

# Head-to-Cloaca Electrical Stunning of Broilers

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**ABSTRACT** This study was performed to identify the electrical current and exposure duration that would instantaneously render broiler chickens unconscious at slaughter when using a head-to-cloaca water bath stunner. The water in which the head was immersed was one electrode, and a steel-coned or cutaneous U-shaped electrode penetrating the cloaca was the other electrode. When an electrode penetrating the cloaca was used, a 640-Hz sinusoidal current induced a tonic-clonic phase on the electroencephalogram that lasted for  $10 \pm 3$  s and an exhaustion phase that lasted for  $34 \pm 12$  s. The heart rate was  $375 \pm 39$  beats/min before stunning. After stunning, the electrocardiogram revealed fibrillating for  $429 \pm 58$  s, after which the heart activity stopped. When a U-shaped electrode was placed on the skin at the cloaca, the same phenomenon was induced. A general epileptiform insult was induced when

using a pulsed alternating square wave current of 33 mA (peak 60 V, 600 Hz, and a duty cycle of 50%), which lasted, on average, for 25 s ( $n = 25$ ). When the broilers were bled within 14 s after stunning, they remained unconscious and the heart activity stopped after  $237 \pm 103$  s. We concluded from this experiment that broilers were effectively stunned with an average current of 111 mA (50 V, 640 Hz, sinusoidal alternating current) for 1 s when using a water bath in which the head of the broiler was immersed in water, with the water being one electrode and a steel electrode penetrating the cloaca or placed around it being the other electrode. Energy use could be reduced when an alternating pulsed square wave is used when the broilers are stunned, by using a current of approximately 33 mA (peak of 60 V, frequency of 600 Hz, and a 50% duty cycle).

**Key words:** broiler, head-to-cloaca stunning, electrical stunning

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## INTRODUCTION

Electrical stunning is normally used to induce unconsciousness during cutting and bleeding for reasons of animal welfare in the European Union or to induce immobilization to facilitate automatic cutting in the United States. It is generally stated that birds must be spared any avoidable excitement, pain, or suffering during movement, transport, restraint, stunning, slaughter, or killing (European Food and Safety Authority, 2004). Furthermore, slaughter should not have negative effects on carcass or meat quality. Cutting after a stun should be carried out as quickly as possible when using head-only stunning because it takes time, depending on the species, before brain responsiveness is lost as a result of cutting, and birds can recover (Cook et al., 1996). It is widely recognized that inducing a cardiac arrest at stunning has distinct welfare advantages: 1) death results in a rapid loss of brain function,

2) it ensures that the bird will not regain consciousness (Savenije et al., 2000), and 3) it does not depend on the operator performing an accurate cut.

In broiler chicken processing, it is common for the birds to be hung by the legs from shackles, and electrocution is done electrically by contact of the head and neck of the bird with an electrified water bath. Insufficient currents may physically immobilize the bird but may not prevent the perception of pain, stress, or discomfort by the bird (Fletcher, 1993). A minimum current of 120 mA per bird is recommended to stun-kill the bird (Gregory and Wotton, 1990). This recommended minimum current for broilers in the European Union increases quality defects (e.g., hemorrhages, broken bones) in carcasses and broiler meat (Veerkamp and de Vries, 1983; Gregory and Wilkins, 1989). It is apparent that there can be a conflict between bird welfare and carcass quality when using electrocution as the stun-kill procedure. Therefore, alternative methods for stunning broilers must be explored.

An improved electrode contact can be achieved in or around the cloaca compared with the feet, where there is sufficient contact of the head with the water. It is hy-

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pothesized that a lower current can be used when the contact between the electrodes and the bird is improved. At present, a variety of waveforms and frequencies of currents can be supplied. Alternatives for the sinusoidal alternating current (AC) are pulsed direct current (DC) and pulsed AC. It is suggested that the depth and duration of unconsciousness induced by electrical stunning be determined by the duration at which the current stays at the minimum level within each cycle [root mean square (RMS) current, duty cycle, AC/DC; Raj and O'Callaghan, 2004; Raj, 2006].

