

The humane slaughter of pigs in the European Union

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Abstract

This dissertation explores the different slaughter methods considered humane, which are used and required by law to kill pigs raised for human consumption in the European Union. The main points covered are - the methods required by current EU Regulation 1099/2009 on the protection of animals at the time of killing which include; electrical stunning (head-only and head-body) and gas stunning (carbon dioxide gas and inert gas mixtures). The advantages and disadvantages of these methods are discussed, using results found online from studies and research conducted on the topic, including a list of other methods studied which are not permitted by law but are being looked into and possibly developed as potential alternative stunning methods. The enforcement of this Regulation and the surrounding issues is also touched upon towards the end of the dissertation. In the conclusion, the question of whether any of these methods can be considered truly humane is explored, based on the true definition of the word humane and the results of the studies discussed.

Keywords: pigs, human consumption, slaughter methods, electrical stunning, gas stunning.

Resumen - *El sacrificio humanitario de cerdos en la Unión Europea*

Este trabajo explora los diferentes métodos de sacrificio considerados humanitarios, que son usados y exigidos por la ley para matar a los cerdos criados para el consumo humano en la Unión Europea. Los principales puntos tratados son: los métodos requeridos por el actual Reglamento 1099/2009 de la UE sobre la protección de los animales en el momento de la matanza, que incluyen; aturdimiento eléctrico (cabeza-cabeza y cabeza-cuerpo) y aturdimiento por gas (dióxido de carbono y mezclas de gases inertes). Se discuten las ventajas y desventajas de estos métodos, utilizando resultados encontrados en internet de estudios e

investigaciones realizados sobre el tema, incluyendo una lista de otros métodos estudiados que no están permitidos por la ley pero que están siendo estudiados y posiblemente sean desarrollados como posibles métodos alternativos de aturdimiento. La aplicación de este Reglamento y los problemas asociados también se abordan hacia el final de este trabajo. En la conclusión, se explora la cuestión de si alguno de estos métodos puede considerarse verdaderamente humanitario, basándose en la definición real de la palabra “humanitario” y los resultados de los estudios discutidos.

Palabras clave: cerdos, consumo humano, métodos de sacrificio, aturdimiento eléctrico, aturdimiento por gas

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1. INTRODUCTION

In modern-day Western society, many of us human animals are faced with the internal battle of juggling the desire to consume non-human animals such as pigs, cows, chickens, sheep, turkeys, ducks and sea creatures, and the ever-growing concern for their well-being. Within the EU, progress has been made, in the sense that, it is now recognised that non-human animals are in fact sentient beings, as mentioned in Article 13 of the Lisbon Treaty 2009¹ which is supported by an abundance of scientific research clearly showing that such non-human animals can feel pain and suffer. This has led to an increased concern amongst consumers for animal welfare and a growing demand of products made from non-human animals raised and slaughtered using humane practices. In this dissertation, I will focus primarily on the humane slaughter of pigs in the EU and henceforth refer to the non-human animals previously mentioned, as animals.

2. PIG SENTIENCE

The European Union Treaty of Lisbon explicitly acknowledging animals raised for slaughter as sentient beings, implies that they are considered as more than just agricultural products or commodities and reflects society's view on the concern for animal welfare. Scientific literature shows that pigs in particular, have rather sophisticated cognitive, emotional and social characteristics and personalities and share many traits with animals who we consider intelligent. For instance, studies have shown that pigs are highly social animals

¹ Treaty on the Functioning of the European Union. Web page:
<https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A12012E%2FTXT>

who display signs of complex cognitive abilities such as; time perception, perspective-taking, self-awareness, emotion, personality, spatial learning and memory, prioritising important memories, anticipating positive and negative situations, novelty seeking, inquisitiveness and play².

Synonymous with the term 'sentient' is the word 'conscious' and various bases of consciousness exist, for example:

- Philosophical (Dennett, 1996)³;
- Neurophysiological (Zeman, 2001)⁴;
- Neurochemical (Perry et al., 2002)⁵

Generally speaking, conscious awareness may be split into two categories – quantitative and qualitative. Quantitative consciousness includes elements such as arousal, alertness and vigilance, whereas the qualitative component involves selective attention and mental experience. From the perspective of humane stunning, consciousness is considered as a brain function and therefore signs of neurophysiological or neurochemical unconsciousness are used to reflect the effectiveness of stunning, stun/killing and slaughtering methods⁶.

