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The effect of stun duration and level of applied current on stun and meat quality of electrically stunned lambs under commercial conditions

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Abstract

*Electrical head-only stunning is a widely used method in sheep (*Ovis aries*) slaughter. To investigate the influence of current level on stun and meat quality in practice, two studies were carried out at a commercial slaughterhouse. In trial one, 200 lambs were randomly assigned to four groups with a current level of 0.6, 0.8, 1.0 and 1.25 A, respectively, using 50-Hz sine wave supply voltage and a stun duration of 10.5 s. In trial two, 135 lambs were randomly assigned to two groups, with electrical current of 1.25 A applied for 14 and 3 s. For each lamb, the position of the tongs was observed and classified as correct or incorrect. The stun quality was evaluated based on observations of the corneal reflex, eye movements, rhythmic breathing, head-righting reflex and kicking during the tonic phase. Blood splash (haemorrhages in* Longissimus dorsi *muscle) was evaluated four days after slaughter. Incorrect tongs' positioning was seen commonly, and positively correlated with poor stun quality. The lowest current level tested produced an unsatisfactory stun in the majority of animals observed. Short stun duration increased the risk of a poor stun quality. There was no significant effect of current level, stun duration or tongs' position on the risk of blood splash. These data underline the importance of a correct technique, including choice of tongs' positioning, sufficient current levels and sufficient stun duration, for electrical stunning of lambs to achieve unconsciousness before sticking and thereby avoiding unnecessary suffering at commercial slaughter.*

Keywords: *animal welfare, blood splash, electrical stunning, sheep, slaughter, stun quality*

Introduction

Electrical head-only stunning of sheep (*Ovis aries*) is a widespread stunning method, which has been in use for more than 50 years (Croft & Hume 1956; Lambooy 1982). According to the recently adopted EU regulation on the protection of animals at the time of killing (European Union 2009), which includes minimum requirements to be met at slaughterhouses, a number of key parameters should be established to ensure sufficient stun quality when head-only stunning is applied on sheep and lambs. These include minimum current, minimum voltage, maximum frequency, minimum time of exposure (throughout this document the duration of the period of exposure to the stunning current is referred to as 'stun duration'), maximum stun-stick interval and position of the electrodes. Furthermore, the regulation sets a specific minimum value for the current to be applied, ie 1.0 A, regardless of the size and type of sheep, or type of equipment with reference to waveform, frequency, stun duration etc. This regulation will apply from 1 January 2013.

In existing national legislation and international guidelines, various values for minimum current for the stunning of lambs are given, and the scientific background of these is often not clear. Warriss (2010) cites recommendations of 0.6 A for lambs and 1.0 A for sheep, whereas other values can be found in other sources. The Council of Europe (1991) recommends a minimum current level of 1.0 A for the stunning of sheep, regardless of their age, while the Swedish national legislation (Jordbruksverket 2007) stipulates a minimum of 1.25 A. Furthermore, the UK-based Humane Slaughter Association (2005) recommends 1.0 A for sheep, but only 0.6 A for lambs, and low current levels for lambs are also often applied in other countries. The stun quality will be influenced not only by the current applied but also by other factors, such as the electrical resistance or impedance of the animal (influenced, eg by the amount of wool where the electrodes are placed) and the cleanliness of the equipment. Together, these factors are vital for the stun quality and hence for the welfare of the animal which is to be slaughtered, although some of them are difficult to regulate and control in a systematic manner.

In the industry and also amongst veterinarians, it is a common belief that the longer the stun duration, ie the longer the application of the electrical current, the better the stun quality. Previous research has clearly demonstrated that this is not necessarily the case (Cook *et al* 1995; Gregory 1998).

There are numerous publications available on the effect of current level and stun duration on the effectiveness of electrical stunning and meat quality parameters in sheep and other species (Lambooy 1982; Gregory & Wotton 1985; Cook *et al* 1995; Velarde *et al* 2000, 2002; Linares *et al* 2007). However, a vast majority of these relate to experimental studies where the conditions are optimal. Under commercial conditions, a number of factors can be expected to vary considerably, because of the process's time constraints and the varying conditions of the animals. For example, high line speed and limitations related to the restraint facilities may result in sub-optimal tongs' maintenance and positioning, and incoming animals may vary in size, wool thickness and cleanliness. All these factors affect the effectiveness of electrical stunning and meat quality.

