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EFFECT OF CURRENT INTENSITY AND DURATION ON THE EFECTIVENESS OF HEAD-ONLY ELECTRICAL STUNNING IN PIGS UNDER COMMERCIAL CONDITIONS

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After head-only electrical stunning of pigs sequential animal-based measurements were carried out right after stunning as well as before and after bleeding in order to analyse how unconsciousness is achieved and maintained in relation to recorded and calculated technical parameters such as electric current intensity, electric work, duration of stunning, and stun-to-bloodletting period. The measurements were performed at three different slaughterhouses on 9 different days under routine slaughtering conditions. The data of 405 pigs were analysed. The effectiveness of stunning was measured by the number of parameters at two (adequate and acceptable) levels. Current intensity had a predominant effect on the effectiveness of stunning and on the maintenance of unconsciousness. The duration of stunning played a role only as part of the electric work, which manifested itself in the maintenance of unconsciousness. Stunning proved acceptable in 99% of the cases, provided that the minimum current intensity of 1.02 Amp was secured. In 99% of the cases unconsciousness could be maintained at an acceptable level beyond bloodletting when the electric work was at least 8,089.38 Joules. Recovery of consciousness depends on the stun-to-stick period: the best time of bloodletting is less than 32 seconds from the end of stunning.

Key words: Pig, electrical stunning, stunning parameters, animal-based measures

Council Regulation (EC) No 1099/2009 on the protection of animals at the time of killing requires that animals must be rendered unconscious and insensible by stunning and they must remain so until death occurs through bleeding (European Commission, 2009). This goal can be approached in two ways. One way is to set the stunning parameters following a guideline (e.g. EFSA, 2004). As for current, Hoenderken (1978) suggested using 1.3 amperes (A) where tongs were placed across the neck behind the ears. Anil (1991) recommended the use of

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0.406 A as a minimum for pigs between 60 and 80 kg liveweight. Since no further data were available, the European Food Safety Authority recommended 1.3 A (EFSA AHAW Panel, 2004). However, the latter recommendation declares that this technical reference is based on old studies conducted under laboratory (experimental) conditions. Council Regulation (EC) No 1099/2009 established 1.3 A for head-only electrical stunning of pigs (European Commission, 2009). The scarcity and uncertainty of available data prompted us to verify these data under commercial conditions (Végh et al., 2010). Another point is that this single parameter fails to inform us on the animal's status until its death.

Another way of studying animal welfare during and after stunning might be monitoring the state of consciousness and nociception in animals. This can be carried out via animal-based measurements that clearly indicate the status of animals (EFSA AHAW Panel, 2013). Since unconsciousness shall be maintained until death, sequential investigations (immediately after stunning, at the time of bleeding and during bleeding) are required to collect relevant information.

The above two ways of welfare provision for stunned pigs involve an apparent contradiction: can we use a single parameter (amperage) to assess the welfare of stunned and slaughtered pigs, or do we need a more complex approach, i.e. studying the effects of environmental factors by means of animal-based measures? If the latter is the case, what methods could be used? The investigation presented here may answer this question.

Materials and methods

The measurements were carried out at Hungarian slaughterhouses on different occasions under routine work conditions. Animals were stunned and slaughtered under routine slaughterhouse operations for human consumption, i.e. no experimental conditions were used. Each slaughterhouse used head-only electrical stunning. The head of pigs was watered before stunning. Tongs were positioned between the eyes and the base of the ears in order to achieve a proper flow of current in the brain.

Each individual stun on the day of examination was included in the study. Some cases, where tongs were positioned across the neck behind the ears or on the snout but the slaughterman did not take corrective action, were excluded from the study, as only correctly positioned tongs can provide an uninterrupted flow of electric current through the brain (Anil and McKinstry, 1998).

Stunning was carried out with an equipment specially designed and produced for the studies by a factory specialising in slaughterhouse facilities (Korax Ltd., Ráckeve, Hungary). The equipment operates with line power. Incoming current is transformed and rectified, which results in a direct current (DC) with an intensity outcome ranging from 20 to 2000 mA. Stunning current intensity can be set with a potentiometer. The equipment is supplemented with an amperemeter and a voltage meter, and it displays current intensity and voltage in an easily readable manner. The duration of load and the stun-to-stick period were measured by a stopwatch.

The data of a total of 405 fattening pigs were analysed. The slaughter weight was between 80 and 130 kg. During the stuns two parameters were varied: current intensity and the duration of stunning. Frequency was set at 150 Hz. Data were collected in two experiments as follows.

(1) In the first experiment we examined whether the varying duration of stunning had any effect on the effectiveness of stunning. For this reason we performed measurements at two different slaughterhouses on four different days. At slaughterhouses A and C 65 and 75 pigs, respectively, were included in this examination. At slaughterhouse A the duration had been randomised in advance by a numerical generator (from 3 to 18 sec with 3-sec intervals), and the slaughterman was asked to perform the stunning accordingly. Current was set according to the slaughterhouse experience (average 0.77 A), voltage was measured between 145 and 360 (average 230 V). At slaughterhouse C the slaughterman was asked to stun according to his own experience, which ranged from 15 to 35 seconds. Current was set according to the slaughterhouse experience (average 0.96 A), and voltage was measured between 110 and 250 (average 161 V).