To determine the effect of the electrical current on the brain and heart, their activity can be measured by recording the electrical potentials. Recording of an electroencephalogram (EEG) is necessary to determine whether an electric current has been sufficient to induce a general epileptiform insult (grand mal seizure), indicating unconsciousness (Wageneder and Schuy, 1967). During high-current electrical stunning, the heart is affected, which is recordable on an electrocardiogram (ECG).

The objective of this study was to identify an electrical current and exposure duration that would render broiler chickens unconscious instantaneously at slaughter when using a head-to-cloaca water bath stunner. The stunning methods were assessed by using electroencephalography (EEG) and electrocardiography (ECG).

## MATERIALS AND METHODS

### *Birds*

The experiments received prior approval from the Ethical Committee of the Animal Sciences Group of Wageningen UR. Broilers from a commercial farm were delivered to the slaughterhouse. Before transport, the birds had a feed withdrawal period of 6 h and were transported in crates. A total of 103 broilers were obtained and used for the experiments. During the experiment, the birds were placed one by one in a specially developed water bath restrainer for stunning and registration of EEG and ECG. The birds were hung individually by the feet from shackles, and stunning was done electrically by immersion of the head of the bird. The water was one electrode and a dry steel cone-shaped or U-shaped electrode inside or at the region around the cloaca was the other electrode. After shackling, the cloacal electrode was moved downward and placed in position. The water bath was then lifted, and the bird was immediately stunned for 1 s (Figure 1). After the stunning experiment, the broilers were weighed and breast and leg muscles were examined for blood splashes (yes or no).

### *Registration of EEG and ECG*

Before stunning, each individual broiler was equipped with EEG and ECG electrodes. To facilitate

implantation of the electrodes, the broiler was hung in the restrainer.

The EEG electrodes (10 mm long and 1.5 mm in diameter; 55% silver, 21% copper, 24% zinc) were placed by pressing them through the skin and skull, one electrode 0.3 cm to the right and one electrode 0.3 cm to the left of the sagittal suture and 0.5 cm of the imaginary transverse line at the caudal margin of the eyes. The ECG electrodes (35 mm long and 1.5 mm in diameter; same metal composition) were placed subcutaneously at the left and right side of the breast directly under the wing. For both the EEG and ECG, the earth electrode was placed subcutaneously, lateral to the right leg. The EEG and ECG were recorded from 30 s before to 5 min after stunning. The recorder used was a DI 720 data recording module with a WinDaq Waveform browser (Dataq Instruments, Akron, OH). The EEG and ECG recordings were analyzed afterward for changes in the waveforms, frequency, and suppression.