It is acknowledged generally that electrical stunning can lead to petechial haemorrhages and ecchymoses (often referred to as 'blood splash') in the carcase, mainly in the *Longissimus dorsi* muscles, and that this occurs as a result of capillary rupture during current flow (Vergara *et al* 2005; Gregory 2007). A number of different theories behind this phenomenon have been presented, but the exact mechanism is still unclear. Recommendations given when aiming at reducing the prevalence of blood splash include the avoidance of rough handling prior to stunning and shortening of the stun-to-stick interval (Gregory 2007).

The main aim of this study was to investigate the relationships between the amount of current (ampere) or duration of current application (stun duration) on the effectiveness of head-only stunning (stun quality) and incidence of blood splash (meat quality) in lambs under commercial conditions, and also to evaluate the influence of tong position on stun quality.

Materials and methods

The present data were collected in both 2007 (trial one) and 2008 (trial two) at a medium-sized commercial slaughterhouse in which haemorrhages in the back muscles (*Longissimus dorsi*) were reported as an increasingly common quality problem without obvious cause. The lambs, mainly Texel and similar meat-type breeds or crosses, 2–3 months of age and with an approximate live weight of 30 kg, were stunned applying head-only stunning using scissor-type stunning tongs, conventional 50-Hz AC sine-wave supply voltage, constant current with a voltage output of up to 230 V (trial one, Electronic Stunning Equipment BTR 108, Freund, Germany; trial two, manufacturer unknown). The tongs were connected to a wall-mounted ampere meter indicating the amount of current and a signal to the operator indicating the duration of current application (stun duration).

The lambs originated from commercial farms and were brought from the abattoir lairage to the stunning area in small groups; they remained in the group pen when stunned. The lambs had relatively short wool on the head, and no wetting of the wool prior to stunning was carried out. No additional method of restraint was used. Within the legally required 20 s (mean 11.9 [± 2.59] s) after stunning, the sheep were bled by severing both jugular veins and both carotid arteries. Procedures applied were those normally seen at this particular slaughterhouse, and no specific instructions were given to the staff by the observer except for the start of trial two, when the importance of correct positioning of the tongs was emphasised. Nor did the observer intervene in any way with the process.

In accordance with standard legal requirements for commercial slaughter, all animals were subjected to ante mortem inspection by the official veterinarian at the slaughterhouse prior to stunning. The study was approved by the Swedish regional ethics committee for animal experiments.

Trial one

Trial one was carried out to determine the effect of head-only electrical stunning current levels. The lambs were assigned randomly to four test groups of 50 animals. For most sheep, it was possible to observe the position of the tongs, classifying it as correct or incorrect. To be classified as correct, the tongs should be positioned across the head of the animal with the electrodes placed between the eye and the ear on each side of the head. Any other position, such as diagonal positioning or behind the ears, and interrupted stunning (in this case stun duration shorter than 10 s, including complete re-positioning of the tongs) was classified as incorrect. The stun duration was 10.5 s for all groups, and the currents applied were 0.6, 0.8, 1.0 and 1.25 A (control). The mean (± SD) carcase weight was 12.7 (± 1.49) kg.

Trial two

Trial two was carried out to determine the effect of electrical stun duration, ie how long the tongs were kept in a locked position with a current flow across the head of the animal. By random assignment, two test groups were formed with 75 and 60 lambs, respectively. The stun duration periods evaluated were 14 and 3 s, respectively, and the current applied was 1.25 A for both groups (constant current), which is in accordance with present Swedish legislation. Tongs' position was classified as in trial one. The mean (± SD) carcase weight of the animals was 13.6 (± 1.27) kg.

In both studies, stun quality was recorded by one observer (CN) after visual examination on the spot. This was carried out immediately after hoisting the animals, ie approximately 3 s after the removal of the tongs, and prior to neck cutting. The stun quality was evaluated using: i) the corneal reflex; ii) eye movements; iii) rhythmic breathing; iv) the head-righting reflex; and vi) excessive kicking during the tonic phase (Gregory 1998; Velarde *et al* 2002, 2003; EFSA 2004), each coded as a dichotomous variable. 'Eye movements' were defined as both eyes co-ordinated, fixed at an object; 'rhythmic breathing' as at least two breaths and 'excessive kicking' was recorded when any substantial kicking, ie more than a minor pull, was seen during the general tonic phase. The stun quality was classified as poor if any of these signs were present. Absence of all the signs was classified as good stun quality.