3. MODERN HISTORY OF THE HUMANE SLAUGHTER OF PIGS

Throughout history, the most commonly used method to slaughter animals, or so-called 'livestock', was taking a sharpened blade to the neck, mainly for food safety reasons, in order to remove the blood from the carcass for better conservation. However, due to increased public concern for animal welfare and the belief that this method caused pain and suffering towards animals, many countries began to adopt certain stunning methods prior to slaughter in order to avoid such pain. It is also worth noting that the idea of stunning an animal before slaughter dates back to the Middle Ages, when the blunt end of an axe or hammer was used to hit the animal on the head, before having their throat slit.

In modern history, Benjamin Ward Richardson was one of the first campaigners for humane slaughter and spent many years developing suitable methods by adapting substances capable of producing general or local anaesthesia to relieve pain in people, which resulted in the design of a gas chamber in 1853⁷. Following on from that, in 1882 Richardson founded the Model Abattoir Society to promote the use of public slaughterhouses, to secure adequate inspection and to require the adoption of the healthiest, most convenient and most humane methods of killing animals for food. In 1869, he was experimenting with different methods which aimed at securing narcosis by either electrocution or inhalation of a lethal gas such as carbon monoxide, before the act of slaughter itself⁸. The further development of stunning technologies occurred mainly in the first half of the twentieth century. In the 1920s the Humane Slaughter Association of the United Kingdom, formerly known as the Council of Justice to Animals at the time, introduced the use of a mechanical stunner and played an

² Marino L., Colvin CM. (2015). Thinking Pigs: A Comparative Review of Cognition, Emotion, and Personality in *Sus domesticus*. *International Journal of Comparative Psychology*, 28. Web page: http://animalstudiesrepository.org/acwp_asic

³ Dennett D.C. (1996). *Kinds of minds: the origins of consciousness*. Phoenix, London, UK.

⁴ Zeman A. (2001). *Consciousness (Review)*. *Brain*, 124: 1263-1289.

⁵ Perry E., Ashton H., Young, A. (2002). *Neurochemistry of consciousness: neurotransmitters in mind*. John Benjamins Publishing Company, Amsterdam.

⁶ *Welfare Aspects of Animal Stunning and Killing Methods*. EFSA Report 2004

⁷ D'Arcy P. (1901). "Richardson, Benjamin Ward". In Lee, Sindy. *Dictionary of National Biography*.

⁸ *Electric Methods of Producing Humane Slaughter*, Sir Leonard Hill, M.B., LL.D., F.R.S. Volume 91, Issue 2, Feb 1935 Pages 51-57 of the *Veterinary Journal* (1900). Web page: <https://www.sciencedirect.com/science/article/pii/S0372554517382044>

important part in the passage of the Slaughter of Animals Act 1993⁹. This act required that the electrical stunner, also known as the ‘electrolethaler’, be used on pigs reared for bacon in factories. Despite this requirement, in slaughterhouses without electricity, workers were permitted to strike pigs with a knife while still fully conscious¹⁰. By the end of the 1930s came the disappearance of pigs being slaughtered in private, however, during the Second World War thousands of pigs were slaughtered for home consumption and many were left to bleed out while fully conscious¹¹.

4. CURRENT EU LAWS ON THE HUMANE SLAUGHTER OF PIGS

More recently, within the EU, the protection of animals at the time of slaughter has been covered by Community law since 1974 and was reinforced by EU Directive 93/119/EC¹² in 1993. This Directive has since been replaced by Council regulation (CE) No. 1099/2009¹³ on the protection of animals at the time of killing, due to the discrepancies observed between the Member States in the implementation of the Directive and major welfare concerns pointed out. The measures for sanitary checks, animal welfare protection and slaughtering procedures are now harmonised throughout the European Union, and detailed by the European Commissions' regulations CE 853/2004, 854/2004 and 1099/2009. The most detailed guidance on the slaughter of animals is found in the Regulation 1099/2009, which sets out rules to govern the killing of animals bred or kept for the production of food, wool, skin, fur or other products, as well as the killing of animals for the purpose of depopulation and for related operations. The general and primary principle of this regulation expresses that animals shall be spared of any avoidable pain, distress or suffering during their killing and related operations¹⁴. Despite this, the Regulation admits that “Killing animals may induce pain, distress, fear or other forms of suffering to the animals even under the best available technical conditions, given that certain operations related to the killing may be stressful and any stunning technique presents certain drawbacks”¹⁵.