### *Experimental Treatments*

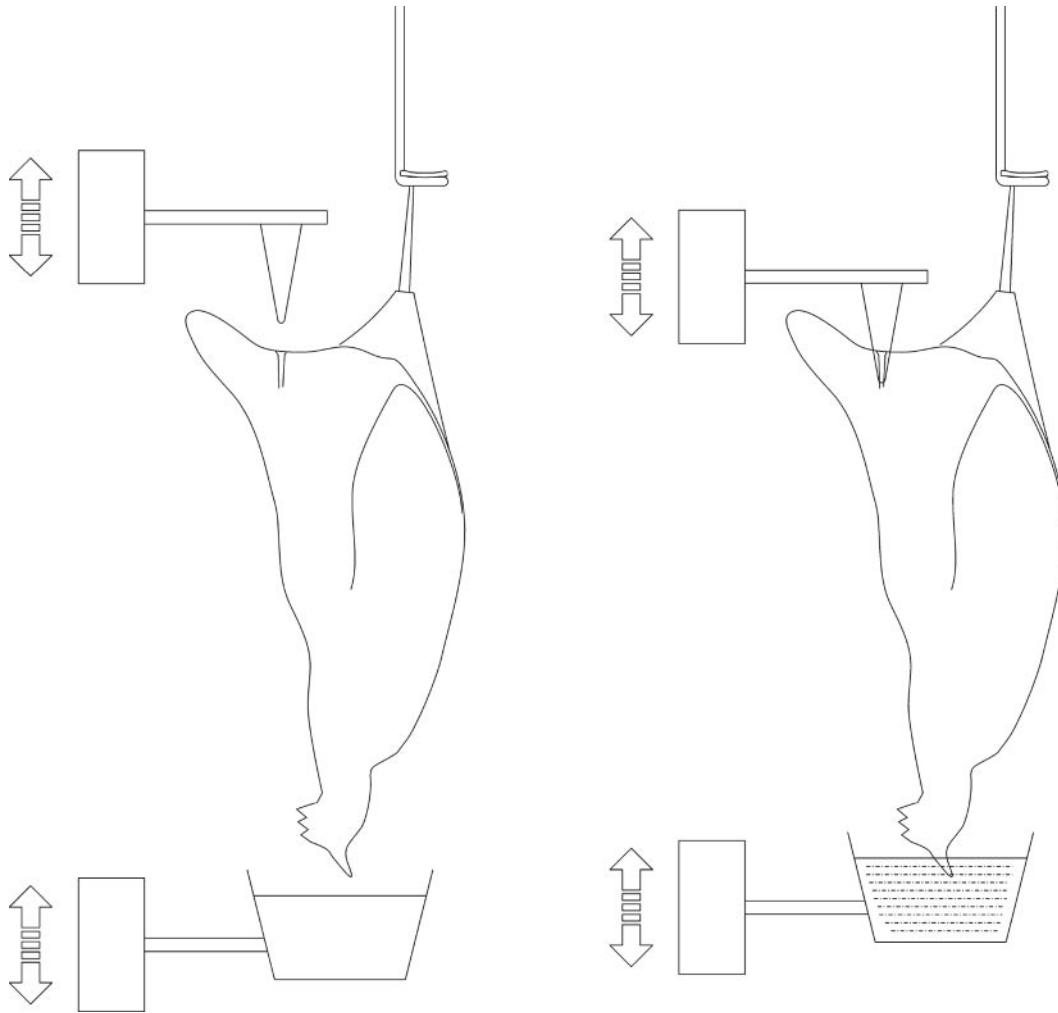
**Pilot Experiment.** Broilers were stunned in the prototype head-to-cloaca stunner. The broilers were hung and shackled, the cloaca electrode was penetrated, and the water bath was lifted to immerse the head in the water. An electrical voltage of 75 V with frequencies of 80, 230, 455, and 630 Hz was applied for 2 s (Figure 1), with 3 broilers stunned at each of the 4 frequencies. The broilers were bled by a cut through the skin and the carotid artery and jugular vein at the left side of the neck. After bleeding, the carcasses were checked for hemorrhages.

**Head to Inside Cloaca.** In the first experiment, 31 broilers were subjected to electrical stunning from the head to inside cloaca for approximately 1 s, using a set voltage of 30 or 50 V (640 Hz, sinusoidal AC) between the electrodes (Rico Turkey Equipment, Zaandam, the Netherlands). The current was delivered by using the water as one electrode and a steel-coned electrode in the cloaca as the second electrode. After the experiment, the bird was weighed and the carcass was subjectively scored for hemorrhages. (Because the birds died, they were not bled.)

**Head to Outside Cloaca.** In the second experiment, 27 broilers were subjected to electrical stunning from the head to the skin around the cloaca for approximately 1 s, using set voltages of 50 V (640 Hz AC) between the electrodes. The current was delivered by using the water as one electrode and a U-shaped steel electrode at the skin around the cloaca as the other electrode.

After the experiment, the bird was weighed and the carcass was subjectively scored for hemorrhages. (Because the birds died, they were not bled.)

**Pulsed Square Wave AC.** A device that generates a pulsed square wave AC was built at IMARES. For stunning, a peak voltage of 60 V (RMS was 44 V) was applied for 1 s. The waveform of the current consisted of a pulse width of 0.42 ms and a period length of 1,67



**Figure 1.** Schematic diagram of the head-to-cloaca stunner.

ms (50% duty cycle). Thus, the frequency of the applied voltage was 600 Hz.