Meat quality was evaluated four days post mortem. The meat quality of the *Longissimus dorsi* muscle was scored

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according to the classification system described by Kirton and co-workers (1980). Score 0 represented absence of blood splash or haemorrhages, 1, one or very few small haemorrhages, 2, more extensive haemorrhages of < 25% of the section surface, 3, considerable haemorrhages of 25–50% of the surface and 4, severe haemorrhages on > 50% of the surface.

Statistical analysis

Data were analysed in Stata™ 10.1 (StataCorp, College Station, TX, USA). Stun quality was modelled by ordinary logistic regression using the LOGISTIC command, and the degree of blood splash by generalised or proportional-odds ordinal logistic regression using the GOLOGIT2 (Williams 2006) and OLOGIT commands. Three different binary traits reflecting poor stun quality were used: i) corneal reflex; ii) eye movements; and iii) poor stun (defined as a positive corneal reflex, eye movements, rhythmic breathing, a positive righting reflex or limb movements). The third trait combined information from various classical signs of poor stun, to ascertain whether this variable had a different association with studied predictors compared to the first two traits. Blood splash was modelled as an ordinal trait, reducing the original 5-point scale to three levels (0, 1, 2) by collapsing scores 2–4 because of few or no observations in higher scores. The analysis thus generated eight final models. Relationships between the different variables expressing stun quality were investigated by cross-tabulation.

In trial one, current level (1.25, 1.0, 0.8 or 0.6 A) and tongs' position (correct or incorrect) were included in the models as categorical predictors. In trial two, stunning time (categorical; 14 or 3 s) and tongs' position were included. In all models, a continuous variable representing live weight was tested for inclusion but was consistently non-significant (P > 0.05) and hence not retained. One-way interactions between the main effects were tested but found to be non-significant (P > 0.05) and not retained.

The logistic models of stun quality were checked for validity by Pearson goodness-of-fit Chi-squared tests and for outliers and their influence by examining standardised Pearson residuals, delta-betas and leverages in different covariate patterns. Each ordinal logistic model of blood splash was checked for validity by running two separate ordinary logistic models, based on separate cut-points of blood splash score (either 0/> 0 or 0–1/> 1) and applying Pearson goodness-of-fit Chi-squared tests. If the assumption of proportional odds was met, as judged by an approximate likelihood-ratio test, a proportional-odds model was run. Predicted probabilities of a poor stun, a positive corneal reflex, eye movements, and different degrees of blood splash were calculated for different covariate patterns.

Results

Tables 1 and 2 show the distribution of observations for different levels of the categorical predictors in trials one and two, respectively. In trial one, two animals were excluded from the stun-quality assessment and four animals from the blood-splash scoring due to practical reasons not related to the study design. In trial two, 42 carcases were shipped to a different packer and could not be used for the meat quality assessment.

In trial one, which was focused on the effect of current levels, a total of 59% of the animals were stunned using an incorrect tongs' position. With 1.25 A, stun quality was good in 92% of the animals. When using 0.6 A, stun quality was good in only 34% of the animals. The corresponding results for 0.8 and 1.0 A were intermediate (64 and 86%, respectively). Meat quality was analysed in samples from 196 animals, and 63% of these displayed blood splash of score 1 or higher.

In trial two, which focused on stun duration, stun-quality data were available for 133 animals. In total, 26% of the lambs were stunned using incorrect positioning of the tongs, which is considerably less than in trial one. The incidence of blood splash was very high; 51% of the samples analysed showed blood splash of score 1 or higher.

Of 62 animals classified as poorly stunned in trial one, 46 (74%) were diagnosed with a positive corneal reflex, 25 (40%) with eye movements, 11 (18%) with rhythmic breathing, 9 (15%) with a positive righting reflex, and 5 (8.1%) with limb movements, indicating that corneal reflex and eye movements are most useful (or at least most used) for assessing poor stun quality. For 39 poorly stunned lambs in trial two, corresponding figures were 4 (10%), 25 (64%), 3 (7.7%), 0 and 11 (28%), respectively. Stratification for level of current in trial one revealed that the percentage of poorly stunned lambs showing a corneal reflex or eye movements did not vary much between strata, indicating that both corneal reflex and eye movements are important to assess poor stun at different current levels (50–79 and 30–56%, respectively) and displayed no apparent linear trend. A similar stratification for stunning time showed that the percentage of poorly stunned lambs with a corneal reflex was rather low in both strata (9.1–17%), while the percentage showing eye movements was 17% (one out of six lambs) at a 14-s stunning time but 73% (24 out of 33 lambs) at three seconds of stunning, indicating that eye movements are more important to assess poor stun due to short stun duration. In both studies, the proportion of poorly stunned animals showing a corneal reflex was considerably higher with an incorrect than with a correct position of the tongs: 89% (31 out of 35 lambs) versus 56% (10 out of 18 lambs) in trial one, and 23% (3 out of 13 lambs) versus 3.9% (1 out of 26 lambs) in trial two. This indicates that corneal reflex is most important to assess poor stun due to incorrect tongs' position.