5. METHODS USED FOR STUNNING PIGS

Given that the intention of humane slaughter regulations is to avoid as much as possible anxiety, pain, distress or suffering during the slaughter process, stunning methods aim to ideally fulfil the following criteria:

- Induce immediate (e.g. <1 sec) and unequivocal loss of consciousness and sensibility;

Or,

⁹ History of the HSA. Web page: <https://www.hsa.org.uk/about/history-of-the-hsa>

¹⁰ History of the HSA. Web page: <https://www.hsa.org.uk/about/history-of-the-hsa>

¹¹ History of the HSA factsheet. Web page : <https://www.hsa.org.uk/downloads/related-items/history-factsheet.pdf>

¹² Council Directive 93/119/EC. Web page: <http://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX:31993L0119>

¹³ Council regulation (CE) No. 1099/2009. Web page: <http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:303:0001:0030:EN:PDF>

¹⁴ Web page: <https://www.ecolex.org/details/legislation/council-regulation-ec-no-10992009-on-the-protection-of-animals-at-the-time-of-killing-lex-faoc090989/>

¹⁵ Council regulation (CE) No. 1099/2009. Web page: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:303:0001:0030:EN:PDF>

- In cases where unconsciousness is not immediately caused, for example with carbon dioxide stunning, the induction of unconsciousness should be non-aversive and avoid causing anxiety, pain, distress or suffering¹⁶.

As stated in Regulation 1099/2009, many killing methods are painful for animals, therefore, stunning is necessary to induce a lack of consciousness and sensibility before, or at the same time as, the animals are killed and must be maintained until the death of the animal. Article 4 of Regulation 1099/2009 states that animals shall only be killed after stunning in accordance with the methods and specific requirements related to the application of those methods set out in Annex I.

The table below describes the stunning methods (mechanical, electrical and gas) allowed for pigs in the EU¹⁷:

Table 1

Name	Description	Condition of use
Penetrative captive bolt device	Severe and irreversible damage of the brain provoked by the shock and the penetration of a captive bolt.	All species. Slaughter, depopulation (reduction of the population of a certain species) and other situations.
Firearm with free projectile	Severe and irreversible damage of the brain provoked by the shock and the penetration of one or more projectiles	All species. Slaughter, depopulation and other situations.
Percussive blow to the head	Firm and accurate blow to the head provoking severe damage to the brain.	Piglets, lambs, kids, rabbits, hares, fur animals and poultry up to 5 kg live weight. Slaughter, depopulation and other situations.
Head-only electrical stunning	Exposure of the brain to a current generating a generalised epileptic form on the electroencephalogram (EEG)	All species. Slaughter, depopulation and other situations.
Head-to-Body electrical stunning	Exposure of the body to a current generating at the same time a generalised epileptic form on the EEG and the fibrillation or the stopping of the heart.	All species. Slaughter, depopulation and other situations.
Carbon dioxide at high concentration	Direct or progressive exposure of conscious animals to a gas mixture containing more than 40 % carbon dioxide. The method may be used in pits, tunnels, containers or building previously sealed.	Pigs, mustelids, chinchillas, poultry except ducks and geese. Slaughter only for pigs. Other situations than slaughter for poultry mustelids, chinchillas, pigs.
Carbon dioxide associated with inert gases	Direct or progressive exposure of conscious animals to a gas mixture containing up to 40 % of carbon dioxide associated with inert gases leading to anoxia. The method may be used in pits, bags, tunnels, containers or in	Pigs and poultry. Slaughter, depopulation and other situations.

¹⁶ Welfare Aspects of Animal Stunning and Killing Methods. EFSA Report 2004

¹⁷ Annex I – List of stunning methods and related specifications. Council regulation (CE) No. 1099/2009. Web page: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:303:0001:0030:EN:PDF>

	buildings previously sealed. Simple stunning for pigs if the duration of exposure to at least 30 % of carbon dioxide is of less than 7 minutes.	
Inert gases	Direct or progressive exposure of conscious animals to an inert gas mixture such as Argon or Nitrogen leading to anoxia. The method may be used in pits, bags, tunnels, containers or in buildings previously sealed.	Pigs and poultry. Slaughter, depopulation and other situations.
Carbon monoxide (pure source)	Exposure of conscious animals to a gas mixture containing more than 4 % of carbon monoxide	Fur animals, poultry and piglets. Other situations than slaughter.
Carbon monoxide associated with other gases	Exposure of conscious animals to a gas mixture containing more than 1 % of carbon monoxide associated with other toxic gases.	Fur animals, poultry and piglets. Other situations than slaughter