Individual broilers ( $n = 28$ ) were stunned with the inside-cloaca electrode. The birds that recovered ( $n = 22$ ) were stunned with the same current, but for 3 s. They were bled in  $14 \pm 4$  s by a cut through the skin, carotid artery, and jugular vein at the left side of the neck to kill the bird. Another 5 birds were bled immediately with the above-mentioned stunning method. After the experiment, the birds were weighed and subjectively scored for hemorrhages.

### Statistical Analyses

Each bird represented an experiment with a probability,  $P$ , that the bird was unconscious during the general epileptiform insult. For  $n$  birds, which were treated independently, the number  $x$  (where  $x$  is unconscious) followed a binomial distribution with total  $n$  and probability  $P$ . The confidence interval could be calculated for the probability  $P$  based on the relationship between the binomial and  $\beta$  distribution. The number of effective stuns followed a binomial distribution. A 95% confidence limit on the probability of an effective

stun could be obtained by means of the well-known relationship with the  $\beta$  distribution (Johnson and Kotz, 1969).

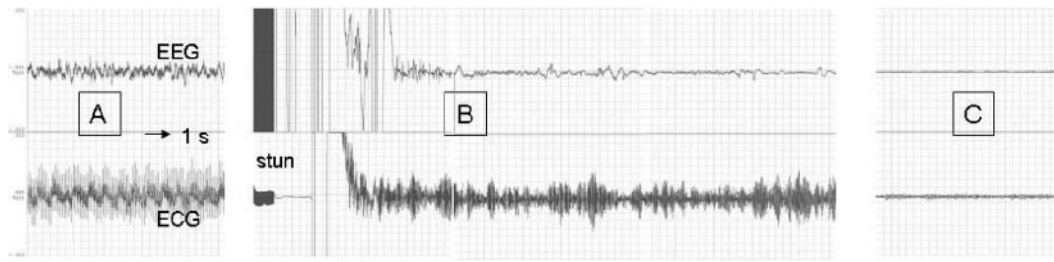
## RESULTS

### Pilot Experiment

The broilers responded to the penetration of the cloaca electrode by contracting the annular fold muscle. Administration of currents of 200 to 300 mA, up to 455 Hz (sinusoidal AC), showed that the birds were stunned; however, hemorrhages were observed in the breast and leg muscles. When a frequency of 630 Hz was used, the birds were stunned, and hemorrhages were not observed in the carcass.

### Head to Inside Cloaca

In the first experiment, using a water bath and a coned, inside-cloaca electrode, the average ( $\pm$ SD) weight of the broilers was  $2.2 \pm 0.3$  kg. The characteristics of a general epileptiform insult were observed in 2 of the 3 broilers stunned with 30 V. The remaining broilers ( $n$



**Figure 2.** Electroencephalogram (EEG) and electrocardiogram (ECG) before and after electrical stunning with the head-to-cloaca water bath stunner. A) Brain and heart activity immediately before stunning. B) Induced general epileptiform insult, which tended toward an isoelectric line (EEG trace) because of the induced heart fibrillation (ECG trace) immediately after stunning. C) Both brain and heart activity were stopped at  $444 \pm 87$  s after stunning.

= 28) were stunned with  $53 \pm 3$  V (640 Hz, sinusoidal AC), resulting in an overall current of  $111 \pm 34$  mA. In 3 birds, the electrodes became disconnected, with the consequence that the EEG could not be recorded. A general epileptiform insult was observed in all 25 broilers for which a successful EEG recording was obtained. The duration of the tonic-clonic phase, as measured on the EEG, was  $10 \pm 3$  s, with the exhaustion phase starting after  $34 \pm 12$  s, and an isoelectric line occurred and remained during the measuring period (Figure 2).

The average heart rate was  $375 \pm 39$  beats/min before stunning. After stunning, the ECG revealed fibrillation for  $429 \pm 58$  s, after which all heart activity stopped. Minimal blood splashes were observed in 9 out of 25 birds, whereas in the other 18 birds, no blood splashes were observed in the breast or leg muscles. Within a confidence limit of 95%, taking into account the number of birds with a reliable EEG ( $n = 25$ ), the chance of an effective stun of all broilers lay between 0.89 and 1.00 when a current of  $111 \pm 34$  mA (53 V and 640 Hz, sinusoidal AC) was used.

