

Chapter 8

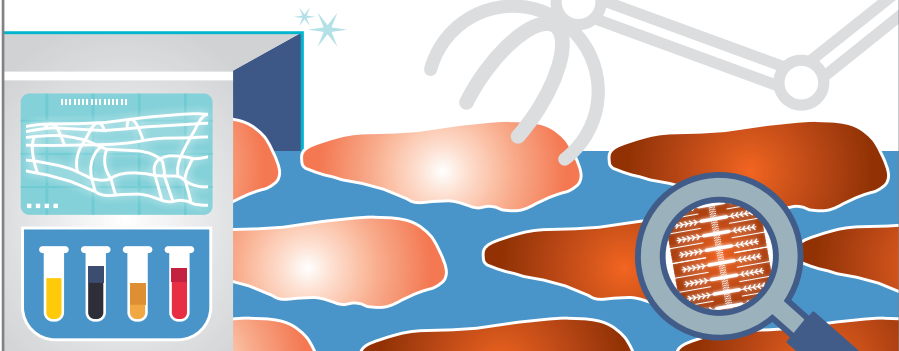
STUNNING



The Science of Poultry and Meat Processing

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Chapters

1. AUTOMATION
2. GLOBAL PERSPECTIVE
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5. PRIMARY PROCESSING OF POULTRY*
6. HACCP IN PRIMARY PROCESSING*
7. INSPECTION AND GRADING*
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* Topics focussing on poultry. Rest of the chapters are related to both red meat and poultry.

Preface

The aim of The Science of Poultry and Meat Processing book is to provide students and industry personnel with a comprehensive view of the modernized primary poultry meat industry and further processing of both red meat and poultry. An emphasis is placed on basic concepts as well as recent advancements such as automation (e.g. increasing poultry line speed from 3,000 to 13,000 birds per hour over the last 40 years) and food safety (e.g. HACCP in primary and the further processing areas). The book also includes chapters explaining basic muscle biology, protein gelation, heat and mass transfer, microbiology, as well as meat colour and texture to help the reader understand the underlying scientific concepts of meat processing. The Science of Poultry and Meat Processing book is based on over two decades of university teaching experiences, and is designed to be used as a course textbook by students, as well as a resource for professionals working in the food industry. The book is available online, at no cost, to any interested learner. Using this format has also allowed me to include many colour pictures, illustrations and graphs to help the reader.

The book is dedicated to my past and current students who have inspired me to learn more and conduct challenging research projects. I see this as an opportunity to give back to the field that I have received so much from as a student and as a faculty member. Looking back, I have learned a great deal from my MSc and PhD advisor, Dr. A. Maurer, who was the student of Dr. R. Baker - the father of poultry processing in North America. I would also like to thank Dr. H. Swatland with whom I worked for almost 20 years, for the many challenging scientific discussions.

Writing The Science of Poultry and Meat Processing book was a long process, which also included having all chapters peer reviewed. I appreciate the help of my colleagues, but I still take responsibility for any inaccuracy in the book. If you have comments or **suggestions**, I would appreciate hearing from you (sbarbut@uoguelph.ca), as I am planning to revise and update a few chapters on a yearly basis.

I would like to thank the many people who have helped me during the writing process. To Deb Drake who entered all of the material for the book, to Mary Anne Smith who assisted in editing, and to ArtWorks Media for the design and desktop publishing of the book. I greatly appreciate the help of my colleagues who reviewed chapters and provided useful discussions. They include Mark B., Ori B., Sarge B., Gregoy B., Joseph C., Mike D., Hans G., Theo H., Melvin H., Myra H., Walter K., Roland K., Anneke L., Massimo M., Johan M., Erik P., Robert R., Uwe T., Rachel T., Jos V., Keith W., and Richard Z. I would also like to thank my family for their love and support during the entire process.

About the Author

Shai Barbut is a professor in the Department of Food Science at the University of Guelph in Ontario, Canada. He received his MSc and PhD at the University of Wisconsin in meat science and food science. He specializes in primary and further processing of poultry and red meat. His research focuses on factors affecting the quality of meat, as well as protein gelation with an emphasis on structure / function relationships, rheological properties and food safety aspects. He has published over two hundred peer reviewed research papers and is the author of the Poultry Products Processing – An Industry Guide textbook. He is a fellow of the Institute of Food Technologists and has received awards from the Meat Science Association, Poultry Science Association, and the Canadian Institute of Food Science and Technology. He is involved in a number of government committees as well as academic and industrial research projects.

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Library and Archives Canada Cataloguing in Publication

Barbut, Shai, author

The science of poultry and meat processing / Shai Barbut, PhD.

Includes bibliographical references and index.

Issued in print and electronic formats.

ISBN 978-0-88955-625-6 (bound).

ISBN 978-0-88955-626-3 (pdf).

1. Poultry--Processing. 2. Meat industry and trade. I. Title.

TS1968.B37 2016 664'.93

C2015-903906-1 C2015-903907-X

STUNNING

8.1 Introduction

Stunning meat producing animals prior to slaughter achieves fast immobilization, onset of insensibility or unconsciousness (i.e., for animal welfare reasons) and allows easier and safer handling (i.e., immobilizing large animals by mechanical, electrical or gas stunning). Overall, welfare considerations are becoming more important and today various agencies evaluate/monitor compliance with animal welfare standards. In Europe, for example, the new suggested stunning regulations that specify detailed conditions and settings (EU, 2009) came into effect in 2013. A notable change from the previous regulations is the requirement that a certain level of current should be applied to each individual bird when electrical stunning is applied. In the past, EU regulations indicated conditions for a group of birds going through a water bath stunner (to be further discussed below). In other regions conditions for poultry stunning are not always specifically legislated (e.g., in the USA, poultry is not covered under the Humane Methods of Slaughter Act, 1978). Nevertheless, all plants use stunning (electrical, gas, or mechanical) with help from national guidelines/regulations.

Stunning and immobilizing poultry also assists in operating an efficient automated line. Initially, electrical stunning for poultry was introduced to immobilize the animals to allow application of bleeding through a high speed automated process. Later, gas stunning was introduced (Fletcher, 1999) and today both methods are widely used around the world. Stunning is usually not employed during traditional religious-based ritual slaughters such as Halal and Kosher (Regenstein et al., 2003; Velarde et al., 2014). For these methods, an exemption is given by the appropriate government agency and it is explained that the fast slaughter method and sharp equipment used prevents animal suffering (see discussion on no stunning later in the chapter). It is interesting to note that a number of regulations found in places where stunning is performed are actually based on Old Testament laws that discuss treating animals in a humane way, preventing suffering, and indicating that animals acceptable for food must be killed and not allowed to die due to natural causes, disease, or accident.

There is no single, universal, animal welfare code and this presents a challenge for processors in meeting different animal welfare codes and developing equipment. This is true not only among regulatory agencies that have different requirements for stunning levels, but also between national and some religious groups. It should be mentioned that the World Organization for Animal Health does have a guideline for animal slaughter (OIE, 2014), but it is not recognized in all places. Overall, the two most common methods used for stunning poultry are electrical and gas stunning. As indicated above, electrical stunning was introduced first and is still used in over half of the birds processed around the world. Controlled gas stunning (CAS) has become more popular in Europe and it is now estimated to account for over half of the birds processed there. The higher use of CAS in Europe is actually the result of the different stunning requirements. As will be described in the chapter, the EU requires a higher degree of stun compared to other regions. This requires a higher voltage and lower frequency, and can result in damaged meat quality (i.e., more muscle contractions and possibly more haemorrhages; see Table 8.1.1). Certain gas stunning treatments can overcome this problem while still yielding a high degree of stunning and have thus become more popular in Europe.

Table 8.1.1 Examples of average haemorrhage scores in breast and thigh meat related to different stunning methods (n = 144). Adapted from Schreurs et al. (1999). Note: averages also depend on exact conditions used, e.g., lower electrical current or higher frequency can lower the values.

Stunning method ¹	Average haemorrhage score ²		pH-time postmortem			R value-time postmortem		
	Thigh meat	Breast meat	1h	2h	4h	1h	2h	4h
Whole body (electrical)	3.15 ± 1.17 ^a	3.56 ± 1.17 ^a	6.47 ^a	6.21 ^a	6.05 ^a	0.87 ^c	0.94 ^c	1.20 ^b
Head only (electrical)	2.42 ± 0.94 ^b	3.07 ± 1.23 ^b	6.01 ^c	6.00 ^b	5.98 ^b	1.14 ^a	1.27 ^a	1.35 ^a
Argon (gas)	2.08 ± 0.96 ^c	1.75 ± 0.89 ^d	6.11 ^{bc}	6.04 ^b	6.00 ^{ab}	0.94 ^b	1.09 ^b	1.29 ^a
CO₂ (gas)	2.07 ± 0.92 ^c	1.66 ± 0.93 ^d	6.30 ^{ab}	6.21 ^a	6.02 ^{ab}	0.88 ^{bc}	0.93 ^c	1.17 ^b
Captive bolt (mechanical)	2.04 ± 0.90 ^c	1.96 ± 0.93 ^c	6.29 ^{ab}	6.23 ^a	5.97 ^b	0.94 ^b	0.99 ^c	1.29 ^a

¹ Whole body - 100 V, 120 mA and 50 Hz for 10 sec. Head only - 120 mA, 300 Hz for 1 sec. Argon - 70% Argon + 30% CO₂. CO₂ - anesthetic mixture of 40% CO₂ + 30% O₂ + 30% N₂ followed by an anoxia mixture of 80% CO₂ + 20% N₂. Captive bolt - mechanical.