The length of the stun-to-stick period was an additional variable. This is the period that lasts from the end of stunning, through shackling and hoisting the pigs, to the moment of sticking. The routine operation was observed in slaughterhouse A, where this parameter was not pre-set but varied depending on the number of available slaughtermen and the efficiency of their work. This variable was recorded on five different days, on a total of 159 pigs. The stun-to-stick period varied between 32 and 85 sec.

Fulltime covers the time period from the beginning of stunning till sticking, about which data were collected and processed in slaughterhouse A on the same 159 pigs as in case of studying the stun-to-stick period.

(2) In the second experiment the effect of current intensity was examined. In this case the measurements took place at two slaughterhouses (A and B) on 8 different days. Data of 296 pigs were collected at the two slaughterhouses. Current intensity was varied randomly by setting the potentiometer on the stunning equipment. Current intensity was between 0.35 and 2.57 A. As for electric work, values between 358 and 10,036 Wattsecundum (= Joule) were calculated. The duration of stunning was set by the slaughterman, and varied between 3 and 28 sec with an average of 13 sec.

The following data were recorded in both experiments in all cases: current intensity (A) and voltage (V), duration of load, and stun-to-stick period. Electric work was calculated from the recorded data ($W = U \times I \times t$, where W = work, U = voltage, I = current, t = time).

The effectiveness of stunning was monitored at three points: (1) immediately after stunning, (2) before the moment of sticking, and (3) after sticking, during bleeding. In order to assess the pigs' state, animal-based measurements were carried out at each monitoring point. For the length of the stun-to-stick period and fulltime, only the second and third monitoring points were used. Based on internal medicine diagnostic tools and the toolbox established by the EFSA AHAW Panel (2013) the following measurements could be carried out.

Measurements immediately after stunning: (1) Examination of breathing: proper electrical stunning of pigs shall result in the immediate onset of apnoe, which could be checked by observation. (2) Observation of posture: a proper stunning shall result in the animal's immediate collapse, which could be checked by observation. (3) Examination of motor activity: electrical stimuli cause motor excitement, which could be observed by the onset of tonic-clonic seizures. (4) Examination of vocalisation: any vocalisation was regarded as a sign of consciousness. (5) Examination of the eyes: depressed excitability of the oculomotor nerve is indicated by pointedly fixed eyeballs or by eyeballs showing upward rotation, which could be observed. Since closer access to the animals after stunning was limited under commercial conditions, some possible measurements could not be included in the examination protocol (e.g. response to nose pricking, provoked corneal reflex).

Altogether five criteria (those described above) were examined. For the evaluation of consciousness a scoring system was used, where score 1 represented proper unconsciousness and score 0 denoted superficial or improper unconsciousness (Végh et al., 2010). Stunning was regarded effective at *adequate* level if all five criteria were scored 1. Cases were regarded effective at *acceptable* level, where at least four of the five criteria were met and scored 1. Consequently, evaluation was carried out at two levels: *adequate* and *acceptable* levels. Stuns under these levels were regarded *non-adequate* and *non-acceptable*, respectively.

Measurements before and after sticking were focused on signs indicating the recovery of consciousness and nociception as follows. (1) Examination of breathing: return of rhythmic breathing could be observed if 3–4 breaths or gags occurred at the same time intervals. (2) Examination of posture: if hoisted and shackled pigs tried to arch their neck or body, this was regarded as an attempt to regain posture. (3) Examination of motor activity: observation and palpation of the ear could reveal stiffness, which occurred when muscle tone was being regained. (4) Examination of nociception/analgesia: any response to nose pricking or ear pinching could be regarded as a sign of recovery of nociception, which was tested with a knife. After sticking, involuntary urination and defecation could also be observed. (5) Examination of vocalisation: any vocalisation was regarded as a sign of consciousness. (6) Examination of the eyes: automatic blinking or blinking provoked by touching the cornea or the eyelid was regarded as a sign of recovery. Checking tonic-clonic seizures at these monitoring points was not part of the protocol, because at these small-sized slaughterhouses the shortest stun-to-stick period was 32 sec, whereas tonic-clonic seizures disappear earlier than that.

Under practical conditions the above six criteria could be examined before and after sticking. Using the above-described scoring system unconsciousness/analgesia was regarded effective at *adequate* level if all criteria were scored 1 (total score: 6). From the practical point of view, effectiveness of unconsciousness at *acceptable* level was also established. In this case at least 5 out of the 6 criteria were scored 1. Stuns under these levels were regarded as *non-adequate* and *non-acceptable*, respectively.

The data collected and recorded from each individual pig were analysed statistically. As examinations were carried out at more than one slaughterhouse, the data collected at each location were analysed separately. Then the data were pooled and evaluated to see if the location had a statistically valid effect on the result. After descriptive statistics, the effect of the given parameter on stunning and maintenance of unconsciousness was analysed by logistic regression. The level of significance was set at $P = 0.05$. Correlations were sought between stunning and all the recorded and calculated technical parameters. Statistical analysis was carried out at both *adequate* and *acceptable* levels of unconsciousness/analgesia. Statistical analysis was carried out with the R Core Team (2016) software.