It was possible to include 181 lamb observations in the modelling of stun quality in trial one, while 133 observations could be used in trial two. Parameter estimates of the logistic models of stun quality are shown in Tables 3–8. Compared to a current of 1.25 A, 0.6 A increased the odds of a poor stun 24 times (P < 0.001) and 0.8 A increased them by a factor of 6.3 (P = 0.03; Table 3). Currents of 0.6 and 0.8 A also increased the odds of a positive corneal reflex (OR = 34, P < 0.001 and OR = 9.9, P = 0.004, respectively;

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Table 1 Distribution of observations in a study of stun quality and blood splash in lambs slaughtered at a Swedish abattoir in 2007 (Trial one); numbers of animals (column percentages, within parentheses).

		Stun quality (n = 198)		Blood splash score[1] (n = 196)			
Predictor	**Level**	**Good**	**Poor**[2]	**0**	**1**	**2**	**3**
Current	1.25 A	44 (32)	4 (6.5)	18 (25)	22 (24)	8 (27)	1 (50)
	1.0 A	43 (32)	7 (11)	21 (29)	26 (29)	3 (10)	0
	0.8 A	32 (24)	18 (29)	18 (25)	21 (23)	8 (27)	0
	0.6 A	17 (13)	33 (53)	16 (22)	22 (24)	11 (37)	1 (50)
	Total	136 (100)	62 (100)	73 (100)	91 (100)	30 (100)	2 (100)
	Missing	0	0	0	0	0	0
Tongs' position	Correct[3]	57 (45)	18 (34)	10 (36)	8 (20)	2 (22)	0
	Incorrect	71 (55)	35 (66)	18 (64)	32 (80)	7 (78)	0
	Total	128 (100)	53 (100)	28 (100)	40 (100)	9 (100)	0
	Missing	8	9	45	51	21	2

[1] No recordings of blood splash score 4.
[2] Defined as presence of a positive corneal reflex, eye movements, rhythmic breathing, a positive righting reflex or limb movements.
[3] Defined as positioning across the head of the animal with the electrodes placed between the eye and the ear on both sides of the head. Any other position was classified as incorrect.

Table 2 Distribution of observations in a study of stun quality and blood splash in lambs slaughtered at a Swedish abattoir in 2008 (Trial two); numbers of animals (column percentages, within parentheses).

		Stun quality (n = 133)		Blood splash score[1] (n = 94)			
Predictor	**Level**	**Good**	**Poor**[2]	**0**	**1**	**2**	**3**
Stunning time	14 s	52 (55)	6 (15)	17 (37)	14 (44)	7 (64)	1 (20)
	3 s	42 (45)	33 (85)	29 (63)	18 (56)	4 (36)	4 (80)
	Total	94 (100)	39 (100)	46 (100)	32 (100)	11 (100)	5 (100)
	Missing	0	0	0	0	0	0
Tongs' position	Correct[3]	73 (78)	26 (67)	33 (72)	24 (75)	7 (64)	4 (100)
	Incorrect	21 (22)	13 (33)	13 (28)	8 (25)	4 (36)	0
	Total	94 (100)	39 (100)	46 (100)	32 (100)	11 (100)	5 (100)
	Missing	0	0	0	0	0	0

[1] No recordings of blood splash score 4.
[2] Defined as presence of a positive corneal reflex, eye movements, rhythmic breathing, a positive righting reflex or limb movements.
[3] Defined as positioning across the head of the animal with the electrodes placed between the eye and the ear on both sides of the head. Any other position was classified as incorrect.

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Table 3 Estimates of a logistic model of poor stun (animals with either a positive corneal reflex, eye movements, rhythmic breathing, a positive righting reflex or limb movements) in lambs slaughtered at a Swedish abattoir in 2007 (Trial one).