² Means and standard deviations, within each column, followed by a different superscript are significantly different (P < 0.05).

It is also important to note that within each of the stunning methods, variations can be seen within the same country and even between two adjacent processing plants.

This chapter mainly focuses on stunning poultry but the principles that apply to other meat producing animals are basically the same. In other species a certain method might be more prevalent (e.g., beef – captive bolt; pigs – electrical and gas stunning; fish – electrical stunning) where conditions (voltage, frequency, gas type, and concentration) and time can vary (see reviews by Gregory, 2008; Grandin, 2014).

8.2 Electrical Stunning

8.2.1 General

Electrical stunning is currently the most commonly used method to immobilize poultry prior to slaughter. The systems developed for poultry were primarily designed to immobilize the animals or render them unconscious long enough to allow manual or automated neck cutting. The equipment is relatively inexpensive, has a small footprint in the plant, is compatible with current line speeds, and is easy to maintain (Bilgili, 1999). However, proper adjustment of currents has sometimes been reported to be a problem at the plant level (Raj, 2003). Different electrical stunner models exist on the market and include high and low voltage, high and low frequency, and stunners that use alternating current (AC), direct current (DC), or DC followed by AC (examples provided below). Usually, a fiberglass water bath (or any other non-conductive, salt resistant material) is fitted under the overhead shackle line. The birds, suspended from the line, are moved into the shallow bath filled with water or a brine solution (1% salt is recommended). The height of the bath can be adjusted in order to ensure that the heads of the birds are fully immersed. Stunning is accomplished by passing a sufficient amount of electrical current through the body of the animal for a specified amount of time. The current may paralyze the birds or render them unconscious, depending on the characteristics of the current applied. The state of unconsciousness results from the inhibition of impulses from both the reticular activating and the somatosensory systems (electroencephalogram data is presented below). The stunning current that reaches the brain must be sufficient to induce an epileptic seizure. The state of unconsciousness that results from electrical stunning is believed to be due to neural disruption of nuclei, and structures within the brain (e.g., intra laminar nuclei in the thalamus) that are needed to maintain a waking state (Butler and Cotterill, 2006). As indicated in the introduction, there are differences in the currents used around the world. The current used in the USA is usually lower than that required for

ventricular fibrillation and an irreversible stun. Therefore, an adequate level of current should be used (adjusted for bird size and number of birds in the water bath) and be followed by rapid bleeding so birds will not regain consciousness (Bilgili, 1999; Joseph et al., 2013). Insufficient current may physically immobilize the bird, but may not prevent perception of pain and stress. In order to apply the current, an electrical metal grate is submerged at the bottom of the brine bath and spans its entire length. In a dry plate application (usually after the birds have been initially stunned) there is no water in the lower part and the birds touch a bottom metal plate. The shackle line is connected to earth, where a ground bar connects the line to complete the electrical circuit. The birds pass through the stunner in a continuous procession (e.g., 180 birds per min in a fast processing line) and the current flows through the bird's body. In this way, the birds on the shackle line represent a series of resistors connected in parallel. The amount of current that flows through each bird depends upon the voltage applied, the electrical impedance of the bird, and the number of birds. It has been shown that the resistance of broiler chickens ranges between 1,000 to 2,600 Ω (Woolley et al., 1986). As birds enter and leave the stunner, they constantly change the total resistance of the system. At a given constant voltage (as is the case for many commercial stunners), the birds receive a current proportional to their own resistance.

The effectiveness of the stunner depends not only on the electrical variables, but also on factors that determine the bird's impedance such as contact of the leg with the shackle, weight, body composition, sex, and feather cover. Therefore, one of the main goals of research and development in this area is focused on defining and standardizing the variables used in the process.

8.2.2 Settings

As indicated above, different regions can have different requirements for stunning. The EU regulations require a deeper stun than the North American requirements. To meet these regulations EU stunners have to operate at a higher voltage (e.g., 50-60 V) to assure minimum currents of 100 to 400 mA per bird, depending on the type of bird (chickens, turkey, ducks, geese or quails) and frequency applied (see Table 8.2.2.1), than stunners in North America that operate at lower voltage (10 – 25 V) and higher frequency (> 400 Hz) resulting in a lower current that passes through the bird (e.g., 25 – 50 mA).

Table 8.2.2.1 Influence of stunning current (50 Hz sine wave AC) on percentage of broiler carcasses showing meat quality defects (n = 1,300; laboratory study). Adapted from Gregory and Wilkins (1989a).

Appearance	Stunning current (mA; average)						
	45	85	121	141	161	181	220
Red wingtips	7	8	15	16	8	9	9
Haemorrhagic wing veins	4	7	11	16	12	8	9
Haemorrhagic shoulder	12	-	22	23	14	18	13
Haemorrhage in deep breast muscle	15	10	17	25	23	28	19
Haemorrhage in superficial breast	8	3	5	8	5	8	5
Haemorrhage in deep leg muscle	5	5	4	3	5	4	6
Haemorrhage superficial leg	12	5	13	14	14	19	13
Birds with ventricular fibrillation	21	80	87	99	99	100	100

The various electrical stunners that are used can also employ different types of waveform (Fig. 8.2.2.1). There are not many scientific papers reporting the conditions used in the field. However, examples from data collected in three different regions in 1987, 1994, and 2014 will be discussed below.

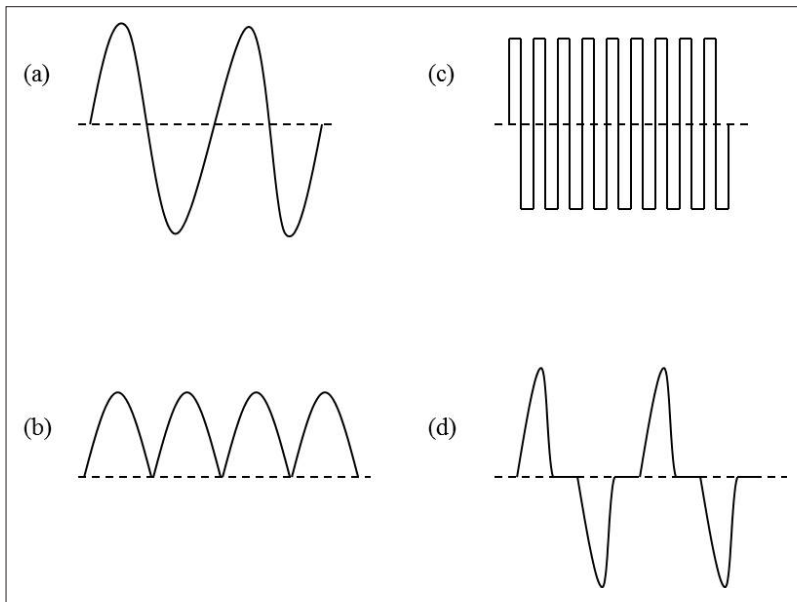


Figure 8.2.2.1 The main types of electrical waveform used in water bath stunners. Based on a survey by Gregory and Wotton (1987) in the UK. See text for details.

The first was a survey done in the UK (Gregory and Wotton, 1987), where 7 of 13 water bath stunners applied a 50 Hz sinusoidal AC (Fig. 8.2.2.1.a). One stunner used a full-wave rectification of the main supply at 100 Hz (see “b”). Square waves, which vary depending on frequency and whether they have a spiked leading edge (usually 280 or 550 Hz), were also used (see “c”). Another stunner used fractional sine waves (see “d”) produced by varying the voltage of the AC current through the introduction of a thyristor into the circuit of the sinusoidal AC at 50 Hz. It was also reported that one stunner was wired up incorrectly, such that the water in the stunning bath was at error potential and the rubbing bar was live (stunner not included in study). This points out the importance of proper installation, maintenance, monitoring, and adjustment of the stunner. In most plants studied, electrical adjustments to the stunner were possible and were done to accommodate different bird sizes, but sometimes the equipment was too old or the operator was not qualified/trained to adjust the current. This can result in under-stunning in which stunning duration is not long enough to allow birds to become unconscious as a result of the blood loss. On the other hand, it could result in over-stunning in which a high percentage of haemorrhages and broken bones could occur (Joseph et al., 2013). Gregory and Wotton (1987) concluded that the diversity of frequencies and waveforms employed made it difficult to recommend a standard current for either stunning or inducing a cardiac arrest (i.e., death by electrocution). This conclusion is especially pertinent when a group of countries, such as the EU, tries to establish a standard recommendation. Later, the revised EU regulation (EU, 2009) presented a change in the requirements where a specified current (mA) has to be delivered to each individual bird (Table 8.2.2.2). Prior to that, the regulations referred to a group of birds, and because of potential variations in body size, fat level, etc., the current received per bird varied. Gregory and Wotton (1987) indicated that when they used a 50 Hz sinusoidal AC current, a level of 148 mA per bird was required to induce cardiac arrest in 99% of the broilers. The minimum recommended current of 100 mA is based on the fact that this amount, when delivered using 50 to 350 Hz, will result in sustained loss of evoked somatosensory responses in the chicken’s brain. Incidentally, when delivered using a low frequency current, it also induces cardiac arrest in about 90% of chickens.