Because animal-based measurements were carried out at three monitoring points (after stunning, before sticking and after sticking), the data permitted us to conclude whether or not stunning was effective at *adequate* or *acceptable* level, the time of sticking was proper, and unconsciousness and analgesia were maintained until death. The joint effect of current and duration could also be examined. On this basis, minimum required values could be set for different variables with different accuracies.

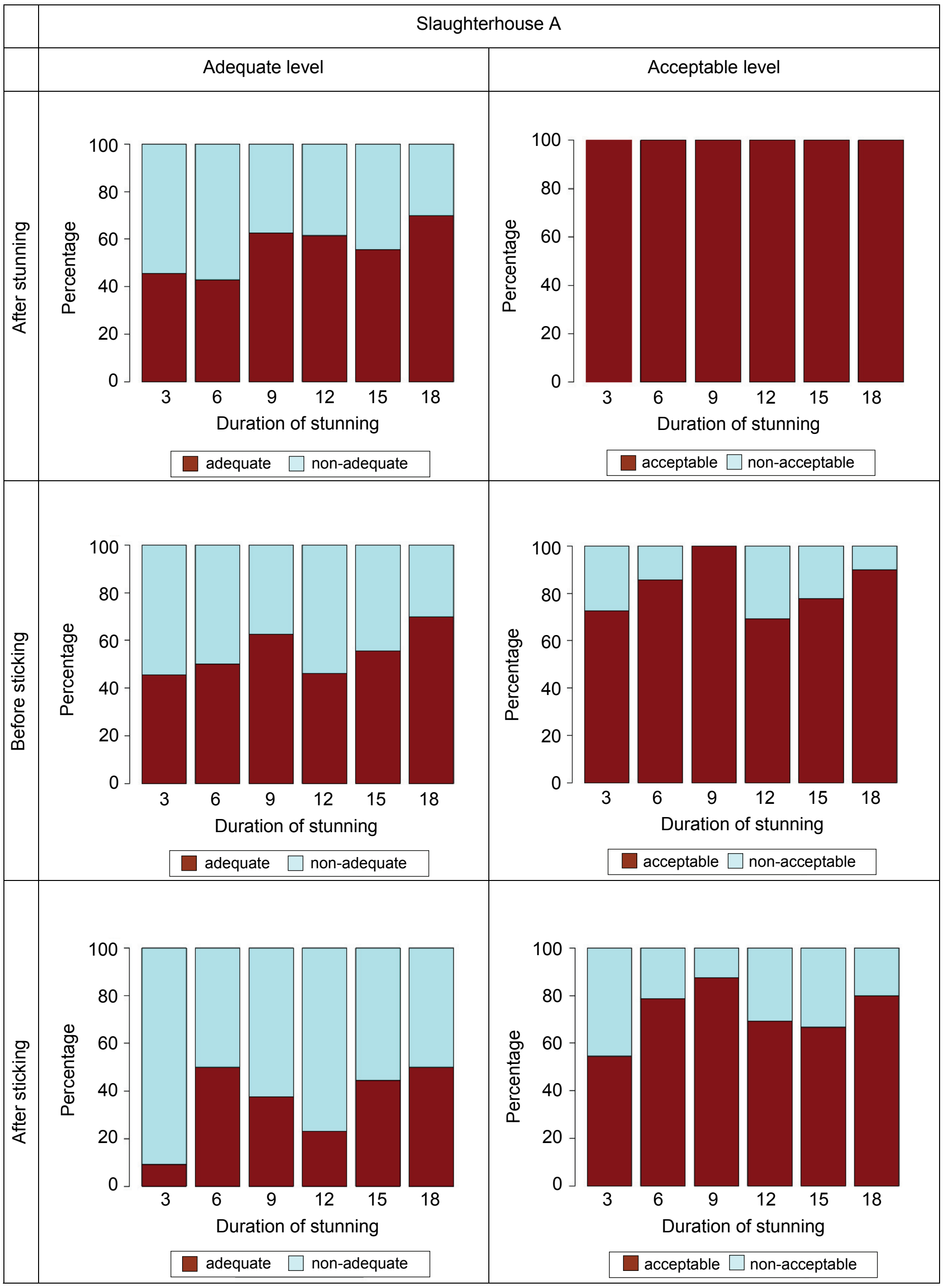
Results

Results regarding the effective duration of stunning and the stun-to-stick period

Duration of load. Percentages of *adequate/non-adequate* and *acceptable/non-acceptable* cases of stunning are shown in Fig. 1.

There was no significant correlation between the duration of load and the effectiveness of stunning either on *adequate* or on *acceptable* level at the three monitoring points at any of the slaughterhouses.

Stun-to-stick period. Before sticking 44 *adequate* and 115 *non-adequate* cases, as well as 104 *acceptable* and 55 *non-acceptable* cases were recorded. The percentages are shown in Fig. 2.