Predictor	Level	Coefficient	*OR*	SE (*OR*)	*P*-value	95% CI (*OR*)
Intercept	–	–2.69	–	–	< 0.001	–
Current (A)	1.25	0	1	–	(< 0.0001[1])	–
	1.0	0.560	1.75	1.16	0.40	0.476–6.44
	0.8	1.84	6.27	3.81	0.003	1.90–20.7
	0.6	3.9	24.4	15.6	< 0.001	6.98–85.2
Tongs' position	Correct[2]	0	1	–	–	–
	Incorrect	0.487	1.63	0.636	0.21	0.756–3.50

[1] Joint Wald's test of effect.
[2] Defined as positioning across the head of the animal with the electrodes placed between the eye and the ear on both sides of the head. Any other position was classified as incorrect. N = 181, pseudo-*R*-square = 0.21.

Table 4 Estimates of a logistic model of positive corneal reflex in lambs slaughtered at a Swedish abattoir in 2007 (Trial one).

Predictor	Level	Coefficient	*OR*	SE (*OR*)	*P*-value	95% CI (*OR*)
Intercept	–	–3.93	–	–	< 0.001	–
Current (A)	1.25	0	1	–	(< 0.001[1])	–
	1.0	0.925	2.52	2.19	0.29	0.460–13.8
	0.8	2.29	9.86	7.92	0.004	2.04–47.6
	0.6	3.52	33.6	27.2	< 0.001	6.88–164
Tongs' position	Correct[2]	0	1	–	–	
	Incorrect	1.15	3.14	1.41	0.011	1.30–7.59

[1] Joint Wald's test of effect.
[2] Defined as positioning across the head of the animal with the electrodes placed between the eye and the ear on both sides of the head. Any other position was classified as incorrect. N = 181, pseudo-*R*-square = 0.24.

Table 5 Estimates of a logistic model of eye movements in lambs slaughtered at a Swedish abattoir in 2007 (Trial one).

Predictor	Level	Coefficient	*OR*	SE (*OR*)	*P*-value	95% CI (*OR*)
Intercept	–	–4.23	–	–	< 0.001	–
Current (A)	1.25	0	1	–	(< 0.018[1])	–
	1.0	0.370	1.45	1.37	0.70	0.288–9.20
	0.8	1.98	7.26	5.95	0.016	1.46–36.2
	0.6	1.84	6.31	5.27	0.028	1.23–32.5
Tongs' position	Correct[2]	0	1	–	–	–
	Incorrect	1.50	2.65	0.011	0.011	1.40–14.3

[1] Joint Wald's test of effect.
[2] Defined as positioning across the head of the animal with the electrodes placed between the eye and the ear on both sides of the head. Any other position was classified as incorrect. N = 182, pseudo-*R*-square = 0.14.

Table 4) and of eye movements ($OR = 6.3$, $P = 0.028$ and $OR = 7.3$, $P = 0.016$, respectively; Table 5), compared with 1.25 A. In comparison with a current duration of 14 s, 3 s increased the odds of a poor stun 8.1-fold ($P < 0.001$; Table 6), and eye movements 29-fold ($P = 0.001$; Table 8), but not the odds of a positive corneal reflex; Table 7. Incorrect position of the tongs increased the odds of a positive corneal reflex 3.1 times ($P = 0.011$; Table 4) in trial one and 11 times ($P = 0.043$; Table 7) in trial two. The effect of incorrect tongs' position on eye movements was significant in trial one ($OR = 4.5$, $P = 0.011$; Table 5) but not in trial two (Table 8). Incorrect position also increased the odds of a poor stun marginally in trial two ($OR = 2.6$, $P = 0.051$; Table 6) but not in trial one (Table 3).

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Table 6 Estimates of a logistic model of poor stun (defined as a positive corneal reflex, eye movements, rhythmic breathing, a positive righting reflex or limb movements) in lambs slaughtered at a Swedish abattoir in 2008 (Trial two).

Predictor	Level	Coefficient	*OR*	SE (*OR*)	*P*-value	95% CI (*OR*)
Intercept	–	–2.53	–	–	< 0.001	–
Stunning time (s)	14	0	1	–	–	–
	3	2.09	8.06	4.13	< 0.001	2.95–22.0
Tongs' position	Correct[1]	0	1	–	–	–
	Incorrect	0.942	2.56	1.24	0.051	0.99–6.61

[1] Defined as positioning across the head of the animal with the electrodes placed between the eye and the ear on both sides of the head. Any other position was classified as incorrect. N = 133, pseudo-*R*-square = 0.15.