Table 8.2.2.2 Electrical requirements for water bath stunning equipment (average values per animal). EU (2009).

Frequency (Hz)	Chickens	Turkeys	Ducks and geese	Quails
< 200 Hz	100 mA	250 mA	130 mA	45 mA
From 200 to 400 Hz	150 mA	400 mA	Not permitted	Not permitted
From 400 to 1 500 Hz	200 mA	400 mA	Not permitted	Not permitted

The second survey (Heath et al., 1994) revealed that low voltage stunners were most popular in 329 US poultry plants that used electrical stunners. Overall, 92% used electrical stunners as a method of pre-slaughter immobilization. The remaining 8% were subject to religious slaughter procedures. Low voltage (10 to 25 V) and high frequency (500 Hz) stunners were used in 77% of the plants that used an electrical stunner. The remaining plants reported variation in stunning conditions ranging from 7.5 to 600 V, with no specified wave form (AC or DC) reported, and currents ranging from 0.3 to 10 mA. The authors concluded that although there were variations in methods of stunning and slaughter, the majority of plants were in voluntary compliance with the humane slaughter provisions, and the birds were stunned sufficiently to remain unconscious through exsanguinations.

The third survey consisted of small scale industry questionnaire, done by this author, which inquired about stunning settings used in the USA. It was found that the three most common conditions are:

- a. 33 to 38 V at 500 to 600 Hz, delivering 25 to 35 mA per bird
- b. 25 to 30 V at 350 Hz, delivering 40 mA per bird
- c. First stage, 12 V DC, followed by 14.5 V delivering about 13 mA per bird (this included 9 sec in a water bath, followed by 3 sec dry plate configuration).

Overall, the North American low voltage systems are different from the high voltage and current systems utilized in Europe. It should also be mentioned that the EU also specifies that electrical stunning must be immediate (< 1 sec current application to result in unconsciousness) and induce heart failure such that broilers could not regain consciousness. This is designed to be an irreversible stun that ensures animal welfare, but does not necessarily avoid carcass defects. Application of high voltages has been associated with possible red wing tips, damaged viscera, bruised wing joints, breast meat haemorrhages, split wishbones, and separation of shoulder muscle tendons (Bilgili, 1999). Under commercial conditions, it is sometimes difficult to isolate the effect of electrical stunning from other causes of injury such as catching, hanging, wing flipping, bleeding deficiency and feather picking (Kranen et al., 2000). Although there is no precise relationship between stunning current and carcass quality, haemorrhages in the deep breast muscle have been shown by some researchers to increase with high stunning currents (Table 8.2.2.1). The data presented show that the percentage of downgrading tended to increase when currents of 121-161 mA per broiler are applied. High stunning voltages have also been linked to increased incidences of red wing tips and broken bones, whereas high stunning frequencies have been shown to reduce the severity of thigh and breast haemorrhages and result in fewer bruised/broken bones. Overall, the causes of muscle haemorrhages in broilers are multi-

factorial and involve factors related to production, loading and unloading, hanging the birds upside down, as well as stunning. Stunning baths present a challenge because a number of birds are connected to the circuitry at the same time, forming a parallel electrical system in which the current experienced by each bird cannot be controlled as a result of variation in electrical resistance among the birds. Also, it is usually unknown how much current is actually flowing through the brain of an individual bird.

Over the years attempts have been made to design a head only electrical stunner for high speed poultry processing lines (Lambooij et al., 2010). However, implementation of such a system in a commercial slaughter line has been limited. In a high speed commercial line it is difficult, if not impossible, to isolate each bird (suspended on shackles approximately 15 cm apart) long enough to determine its resistance and deliver the precise current required. Further development of the system was recommended.

It is important to note that the stunning, neck cutting, and bleeding operations are interrelated. The evolution of electrical stunners has been, for the most part, influenced by different operations/procedures within the slaughter line (e.g., bleed time, scald time, automation of the evisceration process). Usually, the line speed is dictated by the speed of the evisceration line(s). In the US, each kill line typically supplies carcasses for two evisceration lines whereas in Europe it is common that each evisceration line is served by a separate kill line (Bilgili, 1999).

8.2.3 Study Effects on Consciousness and Fibrillation

Several methods are used by scientists/industry people to determine unconsciousness including observation of corneal reflex response, eye blinking, limb movement, and spontaneous breathing. However, EEG analysis is considered the most scientific method (Coenen et al., 2009) and scientific investigation of the effects of stunning on brain function in various animals (broilers, turkeys, pig, sheep) has resulted in its increased use to precisely determine (loss of) consciousness. Therefore, EEG data is also currently used to propose stunning conditions. (e.g., electricity, gas mixtures) as will be discussed below. In general, brain electroplectic activities have three main phases (Fig. 8.2.3.1). The first is the normal alert baseline and the second is seen during stunning and is the epileptiform phase that consists of hyper-synchronous activity that resembles a Grand mal seizure. The third phase is an electrically quiet or “isoelectric” period. It has been suggested that the two latter phases represent the period of unconsciousness following electrical stunning. Gregory and Wotton (1987) studied the effects of different electrical stun settings on the EEG of broilers using a conventional 50 Hz sigmoidal alternating current.

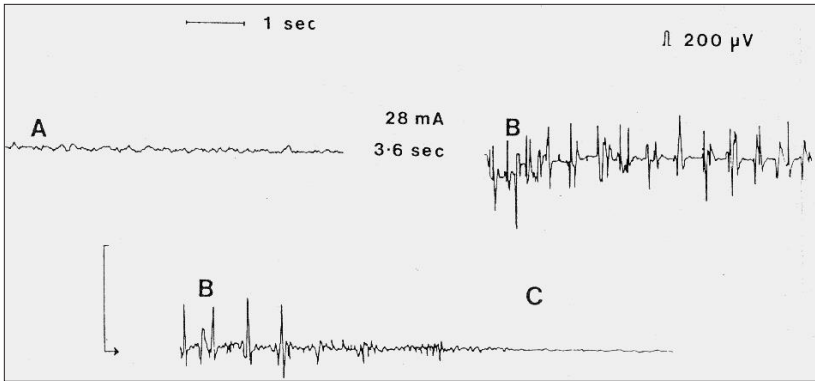


Figure 8.2.3.1 Electroencephalogram of a chicken that developed low frequency polyspike activity after electrical stunning. A is a sample of the period before stunning; B is the epileptiform phase; C is the quiescent phase. From Gregory and Wotton (1987). With permission.

They reported three types of EEG waveforms following stunning when using 20 to 143 mA per bird. The first waveform was low frequency and poly-spiked epileptiform activity (< 5 Hz) followed by a quiescent phase (Fig. 8.2.3.1) The poly-spiked activity was taken to be the typical response to a water bath stunning, which was observed in 16 of the 18 stunned broilers. The remaining two broilers showed high frequency epileptiform activity at approximately 6 Hz (Fig. 8.2.3.2).

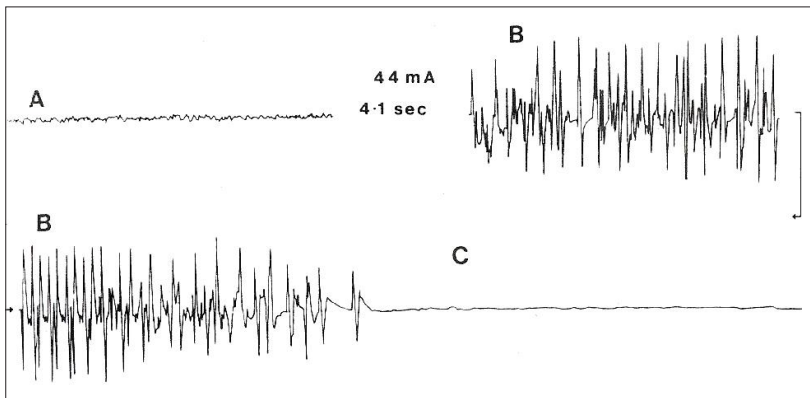


Figure 8.2.3.2 Electroencephalogram of a chicken that developed high frequency polyspike activity after electrical stunning. A is a sample of the period before stunning; B is the epileptiform phase; C is the quiescent phase. From Gregory and Wotton (1987). With permission.

The poly-spike ended abruptly and occurred, on average, 17 sec (between 8-36 sec) after the start of stunning. The poly-spiked activity was followed by a quiescent phase. The authors indicated that it was not possible to quantify the duration of this phase because the broilers were bled before normal EEG activity returned. The low frequency poly-spike activity, seen in the graph, was interpreted by the authors as a Petit mal epilepsy seizure. The authors mentioned that in red meat animals (sheep, pig), the hypersynchronization of EEG activity leads to high activity, in the range of 8 to 13 Hz, or a Grand mal epilepsy seizure followed by a flat isoelectric phase that indicates unconsciousness.