Slaughterhouse A
Adequate level
Acceptable level
After stunning
Before sticking
After sticking
Percentage
100
80
60
40
20
0
3 6 9 12 15 18
Duration of stunning
adequate
non-adequate
acceptable
non-acceptable

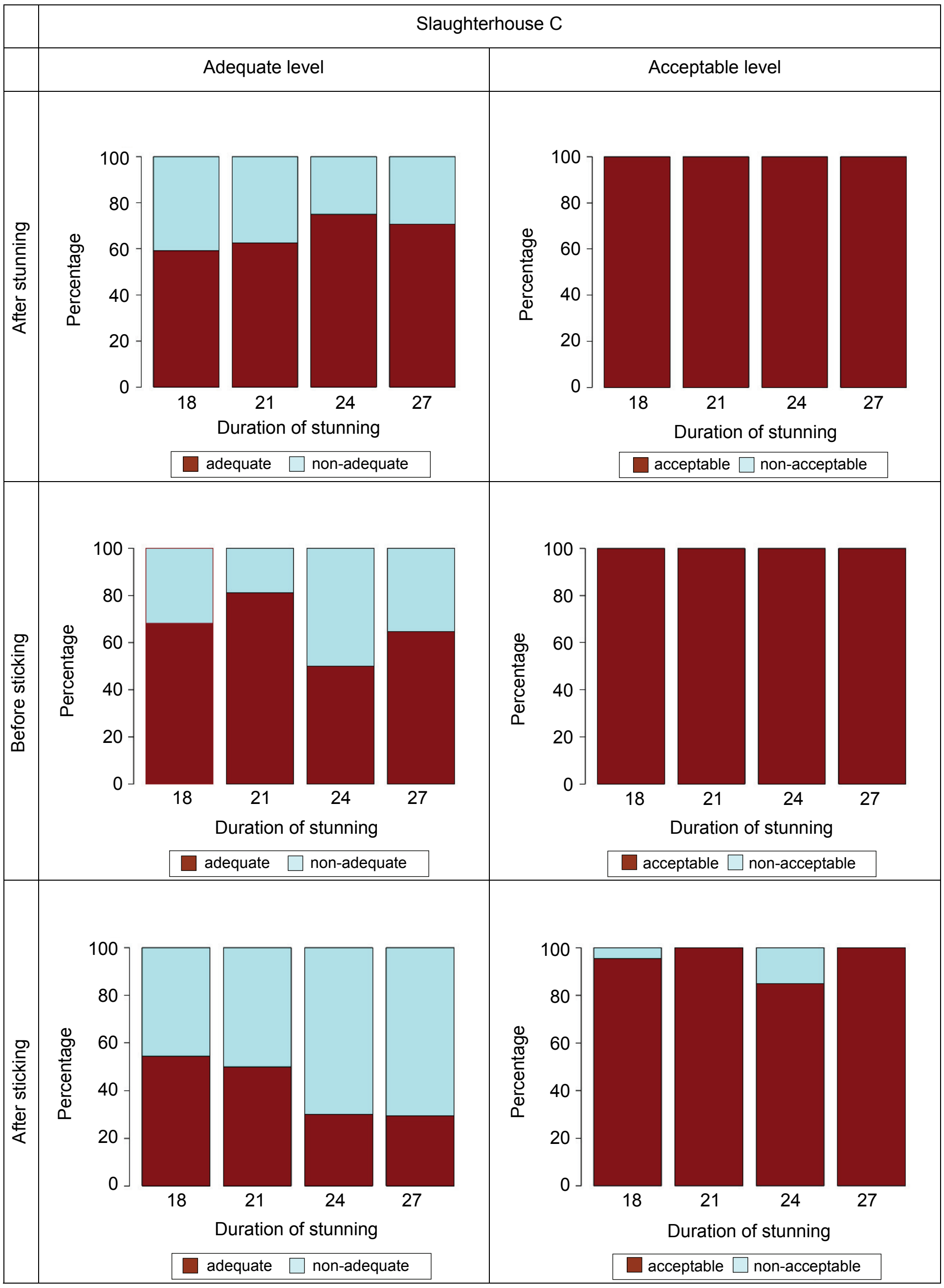


Fig. 1. Percentages of adequate/non-adequate and acceptable/non-acceptable cases in relation to the duration of stunning