Table 7 Estimates of a logistic model of positive corneal reflex in lambs slaughtered at a Swedish abattoir in 2008 (Trial two).

Predictor	Level	Coefficient	*OR*	SE (*OR*)	*P*-value	95% CI (*OR*)
Intercept	–	–5.44	–	–	< 0.001	–
Stunning time (s)	14	0	1	–	–	–
	3	1.18	3.27	3.91	0.32	0.313–34.1
Tongs' position	Correct[1]	0	1	–	–	–
	Incorrect	2.40	11.1	13.1	0.043	1.08–113

[1] Defined as positioning across the head of the animal with the electrodes placed between the eye and the ear on both sides of the head. Any other position was classified as incorrect. N = 133, pseudo-*R*-square = 0.15.

Table 8 Estimates of a logistic model of eye movements in lambs slaughtered at a Swedish abattoir in 2008 (Trial two).

Predictor	Level	Coefficient	*OR*	SE (*OR*)	*P*-value	95% CI (*OR*)
Intercept	–	–4.23	–	–	< 0.001	–
Stunning time (s)	14	0	1	–	–	–
	3	3.36	28.8	30.1	0.001	3.72–22.3
Tongs' position	Correct[1]	0	1	–	–	–
	Incorrect	0.509	1.66	0.933	0.36	0.555–4.99

[1] Defined as positioning across the head of the animal with the electrodes placed between the eye and the ear on both sides of the head. Any other position was classified as incorrect. N = 133, pseudo-*R*-square = 0.20.

With a current of 1.25 A through correctly placed tongs in trial one, the predicted probabilities of a poor stun, a positive corneal reflex and eye movements were 0.064, 0.019 and 0.014, respectively. With a current of 0.6 A and incorrectly placed tongs, the probabilities increased to 0.73, 0.68 and 0.29, respectively. In trial two, the corresponding predicted probabilities for a stunning time of 14 s and correctly placed tongs were 0.074, 0.0043 and 0.014, increasing to 0.62, 0.14 and 0.41, respectively, when stunning time was reduced to 3 s and the tongs were placed incorrectly. None of the ordinary logistic models exhibited any serious signs of poor fit or undue influence of individual observations or covariate patterns.

When modelling blood splash, it was possible to include 77 lamb observations in trial one, while 93 observations could be used in trial two. In both studies, the proportional-odds criterion was met (approximate likelihood-ratio Chi-squared; $P = 0.80$ and 0.98, respectively) and proportional-odds regression was therefore used. There was no significant effect of current level ($P = 0.14$), stunning time ($P = 0.41$) or tongs' position ($P = 0.090$) on the risk of blood splash (not in tables). At a current of 1.25 A through correctly placed tongs in trial one, the predicted probabilities of blood splash score 0, 1 and 2 were 0.49, 0.45 and 0.064, respectively. With a current of 0.6 A and an incorrectly placed tong, these probabilities changed marginally to 0.50, 0.44 and 0.061, respectively. In trial two, the corresponding predicted probabilities for a stunning time of 14 s and correctly placed tongs were 0.44, 0.37 and 0.19, changing to 0.56, 0.31 and 0.13, respectively, when stunning time was reduced to 3 s and the tongs were placed incorrectly. None of the ordinary logistic models based on different cut-points exhibited significant signs of poor fit.

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Discussion

Poor stun quality results when using electrical head-only stunning of lambs has been demonstrated previously, also under controlled experimental conditions. For example, Velarde and co-workers (2000) reported a stunning efficiency rate varying from 0 to 100% depending on the positioning of the tongs, wetness of the skin and amount of wool where the tongs were placed. In our study, it was shown that the required current of 1.25 A stunned a vast majority (92%) of the animals correctly. When using a lower current (0.6 A), however, stun quality results were poor. Furthermore, both trials reported here generally support earlier findings that tongs' position influences stun quality, where a frontal position (as required by Swedish animal welfare legislation) is more efficient than other positions (Velarde *et al* 2000), although these results were only statistically significant in one of the two trials included.