### Head to Outside Cloaca

In the second experiment, using a water bath and an electrode placed on the skin around the cloaca, the average weight of the birds was  $2.1 \pm 0.3$  kg. The voltage applied was  $54 \pm 0$  V and the current measured was  $111 \pm 33$  mA (640 Hz, sinusoidal AC). The electrodes became disconnected in 2 birds. A general epileptiform insult was observed in all 25 broilers for which a successful EEG recording was obtained. The duration of the tonic-clonic phase, as measured on the EEG, was  $11 \pm 3$  s, with the exhaustion phase beginning at  $27 \pm 8$  s, and an isoelectric line occurred and remained during the measuring period (Figure 2).

The average heart rate before stunning was  $362 \pm 39$  beats/min. After stunning, the ECG revealed fibrillation for  $444 \pm 87$  s, after which all heart activity stopped. Minimal blood splashes were observed in 5 out of 25 birds, whereas in the other 20 birds, no blood splashes were observed in the breast or leg muscles.

Within a confidence limit of 95%, taking into account the number of birds with a reliable EEG ( $n = 25$ ), the chance of an effective stun of all broilers lay between

0.89 and 1.00 when a current of  $111 \pm 33$  mA (54 V and 640 Hz, sinusoidal AC) was used.

### Pulsed Square Wave AC

In the third experiment, using a water bath and an electrode placed inside the cloaca, the average weight of the birds was  $2.2 \pm 0.3$  kg. The applied voltage (RMS) and measured current were 40 V and  $33 \pm 11$  mA, with a frequency of 600 Hz (50% duty cycle). The electrodes became disconnected in 3 birds. A general epileptiform insult was observed in all 25 broilers for which a successful EEG recording was obtained. The duration of the pronounced tonic and clonic phases, as measured on the EEG, were  $10 \pm 5$  and  $6 \pm 4$  s, respectively, which were followed by an exhaustion phase of  $7 \pm 4$  s. The total duration of the insult lasted, on average, 25 s and varied between 15 and 97 s. An isoelectric line was observed in 3 birds after the insult.

The average heart rate before stunning was  $362 \pm 39$  beats/min. The heart rates were  $236 \pm 48$ ,  $236 \pm 48$ , and  $253 \pm 53$  beats/min at 0.5, 2, and 5 min after stunning, respectively. Fibrillation was observed in 23 birds, which lasted for  $11 \pm 3$  s.

Within a confidence limit of 95%, taking into account the number of birds with a reliable EEG ( $n = 25$ ), the chance of an effective stun of all broilers lay between 0.89 and 1.00 when a pulsed square wave AC of  $33 \pm 11$  mA (by applying 40-V RMS, 600 Hz, and a 50% duty cycle) was used. After stunning and bleeding of the recovered birds, spikes and theta and delta waves were observed, tending toward an isoelectric line on the EEG in  $151 \pm 70$  s.

The heart rate was  $372 \pm 42$  beats/min before stunning, and at 0.5 and 2 min after stunning, the heart rates were  $255 \pm 64$  and  $274 \pm 57$  beats/min, respectively. A fibrillation was observed in 7 birds, which lasted  $8 \pm 3$  s. A few minimal blood splashes were observed in 3 out of 25 birds in the breast or leg muscles.

The weight of the birds bled after stunning was  $2.5 \pm 0.3$  kg. The current administered was 47 mA (by applying 47-V RMS, a 600-Hz bipolar square wave current, and a 50% duty cycle), and they were bled in  $14 \pm 2$  s. Spikes and theta and delta waves were observed, tending toward an isoelectric line on the EEG in  $195 \pm 72$  s.

The heart rate was  $320 \pm 37$  beats/min before stunning, and the heart rates at 0.5 and 2 min after stunning were  $238 \pm 28$  and  $287 \pm 76$  beats/min, respectively. An effective heart function was not observed after 237  $\pm$  103 s. Hemorrhages were not found in the carcass.

