurements

The animals were weighed once weekly to determine ADG (Average Daily Gain). The quantity of water drunk (called water intake thereafter) was recorded twice daily at 09:00 and 17:00 h for each pen during weeks 1, 3, 4 and 6 of the experiment.

2.4. Carcass measurements

The animals were slaughtered at 134 ± 4.2 days (41.2 ± 6.30 kg of BW, mean ± SD). On two consecutive days for each repetition, with an even number of lambs from each treatment each day, lambs were transported to a commercial abattoir (1 h journey) where they remained 2 h in lairage pens before slaughtering. Temperature and pH of the *M. longissimus dorsi* (at the level of the 12th rib) were measured directly on the carcass using a thermo-sensor and a glass electrode (WTW sentix, WTW, Weilheim, Germany) connected to a digisense pH meter (WTW ph305i, WTW, Weilheim, Germany). Measurements were performed at 30 min, 3 and 24 h after the start of exsanguination (pH at 24 h is called ultimate pH thereafter). Carcasses were weighed 30 min after exsanguination. Carcass yield was calculated using the BW (week 6) and the weight of cooled carcass (98% of carcass weight). According to the EUROP grading scheme (Commission Regulation (EEC) No. 461/93, 1993), conformation was graded by a single assessor into excellent (E), very good (U), good (R), fairly good (O), or poor (P) and fatness was graded into very fat (5), fat (4), covered (3), fairly covered (2), or lean (1).

2.5. Stress physiology measurements

Heart rate measurements were performed at weeks 1 and 3 of voltage exposure, 3 days a week with three animals per treatment recorded each day from 08:00 to 18:00 h. The heart rate monitor used consisted of a watch receiver (Polar® S610i, Polar Electro, Oy, Finland) and two electrodes (Horse Trainer transmitter Polar®, Fleurier, Switzerland) fitted on an elastic belt adjusted to the thorax size of the lambs. The contact between electrodes and skin was improved by small amounts of ultrasound gel smeared on the chest. The heart rate monitor works by averaging the R–R intervals of the QRS electrocardiogram wave complex over 5-s periods as detailed by Karnoven et al. (1984). This procedure was used previously in cows by Hopster and Blokhuis (1994) and in lambs by Roussel et al. (2004). After completion of data collection, the equipment was removed and the Polar® S610i was downloaded by IR communication via a Polar® Interface onto a computer via the software Polar Equine version 4.0 (Polar Electro, Oy, Finland). Cameras were placed above each trough and linked to time-lapse video-recorders. Videos were used to relate the presence of a lamb in the watering stall to its heart rate measurements. This allowed the calculation of the difference between mean heart rate the minute before entering the stall and mean rate in the stall, and the difference between mean heart rate in the stall and mean rate the minute after leaving the stall.

Due to loss of signal and chewing of cables, only part of the heart rate data files could be used (108 drinking sessions for 31 different lambs).

When a lamb made several visits to the watering stall on the same day, data were averaged.

Blood samples were collected at weeks 1 and 6 in order to obtain basal plasma cortisol concentrations at the beginning and at the end of the experiment. At least 1 h before the beginning of sampling, each pen was sub-divided into two small pens, with half of the animals in each, in order to facilitate blood sampling. Animals were adapted to this procedure during the week of habituation. Two blood samples were collected by jugular venipuncture at 14:30 and 15:30 h and within 2 min of the experimenter handling the animal. This interval is likely to be insufficient for plasma cortisol concentration to have been affected by the handling associated with blood collection (Broom and Johnson, 1993). Moreover, Parrott et al. (1994) have shown in sheep that cortisol concentration returned to basal level in less than 30 min after handling. Basal cortisol concentrations for each week were calculated using the average of the two blood samples.

Blood samples were centrifuged at 3000 × *g* for 10 min at 4 °C. Plasma was stored at −20 °C until analysis. The basal level of total cortisol was measured by ELISA using an automated method (Elecsys, Roche Diagnostics, Meylan, France). The sensitivity of the cortisol assay was 0.36 ng mL^{-1}. The inter-assay coefficient of variation was 4.5% at 124.69 ng mL^{-1}.