In this study, a combination of different stun quality indicators was used. Often, the corneal reflex is perceived as a relatively simple and straightforward indicator of stun quality. Although absence of a corneal reflex indicates a satisfactory stun quality, its presence does not necessarily indicate persistence of consciousness following stunning. A positive corneal reflex should be seen as one indicator — out of several — of a poor stun quality. Based on the results of this study, we suggest that a positive corneal reflex is a particularly valuable indicator of poor stun quality caused by an incorrect tongs' position, while eye movements are more useful when poor stun quality might be caused by too short a stun duration. The finding that eye movements are more rarely seen after longer stun duration is interpreted mainly as an indicator of improved stun quality. However, this effect may also partly be attributed to exhaustion of eye muscles as a result of long stun duration, which may confound the results.

It has been previously shown that when low current levels (< 0.3 to 0.66 A) are used, very short stun duration (< 1 s) will result in a shorter duration of insensibility than with a slightly longer stun duration (3 or 6 s; Gregory 2007). Although a 3-s stun duration is sufficient under experimental conditions where the tongs are carefully positioned on saline-wet skin (Velarde *et al* 2002), this study indicates that it can lead to insufficient stunning under commercial conditions where tongs' position may not be as accurate and thick wool increases the resistance. One possible solution would be to use higher voltages to rapidly overcome the elevated resistance. This would, however, require a different type of equipment than the one traditionally used at the abattoirs in question, which were rather small when seen from an international perspective. Nevertheless, any substantial delay in inducing consciousness is unacceptable from an animal welfare point of view and it can be argued that a stun duration of 14 s should certainly not be necessary to sustain loss of consciousness until the animal has been bled. It has been suggested that electrical stunning can cause severe clonic activities when the current is applied for excessively long periods or if the carcase is not bled promptly (Gregory 1998). The latter is inevitably the case if stun duration is long (Cook *et al* 1995). Swedish legislation requires that the prescribed current is obtained within 1 s after the closing of the electrical circuit, and that it shall be maintained until the animal is stunned. Poor electrical contact may be an obstacle, but if so, suitable measures shall be taken to ensure that the electrical contact is improved, particularly by removing wool or wetting the skin, instead of prolonging the stun duration. Stun duration *per se* is not regulated in the legislation (neither in the EU nor nationally), but too long duration may interfere with the possibilities of achieving an acceptable stun-stick interval, as the interval given in the legislation (maximum 20 s) is not prolonged when the tongs are kept in stunning position and active during considerable time after the point in time when the epileptiform activity in the brain has been induced and the animal is properly stunned.

The results of this study stress the importance of proper monitoring of stun quality during standard operation of lamb electrical stunning, to safeguard animal welfare. The staff responsible for stunning and bleeding have to be made aware of the indicators to look for to evaluate stunning efficiency continuously during the slaughterhouse operation. They must also be given relevant instructions regarding re-stunning of poorly stunned animals, before bleeding is commenced. Furthermore, current levels, voltage, optimal tongs' position and stun duration should be defined and included in the written standard operating procedures at each slaughterhouse.

It is generally claimed that electrical stunning can lead to blood splash in lambs and other species (Vergara *et al* 2005; Gregory 2007). However, other studies have not demonstrated such an effect (Velarde *et al* 2003), possibly depending on type of stunning equipment and settings applied, stun duration and/or stun-to-stick interval. There is also an effect of specific factors in the diet, mainly related to pasture composition (Restall 1980). The occurrence of blood splash identified in this study constitutes a meat quality problem, but neither decreasing the current level nor shortening the stun duration was found to decrease the risk of blood splash. However, decreasing the current levels to 0.6 or 0.8 A and decreasing the stun duration to as short as 3 s will increase the risk of poor stun quality.

Kirkton and co-workers (1978) demonstrated that rapid bleed-out, by a short stun-to-stick interval, minimises the incidence of haemorrhages. Apart from possible meat quality benefits, such changes may also be beneficial from an animal welfare point of view, as recent knowledge indicates that the duration of insensitivity in electrically stunned sheep may be shorter than previously believed (EFSA 2004).

Animal welfare implications

These data underline the importance of a correct technique for electrical stunning of lambs, including correct tongs' positioning, sufficient current levels and sufficient stun duration, to achieve unconsciousness before sticking and thereby avoiding unnecessary suffering. At any slaughterhouse, staff must be properly instructed regarding how to monitor stun quality during standard operation of the equipment, as prompt reaction (re-stunning) prior to exsanguination is necessary to safeguard animal welfare in case of stun failure.

Furthermore, it is important that slaughterhouse operators are aware that insufficient stunning will not solve meat quality problems related to the occurrence of blood splash.