Figure 8.2.3.3 shows the waveform pattern in broilers that were stunned at higher currents (> 100 mA). Broilers that fibrillated showed poly-spiked brain activity that was suppressed to the extent that the EEG did not always show an epileptiform phase. Gregory and Wotton (1987) also determined the current necessary to cause a cardiac arrest when broilers were subjected to electrical stunning with sinusoidal AC at 50 Hz. This was done because it was suggested that electrical stunning (in a water bath), under certain conditions, can induce unconsciousness and fibrillate the heart simultaneously. This, in turn, has a potential animal welfare advantage over conventional stunning, which does not cause fibrillation, as fibrillation can result in a quicker kill, and it does not depend on the bleeding step. The authors studied voltages between 50 and 270 V to achieve a range of currents applied through the birds (at least 25 birds in each of the 30 mA increments). They also recorded heart activity (via electrocardiogram, ECG) immediately after stunning to determine whether there was a ventricular fibrillation. On average, the current received by broilers that fibrillated was twice that of non-fibrillated birds. As indicated above, the current required to produce fibrillation in 99% of the birds was 148 mA (95% confidence interval = 132 to 164 mA). The bird's live weight did not significantly affect the incidence of cardiac arrest. At currents of 30 to 60 mA, less than 5% of the broilers underwent fibrillation. As mentioned above, in the broilers that fibrillated, poly-spiked brain activity was suppressed to the extent that the EEG did not always show an epileptiform phase (Fig. 8.2.3.3). Such attenuated brain activity occurred in broilers that received a level of current > 100 mA. Similarly, poly-spiked activities were markedly reduced in broilers subjected to head only stunning when the current was > 100 mA. Overall, using high currents in water bath stunning was found to have two effects. First, there was attenuation of epileptiform expression. Second, there was an increased likelihood of inducing cardiac arrest. The inhibition of epileptiform activity was probably not due to the induction of cardiac arrest, since a similar effect occurred when broilers were stunned with comparable currents across the head and, thereby, did not experience cardiac arrest at all.

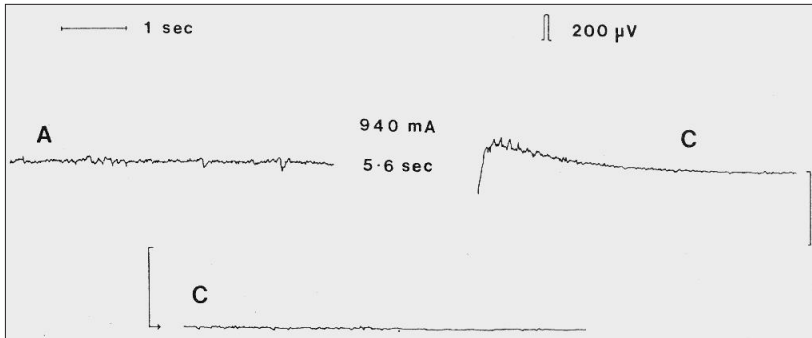


Figure 8.2.3.3 Electroencephalogram of a chicken that did not develop polyspike activity after electrical stunning. A is a sample of the period before stunning; B is the epileptiform phase; C is the quiescent phase. From Gregory and Wotton (1987). With permission.

Lambooij et al. (2010) used EEG to evaluate the electrical stunner for the head only, using pin electrodes, and reported that a general epileptiform insult was observed when a set current of at least 190 mA (approximately 100 V, 50 Hz) was applied for 0.5, 3, or 5 sec. This insult showed a tonic phase, followed by a clonic phase and an exhaustion phase, after which the birds recovered. On the basis of visual observation, these birds may have been unconscious for approximately 30, 44, or 65 sec, respectively. According to correlation dimension analysis scores (note: for more information on this scoring system see Coenen et al., 2007), these durations were 18, 12, and 16 sec, respectively. Within a confidence limit of 95%, taking into account the number of birds with a reliable EEG, the chance of an effective stun lies between 0.95 and 1.00 with an average current of 190 ± 30 mA. After stunning, the ECG revealed fibrillation and the heart rate decreased significantly ($P < 0.05$) but recovered thereafter. It was concluded that broilers were insensible and unconscious after head-only electrical stunning using pin-electrodes. Because broilers can rapidly regain consciousness, cutting the neck immediately after stunning is recommended (Lambooij et al., 2010; Raj, 2003). Prinz et al. (2010) also used EEG and showed that more than 80% of broilers stunned with 120 to 150 mA at 200 Hz or stunned with 100 mA at 70 to 100 Hz did not recover, showing that amperage and frequency interact with respect to stunning efficiency. Generally higher currents are needed with increasing frequency.

8.3. Gas Stunning

8.3.1 General

In the past, gas stunning was mainly used for large red meat animals (e.g., pigs). Although gas stunning of poultry was initially investigated in the 1950s (Kotula et al., 1957), it only started to appear in commercial plants in Europe in the 1990s. Interest in gas stunning for poultry was triggered by concerns that high voltage electrical stunning could result in defects (i.e., also related to the increased demand for cut up poultry meat where defects can be more visible) and challenges related to the use of automation. Schreurs et al. (1999) presented data that compared the incidence of haemorrhages in breast and thigh meat resulting from different stunning methods (Table 8.1.1). According to their data, CAS (two stages, CO₂ or Ar gas) resulted in lower incidences compared to high current electrical stunning (whole body at 100 V, 120 mA, and 50 Hz for 10 sec, or head only at 120 mA, 300 Hz, for 1 sec). Later, more studies and industry data were published that investigated the effects of different gas mixtures (Raj et al., 1998; McKeegan et al., 2007). The goal of those studies was to establish conditions that addressed welfare criteria while reducing meat defects.

As mentioned above, automation was another driver to develop CAS. Gas stunning does not require manual unloading and placing conscious birds on the shackle line. Therefore, it can improve working conditions and reduce injuries associated with removing live birds from their crates. Figure 8.3.1.1 shows a CAS system that employs an automated unloading system (i.e., tilting onto a moving conveyor belt). In this system, bruising is minimal because birds are not manually removed. Currently, there are a number of large scale stunning systems like this installed in Europe and other parts of the world. Other approaches include leaving the birds in their crates and sealing the truck in such a way that CO₂ or other gases can be introduced, or moving the crates off the truck and introducing gas by moving them through a tunnel or lowering them into a pit (CO₂ is heavier than air). This approach reduces stress associated with uncarting and shackling live birds prior to stunning and can be an important consideration as these steps can induce a significant stress response. This also points out the need for more comprehensive studies that evaluate stress levels associated with the whole process (i.e., unloading, shackling and stunning). Most studies today only focus on the stunning phase.

Low atmospheric pressure stunning (LAPS) is done by using a vacuum pump to remove oxygen and induce anoxia. Joseph et al. (2013) stated that although minimal research has been performed on LAPS, Purswell et al. (2007) reported

that it appeared to be an effective method for broilers. Currently, the system is not widely used but it has been tried in some plants in the USA. Purswell et al. (2007) reported arterial blood partial oxygen pressure decreased from 80 to 23 mm Hg when measured right after birds were removed from the system. As mentioned above, the question of when convulsions occur (before or after unconsciousness has been induced) and to what extent is also an important question for the LAPS process.

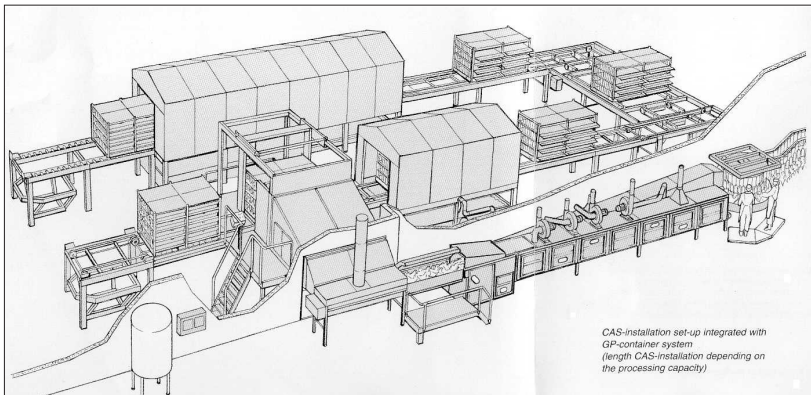


Figure 8.3.1.1 A gas stunning system. Middle – modules with birds arrive on a conveyer belt and then are gently tilted so birds are moved to the row close to the reader where the CAS tunnel is located. The far row is used for washing the modules. Courtesy of Stork Inc.