At slaughter, exsanguination blood was collected in heparinized tubes and stored at 4 °C for 1 h. Samples were centrifuged at 3000 × *g* for 10 min at 4 °C and plasma was stored at −20 °C until determination of cortisol concentration. Slaughter levels of total cortisol were determined using a radioimmunoassay method with an antibody produced in rabbit (Boissy and Bouissou, 1994). The detection limit was 0.02 ng mL^{-1}. Intra- and inter-assay coefficients of variation were 11 and 22% for low (4 ng mL^{-1}) and 7 and 14% for high (32 ng mL^{-1}) controls. The adrenal glands were recovered as soon as possible after exsanguination, frozen in liquid nitrogen and kept at −80 °C until analysis. The mean length of time between slaughter and freezing of the adrenal gland in liquid nitrogen was less than 15 min.

The activities of phenylethanolamine N-methyl transferase (PNMT) that catalyses the N-methylation of noradrenaline to adrenaline and tyrosine hydroxylase (TH) that catalyses the conversion of tyrosine to dihydroxyphenylalanine (DOPA) were determined in the medulla of adrenals by the methods adapted from Waymire et al. (1971) and Axelrod (1962) by Veissier et al. (2001). The adrenal glands were dissected clear of surrounding tissue, the medulla were recovered, weighed (the sum of the weight of the two adrenal medullas is used thereafter), cut in half and homogenates of the two adrenal medullas of each lamb were mixed with a reactional mixture containing either [^{14}C]tyrosine (for TH assay) or S-adenosyl-[^{14}C]methionine (for PNMT assay). The results are expressed in quantity of product ($^{14}CO_2$ for TH and ^{14}C-methylethanolamine for PNMT) per unit of time and per mg of adrenal medulla gland. Intra- and inter-assay coefficients of variation were 4.34 and 4.13% for TH assay and 1.56 and 4.25% for PNMT assay for a control having a TH activity of 2.88 nmol/h/mg and a PNMT activity of 0.144 nmol/h/mg.

2.6. Statistical analysis

Statistical analyses were performed using the Statistical Analysis System software (SAS®, version 9.1.3). The MIXED procedure with comparison of the estimates (*t*-test based) was used with the following general model: $Y = \mu + T_j + R_k + T_j \times R_k + BW0_i + e_{ijk}$; where μ represents the overall mean; T_j the fixed effect of the treatment with three modalities of CONT, PERM and RAND; R_k the fixed effect of the repetition with two modalities of repetitions 1 and 2; $T_j \times R_k$ the interaction between the treatment *j* and the repetition *k*; $BW0_i$ the BW of the animal *i* on the week of habituation as a covariate and e_{ijk} the residual error. Concerning data collected during the 6-week exposure (water intake, body weight and heart rate), the model was completed with W_l the fixed effect of the week *l*; $T_j \times W_l$ the interaction between the treatment $_j$ and the week *l*; and r_i the random effect of the animal *i*. Concerning data collected at the slaughterhouse, D_m the fixed effect of the day of slaughter was added, and $BW6_i$ the covariate BW on the sixth week of voltage application replaced the covariate $BW0_i$.

When assumptions of homogeneity of variance and normal distribution of the residuals were not verified, a log or square root transformation was performed before carrying out the analysis. Qualitative data such as conformation and fatness of the carcass were analysed with a chi-square test. All data are presented as least square means (LSMeans) ± standard errors (SE) except when otherwise stated.

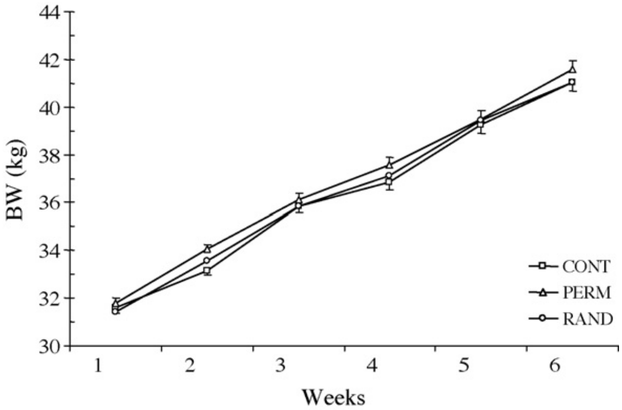

Fig. 2. Evolution of body weight of Romane male lambs submitted to 6 weeks of voltage exposure (3.5 V applied on the water trough) permanently (PERM, *n* = 30), randomly (34 h/week, RAND, *n* = 30) or to no voltage exposure (CONT, *n* = 29).