Conclusion

It is concluded that current levels of 0.8 and 0.6 A, in comparison with 1.25 A, increase substantially the risk of a poor stun in lambs as ascertained using positive corneal reflex and spontaneous eye movements. A stun duration of 3 s, in comparison with 14 s, increases substantially the incidence of eye movements and a poor stun, whereas an incorrect position of the stunning tongs increases the incidence of a positive corneal reflex and eye movements. The results also suggest that lowering of current levels down to 0.6 A, and stun duration down to 3 s, do not decrease the risk of blood splash.

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References

Cook CJ, Devine CE, Gilbert KV, Smith DD and Maasland SA 1995 The effect of head-only stun duration on electroencephalographic-measured seizure and brain amino acid neurotransmitter release. *Meat Science 40*: 137-147. http://dx.doi.org/10.1016/0309-1740(94)00043-7

Council of Europe 1991 *Council of Europe Recommendation No R (91) 7 on the Slaughter of Animals.* Council of Europe: Brussels, Belgium

Croft PG and Hume CW 1956 Electric stunning of sheep. *The Veterinary Record 68*: 318-321

EFSA 2004 Welfare aspects of Animal Stunning and Killing Methods. *European Food Safety Authority, AHAW/04-027 Report.* EFSA: Parma, Italy

European Union 2009 *Council Regulation (EC) No 1099/2009 of 24 September 2009 on the Protection of Animals at the Time of Killing.* EU: Brussels, Belgium

Gregory NG 1998 *Animal Welfare and Meat Science.* CABI Publishing: Wallingford, UK

Gregory NG 2007 *Animal Welfare and Meat Production, Second Edition.* CABI Publishing: Wallingford, UK

Gregory NG and Wotton SB 1985 Sheep slaughtering procedures IV. Responsiveness of the brain following electrical stunning. *British Veterinary Journal 141*: 74-81

Humane Slaughter Association 2005 *Electrical Stunning of Red Meat Animals. Guidance Notes No 4.* HSA: Wheathampstead, Herts, UK

Jordbruksverket 2007 *Statens jordbruksverks föreskrifter och allmänna råd (SJVFS 2007:77, Saknr L22) om slakt och annan avlivning av djur.* Jordbruksverket: Jönköping, Sweden. [Title translation: Swedish Board of Agriculture, Regulations and recommendations on the welfare of animals at slaughter and killing]

Kirton A, Bishop W and Mullord M 1978 Relationships between time of stunning and time of throat cutting and their effect on blood pressure and blood splash in lambs. *Meat Science 2*: 199-206. http://dx.doi.org/10.1016/0309-1740(78)90005-0

Kirton A, Frazerhurst LF, Woods EG and Chrystall BB 1980 Effect of electrical stunning method and cardiac arrest on bleeding efficiency, residual blood and blood splash in lambs. *Meat Science 5*: 347-353. http://dx.doi.org/10.1016/0309-1740(81)90033-4

Lambooy E 1982 Electrical stunning of sheep. *Meat Science 6*: 123-135. http://dx.doi.org/10.1016/0309-1740(82)90022-5

Linares MB, Bórnez R and Vergara H 2007 Effect of different stunning systems on meat quality of light lamb. *Meat Science 76*: 675-681

Restall DJ 1980 Blood splash in lambs: a preliminary study using the one-stage prothrombin time test. *Meat Science 5*: 1215-129

Velarde A, Gispert M, Diestre A and Manteca X 2003 Effect of electrical stunning on meat and carcass quality in lambs. *Meat Science 63*: 35-38. http://dx.doi.org/10.1016/S0309-1740(02)00049-9

Velarde A, Ruiz-de-la-Torre JL, Stub C, Diestre and Manteca X 2000 Factors affecting the effectiveness of head-only electrical stunning in sheep. *Veterinary Record 147*: 40-43

Velarde A, Ruiz-de-la-Torre JL, Rosello C, Farbrega E, Diestre A and Manteca X 2002 Assessment of return to consciousness after electrical stunning in lambs. *Animal Welfare 11*: 333-341

Vergara H, Linares MB, Berruga MI and Galleo L 2005 Meat quality in suckling lambs: effect of pre-slaughter handling. *Meat Science 69*: 473-478.http://dx.doi.org/10.1016/j.meatsci.2004.09.002

Warriss P 2010 *Meat Science, Second Edition.* CABI Publishing: Wallingford, UK

Williams R 2006 Generalized ordered logit/partial proportional odds models for ordinal dependent variables. *The Stata Journal 6*: 58-82