In the EU, pigs are commonly slaughtered by one of the following two methods either individual pigs are introduced into a restraining box where they are rendered unconscious by an electric current or groups of pigs are ushered into a gas chamber where they are gassed to death using carbon dioxide or inert gases, such as argon or nitrogen. On some occasions, mechanical methods such as a captive bolt device (described in Table 1) may be used¹⁸, especially for sows. Given that slaughter is traditionally a two-stage process, after stunning, the animal's throat must then be slit. In the case of pigs, after stunning, the animal may be shackled by a rear leg after stunning and hoisted up on to a rail where the pig is then stuck (sliced across the throat), as animals must be inverted for the blood to drain out¹⁹. Council Regulation (EC) 1099/2009 stipulates that both carotid arteries must be severed²⁰, to reduce the time to loss of sensibility. The Regulation also states that all of these actions (stunning, shackling, hoisting and bleeding of animals) are to be performed by one person, who should carry out the operations consecutively, on one animal at a time, before carrying them out on another animal²¹.

a. Electrical stunning

i. Head-only and head-body stunning

Electric stunning induces instantaneous unconsciousness by causing an epileptic seizure. In order to successfully induce a seizure, the electrodes must be placed so that the current flows through the brain. The minimum amperage requirements for effective (head-only) electric stunning in adult pigs are 1.30 amps²². The following three methods are used for electric stunning and produce different outcomes, depending on the technique used. 1)

¹⁸ The Life of Pigs. Compassion in World Farming. Web page: <https://www.ciwf.org.uk/media/5235118/The-life-of-Pigs.pdf>

¹⁹ Stevenson P. (2001). Welfare Problems in Slaughterhouses. Compassion in World Farming. Web page: https://www.ciwf.org.uk/includes/documents/cm_docs/2008/a/animal_welfare_problems_in_uk_slaughterhouses_2001.pdf

²⁰ Council regulation (CE) No. 1099/2009. Web page: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:303:0001:0030:EN:PDF>

²¹ Annex III Article 3.1. Council regulation (CE) No. 1099/2009. Web page: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:303:0001:0030:EN:PDF>

²² Chapter 2, Article 4.2, Table 1. Web page: Council regulation (CE) No. 1099/2009. Web page: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:303:0001:0030:EN:PDF>

Head-only stunning (reversible outcome) 2) Head-to-body (irreversible cardiac arrest outcome) and 3) Head-only followed by a current applied to the body to stop the heart (irreversible outcome)²³. However, only the first two methods are the ones described and permitted in the stunning methods table (Annex I) of EU Regulation 1099/2009²⁴. Given that the head-only method, which involves two electrodes placed either side of the head below the pig's ears, is reversible and only temporary, the animal will regain consciousness unless they are bled quickly. In fact, it is strongly recommended that the animal is stuck within 15 seconds after the head-only stunned is removed²⁵, given that pigs are said to return to sensibility within 30 seconds after being stunned in this way²⁶. Taking these timings into consideration, and provided that the stunning has been carried out successfully the first time, this means that the slaughterhouse worker is left with less than 30 seconds to shackle and hoist a 300lb pig having an epileptic seizure, upside-down on to rail, before they regain consciousness. This may be problematic, therefore, in an attempt to avoid pigs returning to sensibility, cardiac arrest may be induced immediately after stunning by using the head-body method, which involves a third electrode being placed on the chest of the animal, to deliver a second current that will fibrillate the heart, and thereby cause the death of the animal²⁷.

ii. Problems with head-only stunning

1. Failure to induce unconsciousness

One of the main problems with conventional head-only electric stunning methods is that there is a possibility the stunning fails to induce an unconscious state on the first attempt, which may be extremely stressful and painful for the animal. Research has shown that, in humans, when electro-convulsive shock therapy (ECT) fails to induce a seizure, it is painful and distressing²⁸ ²⁹. Similarly, when this occurs in pigs, the animal will feel the effects of epinephrine secretions and may feel pain³⁰ ³¹. In addition to the pain caused by the failed seizure on the first attempt, the animal will then be submitted to further stress by being handled and stunned for a second time. To ensure that the animal has been successfully stunned, the following signs of return to sensibility must be absent before moving on to the next stage of the production line³²:

²³ Grandin T. (2013). Making slaughterhouses more humane for cattle, pigs and sheep. Web page: https://www.grandin.com/references/making_slaughterhouses_more_humane.html

²⁴ Annex I – List of stunning methods and related specifications. Council regulation (CE) No. 1099/2009. Web page: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:303:0001:0030:EN:PDF>

²⁵ Blackmore D.K., Newhook J.C. (1981). Insensibility during slaughter of pigs in comparison to other domestic stock. *N. Z. Vet. J.* 29:219-22.