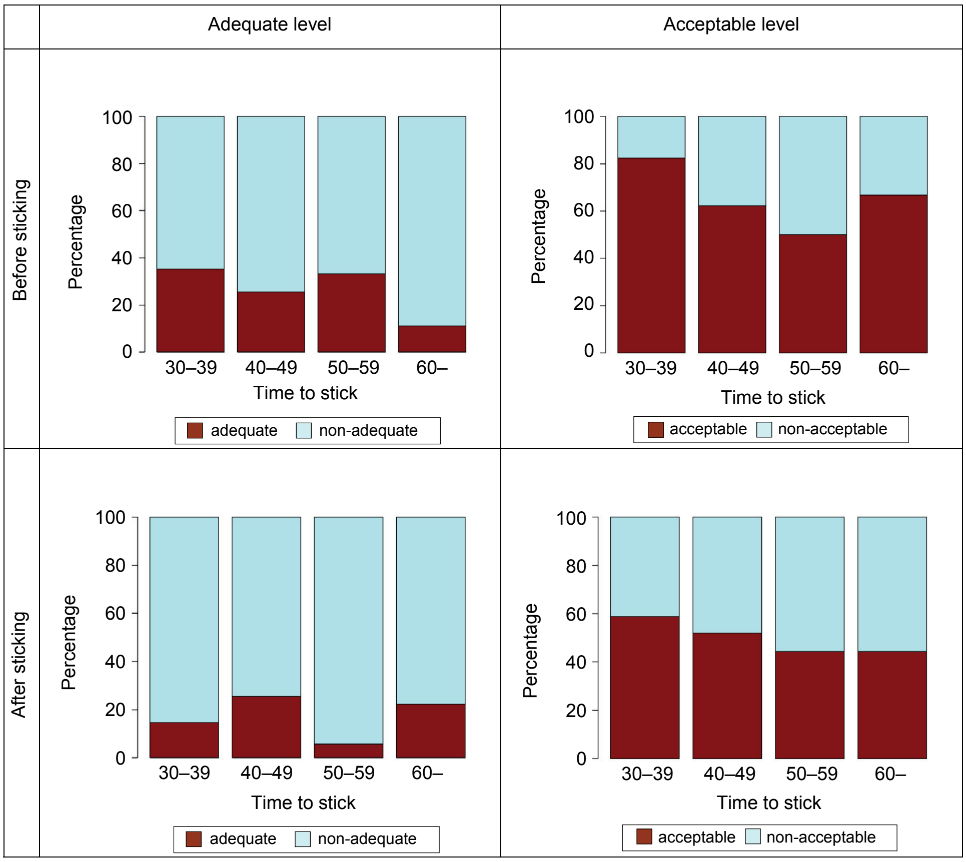


Fig. 2. Percentages of adequate/non-adequate and acceptable/non-acceptable cases in relation to the time-to-stick period in slaughterhouse A

At *acceptable* level the maintenance of unconsciousness decreased significantly when the stun-to-stick period increased. This effect was proved by logistic regression, whereas at *adequate* level this effect could not be proved.

The joint effect of the stun-to-stick period with other parameters (current intensity, electric work) on the maintenance of unconsciousness was also studied. At *acceptable* level the stun-to-stick period had a significant joint effect with current intensity. Higher amperage caused a longer maintenance of unconsciousness, while an extended stun-to-stick period shortened the maintenance of unconsciousness.

After sticking 33 *adequate* and 126 *non-adequate* cases, as well as 83 *acceptable* and 76 *non-acceptable* cases were found. The percentages are shown in Fig. 2.

In spite of the results obtained before sticking, the stun-to-stick period did not have a significant effect on the maintenance of unconsciousness after sticking. We examined the joint effect of the stun-to-stick period with other parameters (current, electric work) on the maintenance of unconsciousness until bleeding. Neither current nor electric work had a significant joint effect.

In addition to the foregoing, another question may arise: what is the interval between the end of effective stunning and the recovery of consciousness and nociception. In order to answer this question, the data of *adequate* and *acceptable* stunning were analysed. It was found that at *acceptable* level the maintenance of unconsciousness significantly decreased when the stun-to-stick period increased. On this basis an attempt was made to calculate the minimum time interval beyond which the effectiveness of anaesthesia declines. Because the calculated limit value fell in a negative region and the smallest real value found was 32 sec, we may only conclude that the optimum time for the start of bloodletting is within 32 sec of the end of stunning.

Fulltime. Before sticking, at *adequate* level there was no significant correlation with the maintenance of unconsciousness. Fulltime did not have a significant joint effect either with current intensity or with electric work. At *acceptable* level, fulltime and the maintenance of unconsciousness did not show significant correlation; however, a decreasing tendency could be revealed, and the joint effect of fulltime and current intensity was significant. Interaction was found between fulltime and current intensity: the lower the amperage, the shorter the period of unconsciousness. After sticking, fulltime did not have a significant correlation with the maintenance of unconsciousness either alone or jointly with other parameters.

Results regarding current intensity and electric load

Results regarding current intensity and electric work are presented together, because amperage was measured while the electric work was calculated.

Data after stunning. After stunning 153 *adequate* and 143 *non-adequate* cases were recorded, whereas at *acceptable* level 282 *acceptable* and 14 *non-acceptable* cases were found. The percentages are shown in Fig. 3.

Analysis of the pooled and separate data of the two slaughterhouses showed that increasing current intensity had a significant effect on the effectiveness of stunning. This significant effect of current intensity was detected at both *adequate* and *acceptable* levels. Electric work and the effectiveness of stunning showed the same correlation: higher electric work resulted in significantly better stunning at both *adequate* and *acceptable* levels.

Logistic regression showed no effect of slaughterhouses on either amperage or electric work and the same negative correlation was found between location (slaughterhouse) and the effectiveness of stunning. Consequently, minimum current and electric work required for *adequate* and *acceptable* stunning could be established irrespective of the location (Table 1).