## DISCUSSION

If sufficient current is administered through the brain of a bird, a general epileptiform insult or grand mal seizure (i.e., when all brain parts are stimulated) will occur (European Food and Safety Authority, 2004). The epileptic process is characterized by rapid and extreme depolarization of the membrane potential, and there is a lot of variation in findings (Kooi et al., 1978). As measured on the EEG, such an insult consists of relatively small waves, increasing in amplitude in the tonic phase and decreasing in frequency in the clonic phase, ultimately resulting in a period of strong depression of electrical activity (Lambooy, 1982; Lambooy and Spanjaard, 1982). A human being is unconscious during the 3 phases of a general epileptiform insult. Moreover, the brain is in a stimulated condition and is unable to respond to additional stimuli. By analogy, a mammal is also supposed to be unconscious and insensible (Lopes da Silva, 1983).

The general epileptiform insult on the EEG, as measured in this experiment, was characterized by a tonic-clonic phase that resulted in a period of strong depression of electrical activity and was followed by an isoelectric line. Figure 2 presents a general epileptiform insult registered on the EEG and the effect of stunning on the heart activity shown on the ECG. The behavior showed one phase of a tonic cramp, followed by relaxation.

Raj and O'Callaghan (2004) suggested that the depth and duration of unconsciousness induced by electrical stunning is determined by the duration of the RMS current instead of the peak current. In our study, the current and frequency used seemed to be sufficient to induce epileptiform activity instantaneously. Furthermore, as a result of the heart fibrillation, which was followed by the stopping of all heart activity, all brain activity ceased. In this case, the time between electrocution and cutting was not a welfare problem, because birds stayed unconscious until death occurred. As in the brain, the neuronal interactions in the heart are integrated and orderly. Disorder is initiated by direct stimulation by an electrical current, and the heart will fibrillate or stop. Heart failure results in a gradual loss of blood pressure and a lack of oxygen to the brain and affects the characteristics of a general epileptiform insult (Savenije et al., 2002). Disorder was observed in our study when using a lower current of 111 mA and a higher frequency of 630 Hz. We suggest that the cloacal electrode caused other and better pathways to stimulate the brain and heart. At present, a variety of waveforms and frequencies of currents can be supplied and are implemented in water bath stunners. The most ef-

fective current seems to be one at 50 to 200 Hz. It is difficult to induce such a seizure by using a current with frequencies lower than 25 Hz. When the frequency is between 200 and 1,600 Hz, a higher current is necessary to induce the seizure. One consequence is that the duration of the insult is shorter (Raj and O'Callaghan, 2004; Raj, 2006). When applying a pulsed DC with a 50% duty cycle, the effective period may be too short in poultry, and the current will be insufficient to induce sustained neuronal inhibition after the epileptiform activity (Raj and O'Callaghan, 2004). The pulse characteristics used in these experiments were AC, which induced a general epileptiform insult that lasted, on average, 25 s. When the birds were bled immediately after the stun, they remained unconscious. This method can be recommended for use in practice. Present practice is to use as low a dose of energy as possible; however, there are doubts whether they cross the seizure threshold. Given our observations, by applying an AC square wave current, the current needed to provoke an immediate loss of consciousness could be reduced to  $33 \pm 11$  mA, compared with  $111 \pm 33$  mA, at 640 Hz with sinusoidal AC. In addition, downgrading of the carcass did not occur. A pulse wave machine that allows for careful energy dosing and determination of the seizure threshold should be developed for poultry stunning in the abattoir. Another aspect of using a pulse wave machine is that hemorrhages can be diminished.

It can be concluded from this experiment that broilers are effectively stunned with an average current of 111 mA (50 V, 640 Hz, AC) for 1 s when using a water bath in which the head of the broiler is immersed in the water, as one electrode, with a steel electrode penetrating or at the cloaca, as the other electrode. Immediately after stunning, heart fibrillation was induced, which lasted until all heart activity stopped, after approximately 5 min.

Energy dosing can be improved when an alternating pulsed square wave current is used when the broilers are stunned with a current of approximately 33 mA (peak of 60 V, 600 Hz, and a 50% duty cycle) for 1 s. The broilers should be bled directly after stunning so that they remain unconscious.

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