²⁶ Hoenderken R. (1983). Electrical and carbon dioxide stunning of pigs for slaughter. In *Stunning of Animals for Slaughter*, ed. G Eikelenboom, pp. 59-63. Boston: Martinus Nijhoff.

²⁷ Head-to-body stunning. Humane Slaughter Association. Web page:

<https://www.hsa.org.uk/electrical-stunning-of-red-meat-animals-equipment/head-to-body>

²⁸ Zivotofsky A.Z., Strous RD (2011). A perspective on the electrical stunning of animals: Are there lessons to be learned from human electroconvulsive therapy (ECT)? *Meat Sci.* 90:956-61

²⁹ Chanpattana W. (2001). Seizure threshold in electroconvulsive therapy: effect of instrument titration schedule. *German J. Psychiat.* 4(3):51-56.

³⁰ Warrington P.D. (1974). Electrical stunning: a review of literature. *Vet. Bull.* 44:617-33.

³¹ Zivotofsky A.Z., Strous RD. (2011). A perspective on the electrical stunning of animals: Are there lessons to be learned from human electroconvulsive therapy (ECT)? *Meat Sci.* 90:956-61.

³² Grandin T. (2010b). Auditing animal welfare at slaughter plants, *Meat Sci.* 86:56-65.

- **Rhythmic breathing** - ribs moving in and out at least twice^{33 34}.
- Natural **spontaneous blinking** or response to a hand waved in front of the eyes without touching the animal³⁵. Nystagmus (vibrating eyelids) must not be confused with natural blinking.
- **Vocalization** - moos, bellows, or squeals³⁶. A single slight grunt or groan, as a result of a sudden exhale of air, may occur immediately after stunning. Any further vocalization must be absent. Squeals from pigs are not acceptable.
- **Righting reflex** or attempt to get up or lift the head. When the animal is hung on the rail, the head should be limp and floppy³⁷.
- **Response to a painful stimulus** (pinprick on the nose).
- **Eye tracking** of moving objects³⁸.

2. Seizures

Another problem associated with this method is the violent kicking, spasms and contractions caused by the epileptic seizure induced by the stunner, which interfere with the shackling and bleeding stage, given that animals are more likely to be bled incorrectly if they are rigid or kicking³⁹. Consequently, if the throat is not cut correctly, this may lead the pigs to regain consciousness before loss of sensibility due to brain death. In addition to this risk, in an attempt to reduce the violent kicking of the pig, slaughterhouse workers have been known to decrease the power of the stunner, which only creates further problems leading to seizures not being induced correctly and therefore pigs being fully conscious whilst inverted and bleeding⁴⁰.

3. Handling issues

Furthermore, when examining the issues involved with certain stunning methods, it is important not to overlook the handling systems used for each one. Given the great speed at which the production line in slaughterhouses works at, the welfare of the animal can be compromised. To give an idea of this scale, a report by Compassion in World Farming in 2001 stated that, in a modern slaughterhouse, pigs are slaughtered at the rate of 300 an hour⁴¹, although this number is hugely variable. Therefore, the handling methods that bring animals up to the stunner play a big role and should also be evaluated. In situations where an electrical stunning system is used, it is worth noting that such a device must be applied individually to

³³Grandin T, Vogel KD. (2010). 2010 Restaurant Welfare and Human Slaughter Audits in Federally Inspected Beef and Pork Slaughter Plants <http://www.grandin.com/survey/2010.restaurant.audits.html>.

³⁴Gregory N.G, Lee CJ, Widdicombe JP. (2007). Depth of concussion in cattle shot by penetrating captive bolt. *Meat Sci.* 77:499-503.

³⁵Grandin T. (2001). Solving return to sensibility problems after electrical stunning in commercial pork slaughter plants. *J. Am. Vet. Med. Assoc.* 219:608-11.

³⁶Grandin T. (2010b). Auditing animal welfare at slaughter plants, *Meat Sci.* 86:56-65.