8.3.2 Settings

Over the past two decades studies dealing with different gas mixtures and low pressures (vacuum) have been published. The gases/gas mixtures mainly included carbon dioxide (CO_2), argon (Ar), nitrogen (N_2), and oxygen (O_2). In these cases, loss of consciousness (reversible or irreversible) can be due to hypoxia (lack of O_2), hypercapnic hypoxia (excess CO_2), hypercapnic anoxia (combination of the first two), hypercapnic hyperoxygenation (elevated O_2 level to $\sim 30\%$ together with enriched CO_2) or by low atmospheric pressure/depressurization (Hoen and Lankhaar, 1999; McKeegan et al., 2007; Coenen et al., 2009; Joseph et al., 2013). McKeegan et al. (2007) mentioned that although gas stunning can reduce some of the welfare problems associated with electrical stunning, it is important that the birds do not find the anaesthesia aversive and that the stunning will introduce minimal stress and pain to the bird. Raj (2003) also indicated a potential problem with reversible stun settings in that birds can regain consciousness shortly after

exiting the controlled gaseous atmosphere. Differences in the initial effects of various gases are known and, therefore, the gas/gas mixture should be introduced in the right concentrations and for the required times. Ar, for example, is an inert gas that can induce anoxia at a high concentration (e.g., > 90%, less than 2% O₂). CO₂, on the other hand, is an acidic gas that can be pungent to inhale at concentrations above 40% for both broilers and turkeys. The gas is also a potent respiratory stimulant that can cause breathlessness before loss of consciousness. From a welfare standpoint, this means that birds could experience an unpleasant sensation during the inhalation of a high concentration of this gas. For example, it was reported that three out of eight hens and six out of 12 turkeys showed an aversion to entering a chamber to obtain food plus water when it contained 72% and 47% atmospheric CO₂, respectively (Raj, 2003). Conversely, when Ar with less than 2% O₂ was used, six out of six hens and 11 out of 12 turkeys spontaneously entered the chamber. Finally, when the chamber contained 30% CO₂, 60% Ar, and 10% air, no aversion was seen in 80% of the turkeys entering the feeding chamber. Analysing the behaviour of broiler chickens exposed to an air stream with a certain gas mix while feeding, suggested mild or at most moderate immediate aversion to carbon dioxide in the form of reduced feeding and occurrence of headshakes (McKeegan et al., 2006). Enrichment with oxygen to 30% was associated with increased feeding time and reduced headshaking. In order to eliminate concern about high initial CO₂ concentrations, a mini system consisting of two-stages was used (Hoen and Lankhaar, 1999). In the first stage, an anaesthetic mixture of 40% CO₂, 30% O₂, 30% N₂ was used, while the second stage had a gas mixture consisting of 80% CO₂, 20% N₂ (i.e., to induce anoxia). Results from a similarly built system (Table 8.1.1) showed lower haemorrhage scores compared to high current electrical stunning. The results for the Ar treatment represent a system developed in Great Britain in which a mixture of 70% Ar and 30% CO₂ is used. Overall, the two gas stunning methods significantly lowered haemorrhage scores in thigh and breast meat as compared to the two electrical stunning methods tested in that study. Captive bolt stunning, also included in the comparison, caused lower haemorrhage scores compared to electrical stunning; however, it is not commonly used in large operations because of technical limitations that will be discussed later.

In a CAS system where broilers and turkeys are kept in cages, the cages can stay on the truck or be placed on a conveyor belt that either carries them to the stunning tunnel or lowers them into a pit where Ar or CO₂ are used. The conveyor speed is adjusted to achieve the required dwell time. The tunnel/pit is equipped with various safety devices to protect employees working in the area and CO₂ and Ar detectors are installed in the room to verify that employees are not exposed to dangerous levels.

After stunning, the unconscious birds are transferred to a moving shackle line, which is easier to operate and causes less downgrading than removing and transferring live birds. If birds are stunned in cages it is crucial that birds dead on arrival (DOA) are removed prior to stunning and do not enter the food chain as this is prohibited by regulatory agencies around the world. In such a system, plants must demonstrate that they can deal with DOAs. Figure 8.3.1.1 shows a system where the birds are placed on a moving conveyer belt that passes by an employee who watches the birds and their postures. This is more complicated with cages but must be done to ensure food safety. Another point that requires attention is the time from stunning to bleeding. If the time between the two is too long (e.g. when a full truck load is stunned at once), poor bleeding can result. Moreover, feather removal could become more difficult, as well as bearing the risk of dislocated wing joints (e.g., muscles get into rigor state).

Several reports have indicated differences in the rate of post mortem pH decline between electrical and gas stunning. Some researchers have shown that electrical stunning can temporarily delay rigor development (see also data in Table 8.1.1). Papinaho and Fletcher (1995) reported that a stunning current between 0 and 200 mA affected the rate of early rigor development, but had no effect on final meat quality. They reported higher breast meat pH for electrically versus gas stunned broilers and mentioned that electrical stunning is known for its inhibition of glycolysis (up to 6 hr) in broilers. Gas stunning methods that are associated with massive convulsive wing flapping, have been found to produce a more rapid post mortem pH drop in broiler and turkey breast meat (Raj, 2003), but after 8 hrs the pH of all samples reached about the same level (6.0). The results for breast meat glycogen content showed the same trend of slower glycolysis early in the post mortem period in electrically stunned birds. Water holding capacity (WHC) averages over time (note: averages were taken since no significant interactions between stunning method and time were found) showed that head only electrical stunning resulted in the highest water loss, while CO₂ stunning resulted in the lowest water loss from the post rigor meat. Similar trends can be seen in Table 8.1.1, where pH values after 4 hrs were similar for all treatments. Data at 8 hrs were very similar to the 4 hrs results (data for 8 hrs not presented here).

8.3.3 Study Effects on Consciousness

Stunning poultry with gas does not result in an instantaneous loss of consciousness and, therefore, it is important to ensure that the induction of unconsciousness is not stressful. Coenen et al. (2009) measured the effects of three gas mixtures with commercial applications:

- a. anoxia with N_2 and $< 2\%$ residual O_2 ,
- b. hypercapnic anoxia with N_2 , 30% CO_2 and $< 2\%$ residual O_2 ,
- c. a two phase stunning employing a hypercapnic hyperoxygenated anesthetic phase with 40% CO_2 , 30% O_2 , and 30% N_2 for 80 sec, followed by a euthanasia phase with 80% CO_2 in air.

The birds in the experiment were placed in a mini commercial unit (small version of a large scale commercial unit) consisting of two compartments (to allow two phase stunning). They entered the first compartment on a moving conveyor belt and spent an average 80 sec in that section. All broilers showed loss of posture in the first compartment. They were then introduced to the second compartment for 120 sec (note: a different gas mixture was only used for the third treatment, but all birds went through the two phases). Figure 8.3.3.1 shows the raw EEG and ECG recordings of all birds at baseline (45 sec) as well as during the first part of the euthanasia process (up to 105 sec). Artifacts, shown in the figure, started immediately after placing the birds in the system and were caused by physical movements of the birds (e.g., wing flaps, clonic convulsions, struggling), which were verified by comparing the EEG traces with behavioral recordings (detailed table provided in their original publication). Movement artifacts occurred over the entire duration of the first compartment, but their number and length strongly diminished with time. Movement artifacts were rare or absent in the second compartment. The data show that both the duration and total number of artifacts were lowest in the two phase group, where the gas mixture in the first compartment was hyperoxygenated.

Overall, the duration of artifacts was much longer than in the EEG traces, except in the two phase treatment. Statistics showed that the latter treatment differed significantly from the first two treatments in the extent of EEG artifacts. It was also apparent that ECG artifacts almost completely coincided with those seen in the EEG recordings (produced by obvious movements of the birds). However, ECG artifacts seen in birds receiving the anoxic treatments only partly coincided with the EEG artifacts. In general, the artifacts lasted much longer and were characterized by prolonged artifacts as opposed to several short disturbances. Behavioral observations indicated that these prolonged ECG artifacts coincided with convulsive activity (such as wing flapping) that was often followed by a distinctive posture in which the wings were held rigidly forward. This is thought to indicate tonic convulsion and, in particular, sustained contraction of the pectoralis muscle. Thus, the artifacts in the ECG recordings were composed of movement artifacts and artifacts caused by tonic convulsions. The results show that the two anoxia treatments (N_2 and $N_2 + CO_2$) induced considerable tonic convulsions, whereas this response was seen only once with the two phase approach. Moreover,

duration of wing flapping was observed to be much longer under anoxic conditions than at the two phase stunning. This also explains the rapid pH decline reported after anoxic gas stunning observed by other authors.