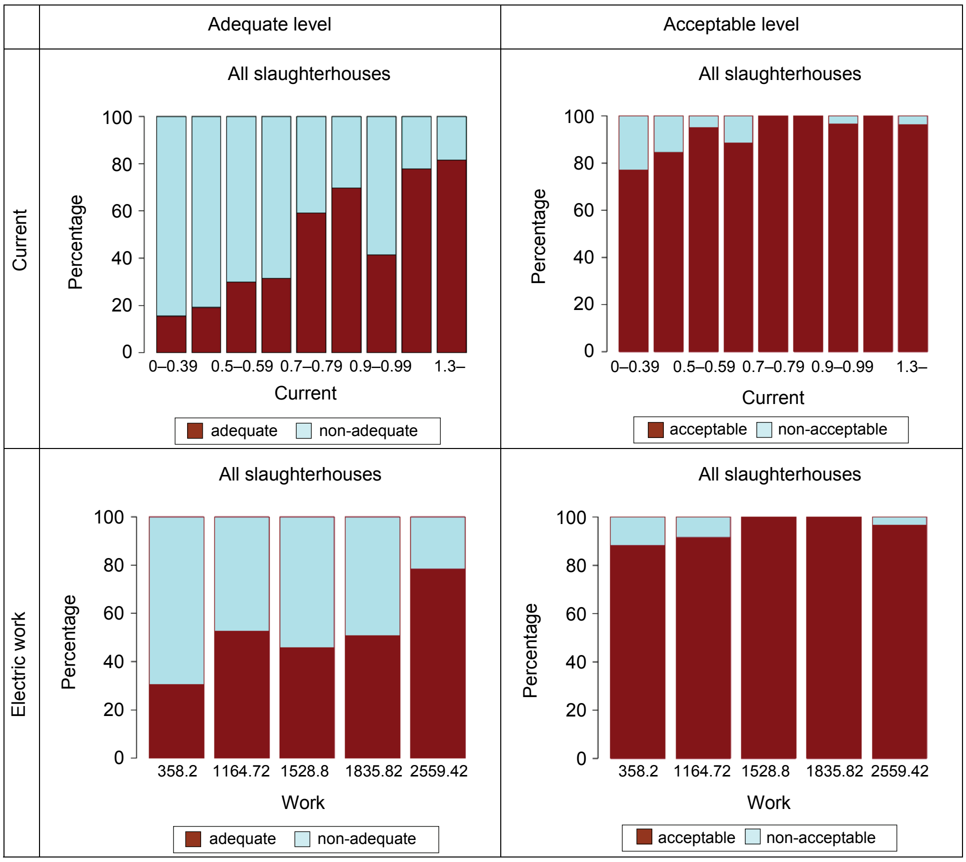


Fig. 3. Percentages of adequate/non-adequate and acceptable/non-acceptable cases in relation to current and electric work after stunning

Table 1

Minimum current and electric work required for adequate and acceptable stunning with different accuracy

Accuracy (%)	90	95	99
Minimum required current (A) at adequate level	1.61	1.91	2.55
Minimum required current (A) at acceptable level	0.51	0.67	1.02
Minimum required electric work (J) at adequate level	6,074.09	7,525.13	10,730.64
Minimum required electric work (J) at acceptable level	5,74.51	1,578.49	3,796.4

A = ampere, J = joule

Data before sticking. Maintenance of unconsciousness was found to be *adequate* in 86 and *acceptable* in 225 cases while 210 and 71 cases were *non-adequate* and *non-acceptable*, respectively (Fig. 4).

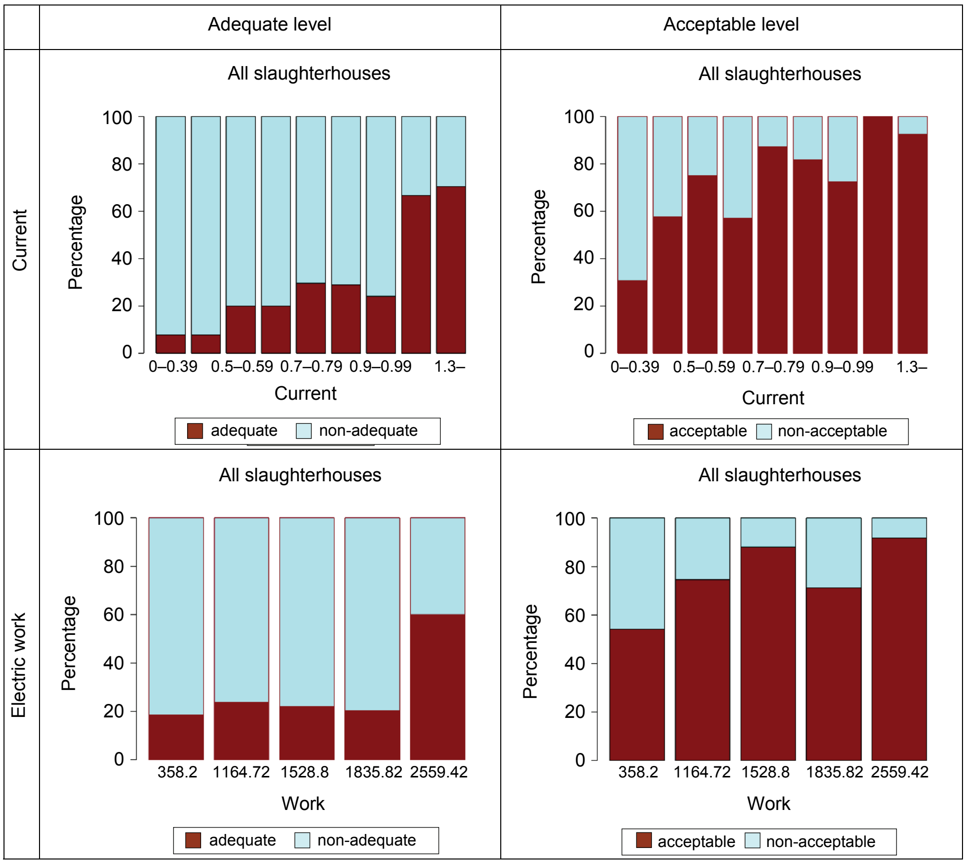


Fig. 4. Percentages of adequate/non-adequate and acceptable/non-acceptable cases in relation to current and electric work before sticking

The analysis of pooled data showed that increasing current intensity had a significant effect on the effectiveness of stunning at both levels. When data found at the slaughterhouses were analysed separately, only a tendency was found, i.e. the effect of current intensity on the maintenance of unconsciousness was statistically not proven. The same interactions were found with the data of electric work.