3. Results

3.1. Production measurements

No effects of treatment were observed on BW. An interaction between treatment and week ($P < 0.01$) was observed: on week 2, PERM lambs were heavier than CONT lambs ($P < 0.01$) and tended to be heavier than RAND lambs ($P = 0.09$); on week 4 PERM lambs tended to be heavier than CONT lambs ($P = 0.10$) (Fig. 2). No effects of treatment were found on the ADG during the 6-week exposure (296 ± 8.6, 310 ± 8.5 and 296 ± 8.5 g/day, for CONT, PERM and RAND, respectively, $P > 0.10$). Moreover, no effect of treatment was observed on water intake (log back-transformed data, 3.4 ± 0.07, 3.4 ± 0.07 and 3.4 ± 0.07 L/lamb/day, for CONT, PERM and RAND, respectively, $P > 0.10$). An effect of repetition was found on water intake ($P < 0.01$).

3.2. Carcass measurements

No effects of treatment were observed on carcass yield (48 ± 0.4, 48 ± 0.4 and 49 ± 0.4%, for CONT, PERM and RAND, respectively, $P > 0.10$). An effect of repetition was found ($P < 0.05$). No effects of treatment were observed on pH of the *M. longissimus dorsi* 30 min after slaughter (6.9 ± 0.03, 6.9 ± 0.03 and 6.9 ± 0.03, $P > 0.10$), 3 h after slaughter (6.6 ± 0.05, 6.6 ± 0.05 and 6.6 ± 0.05, $P > 0.10$) and 24 h after slaughter (5.8 ± 0.02, 5.8 ± 0.02 and 5.8 ± 0.02 for CONT, PERM and RAND, respectively, $P > 0.10$). No effects of treatment were observed on temperature of the *M. longissimus dorsi* 30 min after slaughter (35.6 ± 0.27, 35.6 ± 0.27 and 36.1 ± 0.27 °C, $P > 0.10$), 3 h after slaughter (17.5 ± 0.27, 17.5 ± 0.27 and 17.8 ± 0.27 °C, $P > 0.10$) and 24 h after slaughter (1.7 ± 0.07, 1.7 ± 0.07 and 1.6 ± 0.07 °C for CONT, PERM and RAND, respectively, $P > 0.10$). No effects of treatment were observed on conformation ($\chi^2 = 0.244$, $P > 0.10$) and fatness ($\chi^2 = 4.912$, $P > 0.10$) of the carcasses. However, in the “R” conformation category (which represented 22/29, 24/30 and 22/30 of the carcasses for CONT, PERM and RAND, respectively), less fat carcasses (classification = 4) were observed for PERM and RAND lambs compared to CONT carcasses (8/24, 8/22 and 15/22, respectively; $\chi^2 = 6.735$, $P < 0.05$).

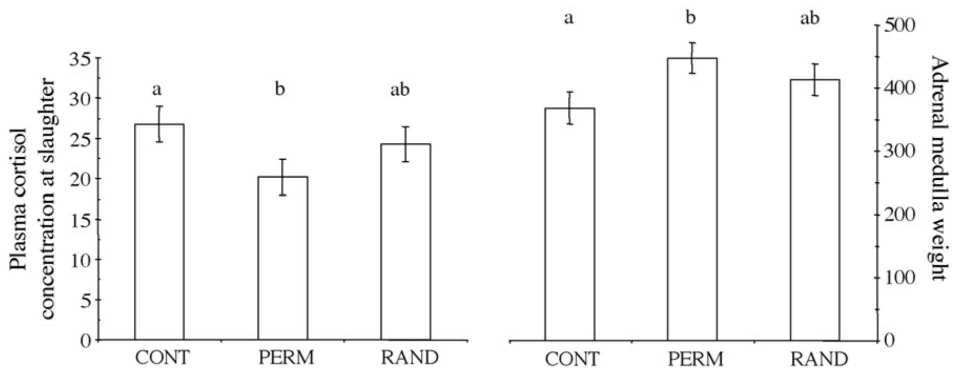

Fig. 3. Plasma cortisol concentration (ng mL^{-1}) and adrenal medulla weight (mg) at slaughter in Romane male lambs submitted to 6 weeks of voltage exposure (3.5 V applied on the water trough) permanently (PERM, $n = 30$), randomly (34 h/week, RAND, $n = 30$) or to no voltage exposure (CONT, $n = 29$).