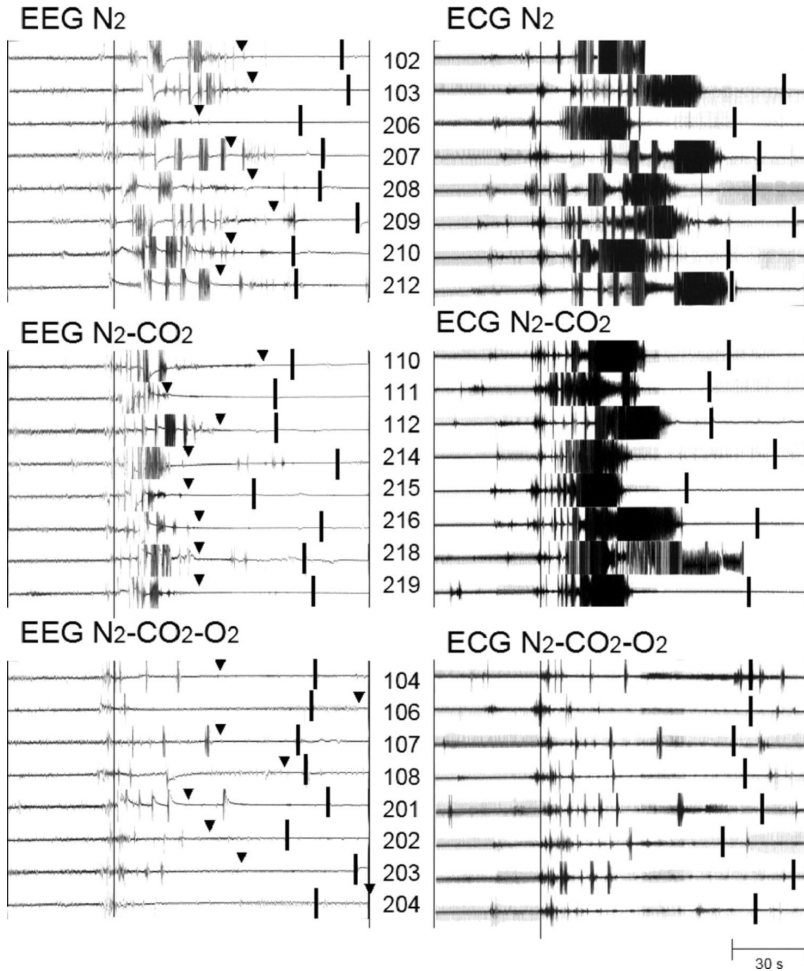


Figure 8.3.3.1 Electroencephalogram (EEG) recordings (left) and electrocardiogram (ECG) recordings (right) of chickens placed in the 3 treatment conditions (N_2 ; $N_2 + CO_2$; 2-phase with $N_2 - CO_2 - O_2$). The recordings were synchronized when birds entered the first compartment, as indicated by a continuous vertical line, representing approximately 45 s after the beginning of the recording (the baseline EEG and ECG). In the EEG recordings, the onset of isoelectricity is indicated by an arrow. The drop artifact (the transition between the first and second compartment) can be seen in variable positions in the right-central part of the recordings and is highlighted with a black vertical bar.

From Coenen et al. (2009). With permission.

Unconsciousness is defined as the point where the EEG shows an isoelectric pattern. The authors indicated that death is the point when birds show an isoelectric EEG pattern with non-reversible properties. They mentioned that this is always so when the heart rate is extremely low (in chickens less than 180 beats per min). Onset of isoelectricity for each bird is shown by arrows marked in Figure 8.3.31. Statistics indicated no significant differences between groups, although the $N_2 + CO_2$ group tended to have the shortest time to isoelectricity. Overall, all three treatments effectively achieved non-recovery states; time to loss of consciousness for each bird was determined by a visual determination of the isoelectric EEG and by calculating the correlation dimension of the EEG. Hypercapnic anoxia resulted in rapid unconsciousness and an irreversible stunning; both anoxic treatments were associated with early onset prolonged wing flapping and sustained tonic convulsions as displayed in the electrophysiological recordings. These responses were seen in the period when consciousness remained a possibility. The two phase approach was associated with respiratory disruption, but this treatment eliminated initial clonic convulsions in the stunning process, and tonic convulsions were not seen. These results suggest that the presence of O_2 in the first stage of CAS is associated with an absence of potentially distressing behavioral responses. In this and their previous study (McKeegan et al., 2007; see additional discussion below), the authors argued that respiratory discomfort, although unpleasant, may be preferred to the risks of vigorous wing flapping and its associated injuries while birds are conscious and struggling.

Raj et al. (1998) also studied the effect of three gas mixtures on time to onset of changes in spontaneous EEG and the loss of stomatal sensory evoked potential (SEP). They evaluated:

- a. argon (Ar) gas by itself
- b. a mixture of 60% Ar, 30% CO_2 in air
- c. a mixture of 40% CO_2 , 30% O_2 , and 30% N_2

In 10 of the 16 birds it was shown that exposure to 100% Ar resulted in high amplitude low frequency (HALF) electrical activity, in the EEG, that started about 10 sec after exposure (Fig. 8.3.3.2). The other six broilers did not show HALF activity, and instead showed a gradual suppression in the amplitude of EEG signals. The average time to onset of EEG suppression was 17 sec ($n = 16$). All broilers showed intermittent convulsion after the onset of HALF activity or suppressed EEG. During the convulsive episodes, the EEG showed either epileptiform activity (bipolar, high amplitude spikes; $n = 4$), high amplitude, low frequency activity ($n = 7$), polyspike activity (unipolar, high amplitude spikes; $n = 2$), or suppressed EEG ($n = 3$). An isoelectric EEG occurred, on average, 58 sec after exposure to the Ar gas.

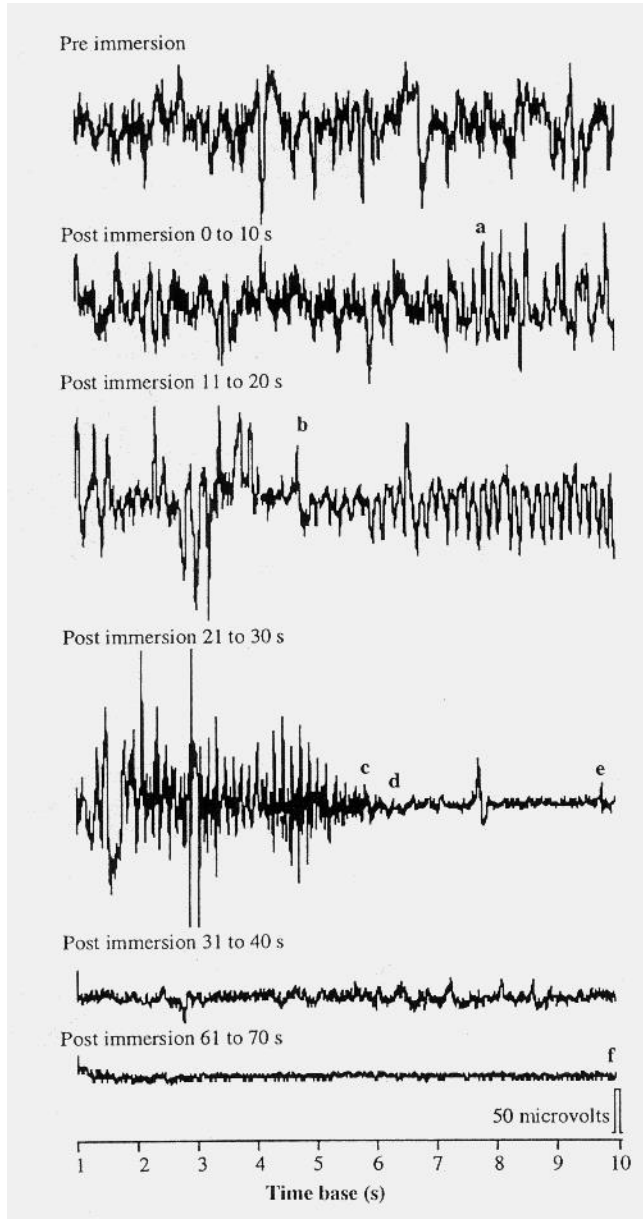


Figure 8.3.3.2 Changes in the spontaneous electroencephalogram (EEG) of a broiler during exposure to Argon with less than 2% oxygen (a = onset of HALF activity; b = onset of convulsions; c = end of convulsions; d = onset of EEG suppression; e = loss of SEP's; f = onset of isoelectric EEG).

From Raj et al. (1998). With permission.

For treatment (b), exposure to 30% CO₂ and 60% Ar in air, only one out of the 12 broilers showed HALF activity in the EEG (at 10 sec). However, all 12 broilers had suppressed EEGs (graph not shown here) and the average time to the onset of EEG suppression was 19 sec. All broilers showed intermittent convulsions after the onset of EEG suppression. During the convulsive episodes, the EEG showed either epileptiform activity (n = 6), polyspike activity (n = 4), or remained suppressed (n = 2). An isoelectric EEG occurred, on average, 41 sec after exposure to this gas mixture.

For treatment (c), exposure to 40% CO₂, 30% O₂ and 30% N₂ for 2 min, none of the 17 broilers showed HALF activity; instead, suppressed EEG with low frequency activity occurred on average 40 sec after exposure (Fig. 8.3.3.3). Only 3 out of the 17 broilers exposed to this mixture died (isoelectric EEG seen after 77, 83 and 93 sec), whereas in the other two gas mixtures, all birds died after 2 min. The 14 broilers that survived the 2 min exposure to the third gas mixture showed two types of electrical activity. The EEG remained suppressed in 8 out of the 14 broilers and in the other 6 broilers there were frequent bursts of unipolar, low frequency, high amplitude spikes that started occurring at random in the suppressed EEG as can be seen in Figure 8.3.3.3. In general, the amplitude of the spikes gradually increased during the initial stages of their development. Analysis of variance showed that the time to onset of EEG suppression was similar in the Ar by itself, and the CO₂ + Ar mixture (17 ± 1.9 sec and 19 ± 1.9 sec, respectively), and both were significantly shorter than the time to onset reported for the O₂ + CO₂ + N₂ mixture, which occurred 40 ± 2.3 sec after exposure. Based on the time to onset of EEG suppression, exposure of broilers to the first two gas mixtures resulted in a quicker loss of consciousness than during exposure to the last gas mixture, which has been suggested as an alternative for stunning broilers, followed by killing with a high concentration of CO₂.