According to the results of logistic regression, at *adequate* level a difference was found between locations in terms of correlations between current intensity and electric work, which was not significant but was regarded as a block effect. At *acceptable* level the effect of location was significant on both the correlation between current intensity and effectiveness as well as on the correlation between electric work and effectiveness. Consequently, the minimum current intensity and electric work required for *adequate* and *acceptable* stunning could be established only by location and with different accuracy (Table 2).

Table 2

Minimum current and electric work required for the maintenance of unconsciousness until sticking on different levels with different accuracy

Accuracy (%)	90	95	99
Minimum required current (A) at adequate level – Slaughterhouse A	1.86	2.12	2.71
Minimum required current (A) at adequate level – Slaughterhouse B	2.02	2.29	2.88
Minimum required current (A) at acceptable level – Slaughterhouse A	1.49	1.87	2.70
Minimum required current (A) at acceptable level – Slaughterhouse B	0.91	1.29	2.13
Minimum required electric work (J) at adequate level – Slaughterhouse A	7,379.62	8,721.25	11,685.05
Minimum required electric work (J) at adequate level – Slaughterhouse B	8,003.47	9,345.10	12,308.90
Minimum required electric work (J) at acceptable level – Slaughterhouse A	4,440.20	5,812.14	8,842.92
Minimum required electric work (J) at acceptable level – Slaughterhouse B	2,395.08	3,767.02	6,797.80

A = ampere, J = joule

As the stun-to-stick period was variable in slaughterhouse A, an attempt was made to correlate the effects of current intensity/electric work with the duration of load, stun-to-stick period or fulltime. No such correlation was found.

Data after sticking. Maintenance of anaesthesia after sticking was found to be *adequate* in 69 and *acceptable* in 178 cases and *non-adequate* in 227 and *non-acceptable* in 118 cases (Fig. 5).

Descriptive statistical analysis of pooled data showed that the effectiveness of stunning increased significantly with increasing current intensity at both levels.

Data analysis by location revealed that current intensity had a significant effect but only in one of the slaughterhouses and only at *acceptable* level. The correlation between electric work and effective maintenance of unconsciousness was similar, i.e. increasing electric work significantly improved the effectiveness at both *adequate* and *acceptable* levels. When data were analysed by location, the electric work had a significant effect at one of the slaughterhouses at *acceptable* level.

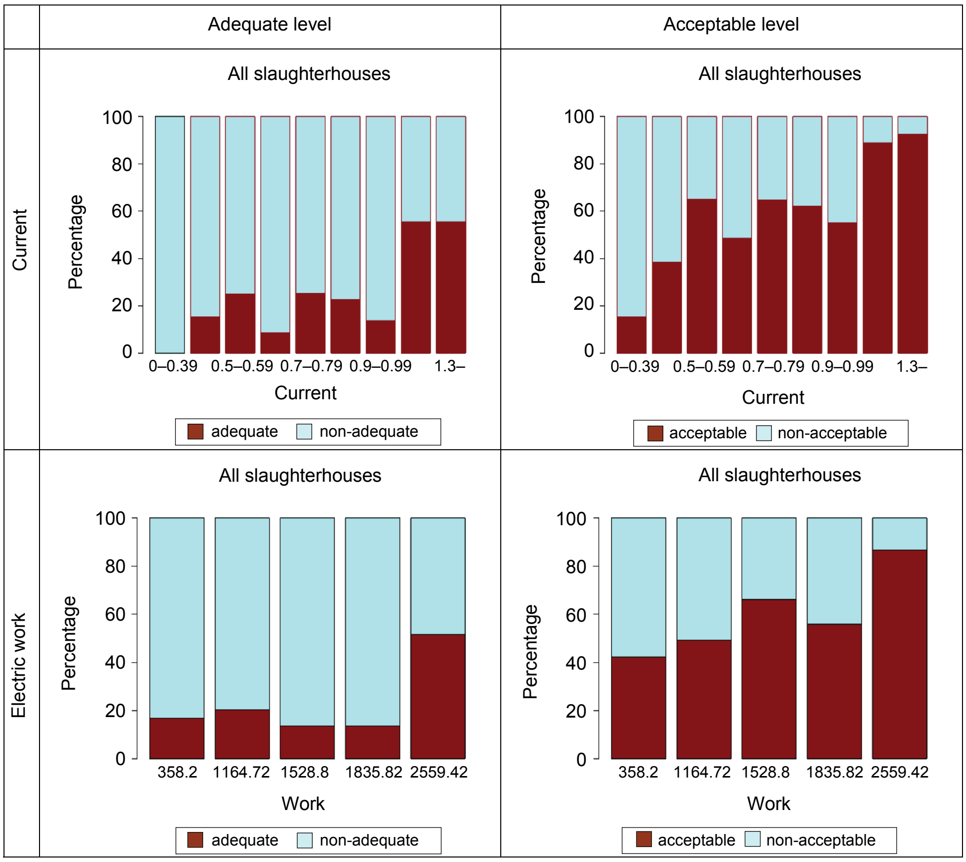


Fig. 5. Percentages of adequate/non-adequate and acceptable/non-acceptable cases in relation to current and electric work after sticking