3.3. *Stress physiology measurements*

No effects of treatment were observed on basal plasma cortisol concentration either 1 week (log back-transformed data, 4.7 ± 0.62, 4.8 ± 0.63 and 4.9 ± 0.64 ng mL^{-1}, for CONT, PERM and RAND, respectively, $P > 0.10$) or 6 weeks after the start of voltage exposure (log back-transformed data, 4.4 ± 0.57, 5.0 ± 0.65 and 5.1 ± 0.67 ng mL^{-1}, respectively, $P > 0.10$). There was an effect of repetition ($P < 0.01$). No effects of treatment were observed on the difference between mean heart rate the minute before entering the stall and mean rate in the stall (-1 ± 2.9, -4 ± 3.6 and -6 ± 3.4 bpm, $P > 0.10$) and on the difference between mean heart rate in the stall and mean rate the minute after leaving the stall ($+4 \pm 1.9$, $+5 \pm 2.1$ and $+7 \pm 2.2$ bpm, for CONT, PERM and RAND, respectively, $P > 0.10$). A trend for a treatment effect ($P = 0.09$) was found for cortisol at slaughter: PERM lambs had a lower plasma cortisol concentration than CONT lambs ($P < 0.05$; Fig. 3) while no differences were observed between the other treatments. In addition, a trend for a treatment effect was observed for the weight of the adrenal medulla ($P = 0.08$): PERM lambs had heavier adrenal medullas than CONT lambs ($P < 0.05$; Fig. 3) while no differences were observed between the other treatments. There was an effect of repetition ($P < 0.001$). No effects of treatment were observed on TH activity (log back-transformed data, 1.05 ± 0.042, 1.04 ± 0.037 and 1.01 ± 0.040 nmol/h/mg, $P > 0.10$) and PNMT activity (square back-transformed data, 0.15 ± 0.013, 0.14 ± 0.011 and 0.12 ± 0.011 nmol/h/mg, for CONT, PERM and RAND, respectively, $P > 0.10$). An effect of repetition was found ($P < 0.01$) only for TH activity.

4. Discussion

To our knowledge, no experiments have been performed to study effects of stray voltage on intensively reared lambs. The feeding, watering and housing conditions of the lambs used in the present experiment were similar to farm conditions.

4.1. *Production*

The lack of effect of voltage exposure on lamb weight, ADG and water intake during the fattening period are in agreement with many studies in fattening pigs (Gustafson et al., 1986; Robert et al., 1992; Godcharles et al., 1993). However, daily feed intake and average daily gain were reduced in growing–finishing pigs submitted to 5 V (applied to the feeder and the water trough) compared to control pigs but only in the second half of the experiment (between 14 and 21 weeks of age) (Robert et al., 1991). These results were partly explained by the fact that the electric resistance of pigs is negatively correlated to BW (Robert et al., 1991). In addition, in growing–finishing pigs, Gustafson et al. (1986) showed that a current above 3 mA was needed to affect the duration of drinking and 4 mA to affect water intake. In our experimental conditions, the 3.5 V applied to the water trough generated a current of 2.4 mA (±0.47 mA) (data collected in a similar experiment conducted with ewe lambs at the same age). This range of current did not affect water intake although we cannot exclude changes in drinking behaviour.