³⁷Grandin T. (2001). Solving return to sensibility problems after electrical stunning in commercial pork slaughter plants. *J. Am. Vet. Med. Assoc.* 219:608-11.

³⁸Vogel K.D, Badtram G, Claus JR, Grandin T, Turpin S, et al. (2011). Head only followed by cardiac arrest electrical stunning in an affective alternative to head only electrical stunning in pigs. *Meat Sci.* 89:1412-18.

³⁹Grandin T. (1997) updates. Cardiac Arrest Stunning State of the Art. Web page: <http://www.grandin.com/humane/cardiac.arrest.html>

⁴⁰Grandin T. (1997) updates. Cardiac Arrest Stunning State of the Art. Web page: <http://www.grandin.com/humane/cardiac.arrest.html>

⁴¹Stevenson P. (2001). Welfare Problems in Slaughterhouses. *Compassion in World Farming*. Web page: https://www.ciwf.org.uk/includes/documents/cm_docs/2008/a/animal_welfare_problems_in_uk_slaughterhouses_2001.pdf

every single pig. In large facilities, electric prods may be deemed necessary to move pigs down the single-file chute into the restrainer for electric stunning, which may induce stress and instant pain caused by the electric shock from the prod⁴².

Pigs can be restrained in a V-shaped restrainer with manual or automatic positioning of the stunning tongs for both head-only and head-body stunning, however, this can be stressful and is not always adequate due to the differing sizing of animals, which therefore can lead to inefficient stunning. However, an automatic electrical stunning device has been developed where pigs are moved forward on a conveyor belt system, also known as a belt restrainer, riding on the chest with the legs hanging down on both sides of the belt which has appeared to be very useful to restrain and stun pigs^{43 44 45}. Despite this, it is worth noting that the automatically positioned head electrodes consist of three pointed metal electrodes which pierce through the animal's skin.

iii. Advantages of head-body stunning

On the one hand, a practical solution to the previously mentioned issues posed by head-only stunning (apart from the handling issues which are inevitable in both of the described methods), may be cardiac arrest stunning (head-body), as it greatly reduces or even eliminates the kicking action due to the electricity passing through the spinal cord and depolarizing spinal neurons⁴⁶. Depending on the position that the third electrode is placed on the body (either head-to-back, head-to-foreleg or head-to-groin⁴⁷), the outcomes of the stunning and the effect it has on the animal differ. Properly applied head-to-back or head-to-foreleg cardiac arrest stunning, with the recommended stunning times of 4 seconds and good electrode contact, will result in a relaxed carcass which facilitates the bleeding process⁴⁸.

Evidently, the danger of pigs regaining consciousness has led many scientists to the conclusion that a method of slaughtering pigs which fibrillates the heart at the same time as stunning the brain is likely to be more humane than head-only stunning^{49 50} as it is said to reliably render the animal insensible to pain and sensation prior to hoisting and bleeding, which is essential to prevent suffering, making it more effective than conventional electric stunning⁵¹. In addition, Gregory and Wotton (1986)⁵² found that on average, cardiac fibrillation took as little as 19 seconds to induce loss of brain responsiveness. For these reasons it should, in theory, be the method of choice from an animal welfare standpoint.

⁴² Grandin T. (2013). Making slaughterhouses more humane for cattle, pigs and sheep.

⁴³ Troeger K. (1999). Slaughter method and animal welfare. 45th International Congress of Meat Science and Technology, Yokohama, Japan. Proceedings, Vol. 1: 40-48.

⁴⁴ Lambooj E., Merkus G., Hulsegge I. (1992). A band restrainer for slaughter of pigs. *Fleischwirtschaft*, 72: 1271-1272.

⁴⁵ Von Wenzlawowicz M., Schütte A., Holleben KV., Altröck AV., Bostelmann, N., Roeb S. (1999). Field-study on welfare and meat quality aspects of the Midas pigstunning device with Inarco System. Part I: Current characteristics and stunning effectiveness. *Fleischwirtschaft International*, 2, 8-13.

⁴⁶ Gilbert K.Y., Devine CE., Hand R., Ellery S. (1984). Electrical stunning and stillness of lambs. *Meat Sci.* 11:45-58.

⁴⁷ Gilbert K.U. (1980). Developments in stunning and slaughter. 21st Meat Industry Conference. MIRINZ. Hamilton, New Zealand. pp. 18-25.