Logistic regression showed that current intensity interacted partly with the location and partly with the duration of stunning. From this it follows that no opportunity was found to calculate the minimum current intensity required for the maintenance of efficient anaesthesia after bleeding. For electric work no such interaction was found, and therefore the minimum electric work required for the maintenance of efficient anaesthesia after bleeding was calculable. The data are shown in Table 3.

Because the stun-to-stick period varied at slaughterhouse A, the interaction between the maintenance of unconsciousness after bleeding and parameters including current intensity, duration of stunning or the time interval between the end of stunning and bloodletting could not be proved statistically.

Table 3

Minimum electric work required for the maintenance of unconsciousness beyond sticking on different levels with different accuracy

Accuracy (%)	90	95	99
Minimum required electric work (J) at adequate level	9,374.55	10,961.06	14,465.84
Minimum required electric work (J) at acceptable level	4,515.59	5,629.23	8,089.38

J = joule

Discussion

Effectiveness of stunning

The data presented above indicate that the effectiveness of stunning is influenced by current intensity. This observation is consistent with the findings of Velarde et al. (2000). No correlation was found between the duration of stunning and the effectiveness of stunning in the range examined (3 to 35 seconds).

Because no stuns shorter than 3 sec were tested in this experiment, the 3-sec minimum duration of stunning recommended earlier by Anil (1991) is still regarded valid. The common belief of slaughterhouse workers as well as the suggestion from an earlier study (Wenzlawowicz et al., 2012), i.e. the longer the stunning, the better the result, was not verified by the present investigation. Channon et al. (2003) examined the effect of different stunning durations on pork quality but they revealed inconsistent effects on muscle pH too.

The increase of electric work also had a significant effect on the effectiveness of stunning. However, as the duration of stunning was not demonstrated to have an effect, the positive effect of electric work is attributed to the current intensity.

The minimum current intensity required for *adequate* or *acceptable* stunning is important from the practical point of view. Provided that the tongs are correctly positioned (see earlier), stunning is *acceptable* in 99% of the cases if the minimum current intensity and the electric work is 1.02 A and 3,796 J, respectively.

Maintenance of unconsciousness until sticking

Analysis of the maintenance of unconsciousness until sticking showed that the current intensity used for stunning also has a crucial role. However, we concluded that minimum thresholds could be established only by location. Besides, it seems that the maintenance of unconsciousness is also influenced by the stun-to-stick period. This is shown by the fact that increasing the stun-to-stick period significantly decreased the incidence of effective maintenance of unconsciousness. On the other hand, stun-to-stick period and fulltime showed a significant joint effect (negative correlation) with current intensity: higher current intensity resulted in a better maintenance of unconsciousness, while a longer stun-to-stick period had the opposite effect. This joint effect can explain the fact that current thresholds could be established only by location, because the stun-to-stick period can be different in different slaughterhouses.

The recovery of consciousness is more probable if the stun-to-stick period is longer: the time of sticking must be somewhere within 32 seconds of the end of stunning. This finding suggests to keep the earlier recommended 15 seconds (Anil, 1991; McKinstry and Anil, 2004) as the latest time for sticking.

Electric work had a similar effect as current intensity on the maintenance of unconsciousness until sticking, which can be attributed to the fact that current intensity is one of the variables used for calculating the electric work.

Maintenance of unconsciousness beyond sticking

Current intensity also had a considerable impact on the maintenance of unconsciousness beyond sticking. However, in addition to current intensity, the location and the duration of stunning also had an influence at that monitoring point. From this it follows that it was not possible to establish a threshold for current intensity. This can again be explained by the fact that the stun-to-stick period can be different in different slaughterhouses. This problem might be overcome by establishing figures for electric work. In 99% of the cases unconsciousness can be maintained at an acceptable level beyond sticking when the electric work is at least 8,089 J. The effects of current intensity and stunning duration are combined in the electric work. The electric resistance inbuilt in a circuit transforms electricity into heat. In our case the head and its tissues and cells create electric resistance in head-only stunning. The heat causes coagulation necrosis and denaturation of proteins in cells and tissues. It is assumed that the tissue destruction caused by electric work might play a role in the maintenance of unconsciousness beyond sticking, even in cases when bloodletting starts beyond 32 seconds after the conclusion of stunning.

In summary, on the basis of our measurements conducted under commercial conditions we may conclude that current intensity plays a predominant role in the effectiveness of stunning and the maintenance of unconsciousness. The duration of stunning is a parameter included in the electric work. The importance of electric work is shown in the long-lasting maintenance of unconsciousness. The settings of stunning devices cannot be standardised. Parameters ensuring proper unconsciousness can be established only by location by the use of animal-based measures.

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