4.2. *Carcass*

No effect of voltage exposure was observed on pH and temperature of the *M. longissimus dorsi* 30 min, 3 and 24 h after slaughter. The only voltage effect on carcass parameters was, in the good conformation class (representing more than 70% of carcasses), a lower number of fat carcasses in lambs submitted to permanent or random voltage exposure compared to control lambs. Considering that, on the one hand, voltage exposure is considered as a stressor and that, on the other hand, cortisol favours the accretion of fat at the expense of protein (Devenport et al., 1989), a higher number of fat carcasses could have been expected in the lambs submitted to voltage compared to the control group. However, the opposite was observed. Two hypotheses may explain this discrepancy. Firstly, the repetition of the stressor over a 6-week period of exposure could have in fact reduced the lamb's reaction to stressor and therefore the release of cortisol. Indeed, chronic stress can decrease the reactivity of adrenal glands (review by Mormède et al., 2007), a larger dose of ACTH being necessary to obtain the release of the same quantity of cortisol. This hypothesis is corroborated by the trend for a reduced cortisol level observed in lambs submitted to permanent voltage compared to control lambs at slaughter. Secondly, the difference in fatness could be partly explained by an effect of stress on lamb metabolism during the fattening period since cortisol has a direct lipolytic action on fat cells (Sapolsky et al., 2000). In addition, an elevated metabolic requirement of the tissues imposed by a prolonged exposure to the stressor could have resulted in a reduction in fat deposition. However, the fact that basal cortisol concentration was not modified by the treatments, either after 1-week of voltage exposure or after 6 weeks, does not really corroborate these two hypotheses.

Ultimate pH of the *M. longissimus dorsi* reflects the level of depletion of muscle glycogen stores and its reduction suggests physical activity ante mortem. A high muscle temperature and/or a low pH within minutes or hours after slaughter are indicators of high activity and/or high stress level in the minutes before slaughter (Terlouw and Rybarczyk, 2008). Ultimate pH and muscle temperature were similar between lambs submitted to voltage and control lambs. It is possible that the stress induced by slaughter (transport, novel environment and handling by unfamiliar people) was large enough to mask a possible effect of a prolonged voltage exposure during fattening on these slaughter parameters. However, as discussed thereafter, the cortisol concentrations measured at slaughter were quite low compared to other studies (Deiss et al., 2009) which suggests that stress prior to slaughter was quite low.

4.3. Stress physiology

Most of the stress physiology parameters were not modified by the voltage exposure: there was no effect of voltage exposure on heart rate, basal cortisol concentration and TH and PNMT activities. When lambs entered or left the watering stall, no differences on heart rate were observed between treatments. Several authors (Lefcourt et al., 1985; Gorewit and Scott, 1986; Lefcourt et al., 1986) showed an increase in heart rate (from +3 to +30 bpm) in dairy cows exposed to voltage. However, in these experiments, the current through the body of cows varied from 3.6 to 12.5 mA which was higher than the current obtained in our conditions. Moreover, the lack of difference between treatments in TH and PNMT activities could indicate that the catecholaminergic system was not affected by voltage exposure. This result is supported by two experiments with dairy cows (Lefcourt and Akers, 1982; Lefcourt et al., 1986), which concluded that current exposure (from 2.5 to 12 mA) did not affect plasma catecholamine concentrations.

The higher weight of the adrenal medulla in lambs exposed permanently to the stressor could be partly explained by morphological alterations of the adrenals due to stress. Indeed, in pigs, the number of cells in the adrenal medulla is increased after repeated exposure to a noise stressor (Kanitz et al., 2005). Adrenocorticotropic hormone (ACTH), which is liberated during stress, exerts a trophic action on the adrenal glands, which can result in their hypertrophy, especially in case of prolonged stress, as it was previously observed in rats by Lemaire et al. (1993).

Lambs exposed permanently to electricity on the water trough had a lower plasma cortisol concentration at slaughter compared to control lambs. As previously discussed, this lower concentration can result from a functional modification of the adrenals in response to the stressor (review by Mormède et al., 2007). If no functional modification of the HPA axis was involved, a second hypothesis could be the modification of the lamb's evaluation of the environment indicating that lambs submitted to permanent voltage exposure were less stressed at slaughter. It could be reasonable to consider that prolonged exposure to a stressor (if it is mild and allows the animals to become adapted to it) could help the lamb to better handle a subsequent exposure to another stressor as reported in the study of Boissy et al. (2001) where repeated changes in the social and physical environment of calves favoured their adaptation to potential changes in the environment. However, cortisol concentrations measured at slaughter in our experiment were relatively low compared to the literature, indicating that the slaughtering conditions were very good and consequently the stress of the animals was limited. Deiss et al. (2009) categorised stress levels in lambs according to their cortisol concentrations at exsanguination. Based on the 12 categories that they identified and using cortisol steps of 5 ng/L, our lambs would be included in the first 5 categories reflecting low stress.