The time to induce anaesthesia for each of the three gas mixtures was determined from the time required to lose stomatal sensory evoked potentials (SEP) in the brain. The mean time to lose SEP in broilers and turkeys exposed to Ar were 29 and 44 sec, respectively. For the Ar + CO₂ mixture times were reduced to 19 and 22 sec, respectively. The results indicate that the Ar + CO₂ mixture is more rapid than Ar alone in achieving a loss in brain function in both chickens and turkeys. However, the turkey brain appeared to be relatively more tolerant of anoxia than the chicken brain. Raj et al. (1998) indicated that the use of CO₂ for killing chickens does not seem to have a welfare advantage over using 90% Ar in air or 60% Ar + 30% CO₂ in air. For turkeys, times to lose SEP during exposure to 50, 65 or 85% CO₂ in air were reported to be 20, 15 and 21 sec, respectively. These times were not significantly different from the times measured when a mixture of Ar and CO₂ was used. The authors indicated that in commercial trials, turkeys

stunned and killed with Ar or an Ar + CO₂ mixture showed less breast muscle haemorrhaging and downgrading over turkeys stunned with 50 Hz sinusoidal AC electrical current.

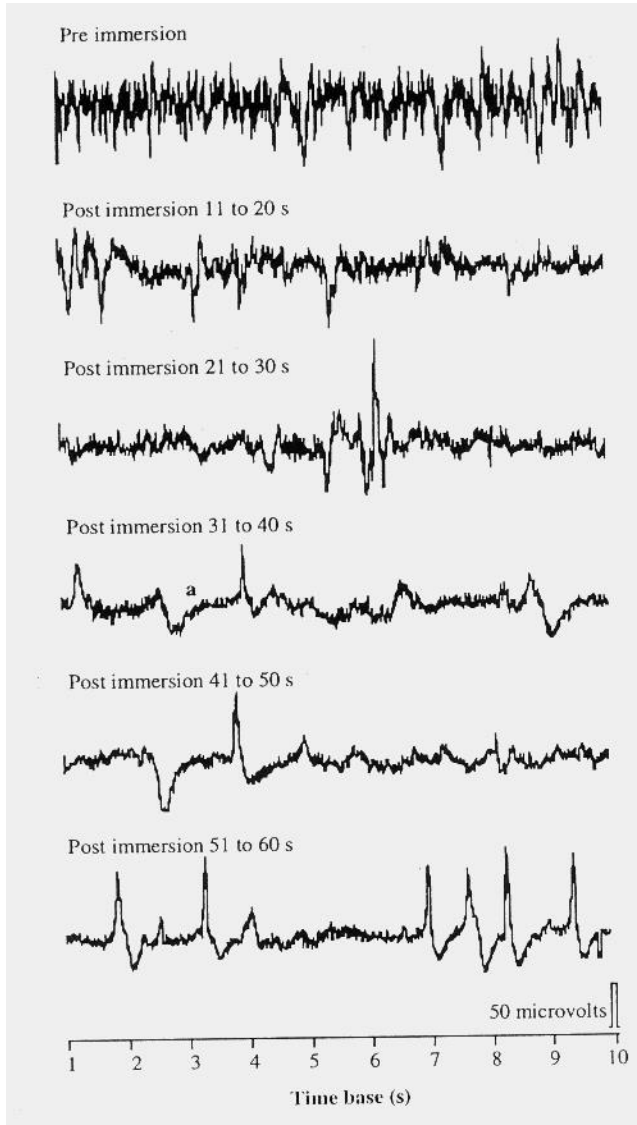


Figure 8.3.3 Changes in the spontaneous electroencephalogram (EEG) of a broiler during exposure to mixture of 30% oxygen, 40% carbon dioxide and 30% nitrogen (a = onset of suppressed EEG with random spike activity).

From Raj et al. (1998). With permission.

McKeegan et al. (2007) evaluated the welfare implications (likelihood of an induced negative state or experiences during the conscious phase) of three treatments:

- a. induction of anoxia with either N₂ or Ar; both with < 2% residual O₂,
- b. hypercapnic anoxia with either 30% CO₂ in Ar or 40% CO₂ in N₂,
- c. a biphasic method employing 40% CO₂, 30% O₂, 30% N₂ for 60 sec, followed by 80% CO₂ in air.

Anoxic mixtures induced vigorous wing flapping (graphic presentation is provided in the paper), and EEG analysis using the correlation dimension (i.e., a non-linear measure of complexity) suggested that anoxic wing flapping occurred during periods in which a form of consciousness could not be excluded. Hypercapnic mixtures were associated with strong respiratory responses. The biphasic approach exacerbated respiratory responses but eliminated the possibility of vigorous behavioural responses occurring during a conscious phase. As indicated above, the authors have stated that respiratory discomfort may be preferable to the risks of vigorous wing flapping and its associated injuries in poultry conscious during CAS.

8.4 No Stunning

Certain traditional slaughter practices forbid stunning as part of religious laws. The most well-known practices are the Jewish and Muslim regulations (known as Kosher and Halal, respectively), which indicate that animals cannot be stunned and should die by bleeding only. However, it should be mentioned that some Muslim authorities have accepted high frequency stunning of poultry that causes a reversible stun rather than cardiac arrest prior to religious slaughter. Slaughtering without stunning is performed by a trained person using a very sharp knife to cut the jugular veins. During the process, a blessing is cited and the whole process should be done very quickly to prevent animal suffering (Regenstein et al., 2003). As mentioned earlier, under these religious or ritual slaughter procedures, animals must be killed under strict guidelines, many of which are based on solid health and sanitary principles. For example, animals acceptable for food must be killed and may not be allowed to die by a disease or accident. The same principles are used for today's inspection regulations performed by non-religious government bodies. Velarde et al. (2014) evaluated current practices for the Halal and Kosher slaughter of poultry, cattle, and sheep. Information was collected by visiting religious slaughter abattoirs in Australia, Belgium, Germany, Italy, the Netherlands, Spain,

Turkey, and the United Kingdom. To standardize the information, a questionnaire was designed for each species. The results showed differences in the time from restraining to cutting, bleeding times, and cutting procedures.

8.5 Mechanical Stunning

Mechanical means of stunning, including concussion, are common in large, red meat animals (e.g., cows, steers) but not poultry. Currently, there are no large scale mechanical stunning systems in use for poultry because of the welfare and logistical difficulties of precisely positioning the bird's head on a high speed line. In general, the lack of a fast, suitable head fixing device, required for animal welfare, has prevented commercial application/development of such a system for broilers, turkeys, or ducks. In addition, this stunning method requires adequate restraint of the birds to prevent carcass damage that may occur during post-stun convulsions (e.g., wing flapping) while the birds are on the shackle line. Over the past few years a European company has been trying to develop a system that includes head and body restraints, mainly for high speed electrical head only stunning; however, the system has yet to be proven economical/viable.

Table 8.1.1 shows that captive bolt stunning with adequate head and body restraints results in comparable haemorrhage scores to gas stunning. Lambooij et al. (1999) evaluated captive bolt stunning of broilers using a pneumatically propelled solid captive bolt (5 mm in diameter and 25 mm penetration depth) or a similarly propelled hollow bolt (needle) that injected compressed air (2 atm) into the skull. Although the main objective was to determine the effects of captive bolt stunning on carcass and meat quality, the researchers also evaluated the effectiveness of this type of stunning. They concluded that these devices are acceptable in terms of bird welfare. However, more studies are needed to evaluate whether captive bolt stunning induces an immediate loss of consciousness and sensibility in poultry species, and to determine the effects associated with the dimensions and velocity of the bolt.

8.6 Neck Cutting and Bleeding

Following stunning (electrical, gas, mechanical), blood vessels in the animal's neck are cut. In North America, the carotid arteries and jugular veins are usually cut on both sides by a deep ventral cut within 8 to 12 sec of electrical stunning. This is usually done using automatic equipment and backup personnel. Ensuring

rapid blood drainage causes anoxia and usually prevents birds from regaining consciousness during the subsequent 80-90 sec bleed time. In Europe, neck cutting is usually performed dorsolaterally or on one side only. Because the rate of blood loss is slower, bleed times are usually extended to 120-180 sec (Bilgili, 1999). This type of cut often leaves some blood supply to the brain, which gives birds the opportunity to regain consciousness if the cut or bleeding is incomplete. From an animal welfare standpoint, this potential to regain consciousness has been a major reason that 100 mA per bird (i.e. an instantaneous and irreversible stun) has been mandated in Europe (EU, 2009). In contrast with Europe, electrical currents in North America have traditionally been in the range of 25-45 mA per bird, as explained earlier in the chapter. In Europe, concerns over a deep bilateral neck cut, which can often sever the trachea and might cause the head to be pulled off in the picker, have also prevented processors from using this technique in the past.

The time between stunning and neck cutting should be closely monitored to ensure adequate bleeding (see Chapter 5 for more details). It is usually recommended that neck cutting occur within 10 sec of electrical stunning, especially if a low current is applied. The time between gas stunning and neck cutting would be longer than that for electrical stunning because the birds are in crates or on a conveyor belt and have to be transferred to the shackle line. Although research has shown that the efficiency of bleeding in broiler chickens is not impaired when neck cutting is done immediately after gas stunning/killing (e.g., can be a few min), a long delay could increase the prevalence of downgrading associated with poor bleeding. By contrast, delayed neck cutting (after gas killing) of turkeys does not impede blood loss as much. The difference between chickens and turkeys may be attributable to a difference in carcass cooling rate, but other factors may also be involved (Raj and Johnson, 1997). Usual blood loss represents about 4-5% of the total body weight (i.e., some blood stays in the carcass). However, the initial rate of bleeding has been shown to be slower in birds that were killed rather than stunned, due to the lack of sharp reduction in heart activity. Considering the minimum legislated bleed out time in the US, 90 sec for broilers and 120 sec for turkeys, the industry should be able to achieve a satisfactory bleed out via a bilateral cut (Gregory and Wilkins, 1989b).

Another concern is that birds killed by inducing cardiac arrest, during electrical or gas stunning, might not bleed out adequately since their wings might hang too low, resulting in a stagnation of blood in their wing veins. Such situations could exacerbate the presence of engorged wing veins and noticeable haemorrhages associated with the massaging of the plucking machine. In fact, stunning currents that induce ventricular fibrillation can be associated with a higher incidence of red wing tips and haemorrhaging in the shoulders and wings.

In case of waterfowl, Fernandez et al. (2010) compared four methods to stun ducks and three methods for geese while also examining bleeding efficiencies, pH drop, meat texture, and sensory characteristics. They evaluated water bath stunning (50 Hz AC, 130 mA for 4 sec), head only electrical stunning (50 Hz AC, 600 mA for 4 sec), mechanical stunning (captive bolt) and CAS (two phases as described earlier in the chapter). For geese, the head only method was not used. Compared to CAS and water bath methods, mechanical stunning allowed the highest recovery of blood in geese. In ducks, water bath stunning resulted in the lowest bleeding efficiency. During the first 5 min after slaughter more convulsions and wing flapping were seen in the mechanically stunned birds and there were higher incidences of head movement in the electrical head only stunning as well as the captive bolt method in both ducks and geese. Meat texture, assessed instrumentally, and drip loss were not affected by the stunning method.

References

- Bilgili, S.F. 1999. Recent advances in electrical stunning. *Poultry Sci.* 78:282.
- Butler, A.B. and M.J. Cotterill. 2006. Mammalian and avian neuroanatomy and the question of consciousness in birds. *Biol. Bull.* 211:106.
- Coenen, A.M.L., J. Lankhaar, J.C. Lowe and D.E.F. McKeegan. 2009. Remote monitoring of electroencephalogram, electrocardiogram, and behavior during controlled atmosphere stunning in broilers: implications for welfare. *Poultry Sci.* 88(1):10.
- EU. 2009. European Union: Council regulation No 1099/2009 Protection of animals at the time of killing. <http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:303:0001:0030:EN:PDF>. Accessed September 2014.
- Fernandez, X., E. Lahirigoyen, A. Auvergne, C. Molette and M. Bouillier-Oudot. 2010. The effects of stunning methods on product qualities in force-fed ducks and geese. 1. Carcass downgrading and meat quality. *Anim.* 4(1):128.
- Fletcher, D.L. 1999. Symposium: recent advances in poultry slaughter technology. *Slaughter technology. Poultry Sci.* 78:277.
- Grandin, T. 2014. Animal welfare evaluation of gas stunning (controlled atmosphere stunning) of chickens and other poultry. <http://www.grandin.com/gas.stunning.poultry.eval.html>. Accessed November 2014.
- Gregory, N. G. 2008. Animal welfare at markets and during transport and slaughter. *Meat Sci.* 80(1):2.
- Gregory, N.G. and L.J. Wilkins. 1989a. Effect of stunning current on carcass quality of chickens. *Vet. Record* 124:530.
- Gregory, N.G. and L.J. Wilkins. 1989b. Effect of slaughter method on bleeding efficiency in chickens. *J. Sci. Food Agric.* 47:13.
- Gregory, N.G. and S.B. Wotton. 1987. Effect of electrical stunning on the electroencephalogram in chickens. *British Vet. J.* 143:175.

- Heath, G.E., A.M. Thaler and W.O. James. 1994. A survey of stunning methods currently used during slaughter of poultry in commercial poultry plants. *J. Appl. Poultry Res.* 3:297.
- Hoen, T. and J. Lankhaar. 1999. Controlled atmosphere stunning of poultry. *Poultry Sci.* 78:287.
- Humane Methods of Slaughter Act. 1978. United States Code Annotated. United States Department of Agriculture. Title 7: Agriculture, Chapter 48. Sections 1901-1907.
- Joseph, P., M.W. Schilling, J.B. Williams, V. Radhakrishnan, V. Battula, K. Christensen, Y. Vizzier-Thaxton and T.B. Schmidt. 2013. Broiler stunning methods and their effects on welfare, rigor mortis, and meat quality. *World's Poultry Sci. J.* 69(01):99.
- Kotula, A.W., E.E. Drewniak and L.L. Davis. 1957. Effect of carbon dioxide immobilization on the bleeding of chickens. *Poultry Sci.* 37:585.
- Kranen, R.W., E. Lambooj, C.H. Veerkamp, T.H. Van Kuppevelt and J.H. Veerkamp. 2000. Hemorrhages in muscles of broiler chickens. *World's Poultry Sci. J.* 56:93.
- Lambooj, E., H.G.M. Reimert and V.A. Hindle. 2010. Evaluation of head-only electrical stunning for practical application: assessment of neural and meat quality parameters. *Poultry Sci.* 89(12):2551.
- Lambooj, E., C. Pieterse, S.J.W. Hillebrand and G.B. Dijksterhuis. 1999. The effects of captive bolt and electrical stunning, and restraining methods on broiler meat quality. *Poultry Sci.* 78:600.
- McKeegan, D.E.F., S.M. Abeyesinghe, M.A. Mcleman, J.C. Lowe, T.G.M. Demmers, R.P. White, R.W. Kranen, H. Van Bommel, J.A.C. Lankhaar and C.M. Wathes. 2007. Controlled atmosphere stunning of broiler chickens: II. Effects on behavior, physiology and meat quality in a commercial processing plant. *British Poultry Sci.* 48:430.
- OIE. 2014. Slaughter of Animals. In: Terrestrial Animal Health Code. http://www.oie.int/index.php?id=169&L=0&htmfile=chapitre_aw_slaughter.htm Accessed January 2015.

- Papinaho, P.A. and D.L. Fletcher. 1995. Effects of stunning amperage on broiler breast muscle rigor development and meat quality. *Poultry Sci.* 74:1527.
- Prinz, S., G. Van Oijen, F. Ehinger, A. Coenen, and W. Bessei. 2010. Electroencephalograms and physical reflexes of broilers after electrical water bath stunning using an alternating current. *Poultry Sci.* 89(6): 1265.
- Purswell, J.L., J.P. Thaxton and S.L. Branton. 2007. Identifying process variables for a low atmospheric pressure stunning-killing system. *J. Appl. Poult. Res.* 16(4):509.
- Raj, A.B.M. 2003. A critical appraisal of electrical stunning in chickens. *World's Poultry Sci. J.* 59(01):89.
- Raj, A.B.M., S.B. Wotton, J.L. McKinstry, S.J.W. Hillebrand and C. Pieterse. 1998. Changes in the somatosensory evoked potentials and spontaneous electroencephalogram of broiler chickens during exposure to gas mixtures. *British Poultry Sci.* 39:686.
- Raj, A.B.M. and S.P. Johnson. 1997. Effect of the method of killing, interval between killing and neck cutting and blood vessels cut on blood loss in broilers. *Br. Poult. Sci.* 38:190.
- Regenstein, J.M., M.M. Chaudry and C.E. Regenstein. 2003. The kosher and halal food laws. *Compr. Rev. Food Sci. Food Saf.* 2(3):111.
- Schreurs, F.J.G., H. Goedhart and T.G. Uijttenboogaart. 1999. Effects of different methods of stunning on meat quality and post mortem muscle metabolism. *Proc. Eur. Symp. Qual. Poult. Meat.* Bologna, Italy. p.353.
- Velarde A., P. Rodriguez, A. Dalmau, C. Fuentes, P. Llonch, K.V. von Holleben, M.H. Anil, J.B. Lambooj, H. Pleiter, T. Yesildere and B.T. Cenci-Goga. 2014. Religious slaughter: evaluation of current practices in selected countries. *Meat Sci.* 96:278.
- Woolley, S.C., F.J.W. Borthwick and M.J. Gentle. 1986. Flow routes of electrical current in domestic hens during pre-slaughter stunning. *British Poultry Sci.* 27:403.