4.4. Lack of effects

Although voltage exposure had some effects on lamb stress physiology, no major effects were found on production parameters. At least four hypotheses could explain this lack of major effects. (1) The voltage level of 3.5 V was chosen according to the results obtained by Duvaux-Ponter et al. (2005) after applying different voltages to a metallic feeder and were adjusted during a preliminary experiment in order to get the same intensity crossing the lambs when the electricity was applied to a water trough. This voltage may have been just high enough to modify stress physiology but not high enough to induce production impairment. (2) It is possible that only the presence of multiple stressors in addition to stray voltage would have induced a negative impact on performance of lambs. Indeed, the effects of voltage (modified feeding and drinking behaviours, an increase in agonistic interactions and a decrease in rest time) were more pronounced in pigs already facing a stressful situation such as rationing compared to when voltage was applied alone (Robert et al., 1991, 1992). During our experiment, male lambs were housed in good living conditions: enough space, no competition at feeding and no mixing of animals. These conditions allowed the animals to express their full growth potential. Indeed, ADG of our lambs was similar to ADG (321 g/day) measured in Romane male lambs consuming concentrate *ad libitum* from 32 to 46 kg BW (Berthelot et al., 2004). These "comfortable" rearing conditions may in part explain the lack of effects of stray voltage in male lambs. (3) Another hypothesis could be that the lambs modified their behaviour in order to reduce voltage exposure. According to Ohm's Law, the magnitude of current (intensity) depends on voltage level and electrical resistance (impedance) of the animal. This resistance is the sum of the resistance of body tissues and contact resistance of the animal to the ground and electrified trough. It could be hypothesized that the animal, by modifying its response, for example, by changing the position of its muzzle in the water trough, could change the resistance of the contact point and thus modify the intensity crossing its body, making the treatment less effective. For example, in dairy cows subjected to voltage on their water trough, Reinemann et al. (2005) observed a change in drinking behaviour: cows exerted a pressure on the trough, thereby increasing the contact surface at the muzzle-trough interface and thus reducing current density at the level of the muzzle. In our experiment, no fine facial behavioural observations were performed. It would be interesting to study behavioural modifications more thoroughly in a subsequent study. (4) Finally, habituation could also explain part of the lack of effect of voltage exposure. During the first days following an acute stress response, habituation could subsequently take place. Indeed, several experiments showed that animals become habituated to an electric stressor, for example, after 24 h of exposure in dairy cows (Gorewit et al., 1985) and after 6 h of exposure in pigs (Ziecik et al., 1993).

In farm conditions, stray voltage can occur in an unpredictable way (Hultgren, 1990). To mimic the farm conditions, our lambs were randomly exposed to voltage on the water trough. However, on the contrary to our hypothesis that random exposure was at least as detrimental as permanent voltage exposure, the consequences of permanent exposure to electricity were higher than random exposure. Different consequences of unpredictability were found in the literature: an increase in agonistic behaviour in pigs (Carlstead, 1986), a modification of emotional reactivity in sheep (Greiveldinger et al., 2007) and a modification of stress physiology in rodents and primates (review by Levine, 2000). Even if no signal warned the animal of the presence of voltage on the trough, the lambs could have learned to drink at time when voltage was not applied, thus limiting the exposure to the stressor. This could have involved observational learning as already shown in lambs (Veissier and Stefanova, 1993). The lambs could have got information, concerning the presence of voltage, from the lamb that was currently drinking and could have adapted their behaviour by postponing visits to the water trough in case of a sign of stress from a conspecific.

5. Conclusion

The present study failed to demonstrate an effect of voltage exposure on the water trough on growth and water intake of male lambs. The unpredictability of voltage exposure was not as detrimental as could have been expected. Nevertheless, some evidence, such as the reduction in carcass fatness, lower plasma cortisol concentration at slaughter and the increased adrenal medulla weight, suggest that permanent voltage exposure could induce a modification of the stress physiology of lambs exposed to stray voltage probably indicating a mild chronic stress in these animals.

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