⁴⁸ Grandin T. (1997 updates). Cardiac Arrest Stunning State of the Art. Web page: <http://www.grandin.com/humane/cardiac.arrest.html>

⁴⁹ Gregory N.G., Wotton SB. (1986). Pig slaughtering procedures: time to loss of brain responsiveness after exsanguination or cardiac arrest. *Research in Veterinary Science* 40: 148-151.

⁵⁰ Wotton S.B., Anil M.H., Whittington P.E., McKinstry J.L. (1992). Pig slaughtering procedures: head-to-back stunning. *Meat Science* 32: 245-255.

⁵¹ Grandin T. (1997 updates). Cardiac Arrest Stunning State of the Art. Web page: <http://www.grandin.com/humane/cardiac.arrest.html>

⁵² Gregory N.G., Wotton S.B. (1986). Pig slaughtering procedures: time to loss of brain responsiveness after exsanguination or cardiac arrest. *Research in Veterinary Science* 40: 148-151.

iv. Problems with head-body stunning

On the other hand, head-to-body stunning may cause carcass damage such as blood splash and haemorrhages in the muscle, fat and connective tissue and therefore adversely affects the end product. The electric current passed through the back of the animal is also known to provoke petechiae, ecchymosis and broken bones due to the strong body contractions caused. Such contractions may harm the meat and carcass quality and therefore discourages slaughterhouse to implement the method. These damages cause great economic losses and in some cases, lead to the flesh being rejected completely. The European pork industry may be susceptible to suffering even greater economic losses due to haemorrhages, as the pork in Europe is sold with the skin intact⁵³. For these reasons, despite being considered the more humane method for the animal, this method of stunning is rarely used in the industry⁵⁴.

This implies that, although humane slaughter methods are said to be in place to increase animal welfare, the industries' focus is clearly elsewhere and not their top priority or concern. Moreover, another risk associated with cardiac arrest stunning is that, if it is not performed correctly and a sufficient electric current doesn't pass through both the brain and the heart, at an adequately intense current, instantaneous unconsciousness will not be induced and the cardiac arrest will, of course, be painful⁵⁵.

Furthermore, the variability in the sensitivity of different animals may pose a problem when using this method of stunning. For example, a stunner setting which will reliably induce cardiac arrest in pigs in one slaughterhouse may not necessarily induce it in another⁵⁶. Many factors are involved in determining the sensitivity of a pig, such as, weight, fat thickness, access to drinking water prior to stunning, wetness of the skin, mineral content or salt content in the water which is on the skin, hair coat length, skin thickness and age^{57 58}. That said, most of the current stunner setting automatically calculate the current voltage to reach a minimum current intensity by modifying resistance using Ohm's law ($I=V/R$).

In addition, research has proven that the minimum current of 1.3 amps for electric stunning methods, recommended by the European Food Safety Authority and also required by Regulation 1099/2009, is not ideal and does not reliably render pigs unconscious⁵⁹. In 2010, a study performed in four different slaughterhouses in Hungary, was carried out to verify the electrical parameters of pig stunning under commercial conditions⁶⁰. In total, 145 fatterer pigs with a median body weight of 109kg were used to test the head-only electrical stunners at different voltages and the following data were recorded: individual liveweight (kg), current (A) and voltage (V), current duration (s), effectiveness of stunning, grading of

⁵³ Grandin T. (1997 updates). Cardiac Arrest Stunning State of the Art. Web page: <http://www.grandin.com/humane/cardiac.arrest.html>

⁵⁴ Stevenson P. (1993). The welfare of pigs cattle and sheep at slaughter. Compassion in World Farming. Web page: https://www.ciwf.org.uk/includes/documents/cm_docs/2008/t/the_welfare_of_pigs_cattle_sheep_at_sl_aughter_1993.pdf

⁵⁵ Stevenson P. (1993). The welfare of pigs cattle and sheep at slaughter. Compassion in World Farming. Web page: https://www.ciwf.org.uk/includes/documents/cm_docs/2008/t/the_welfare_of_pigs_cattle_sheep_at_sl_aughter_1993.pdf

⁵⁶ Grandin T. (1997 updates). Cardiac Arrest Stunning State of the Art. Web page: <http://www.grandin.com/humane/cardiac.arrest.html>

⁵⁷ Croft P.S. (1952). Problems of electrical stunning. *Vet. Rec.* 64:255-8.

⁵⁸ Hoenderken R. (1978a). Electrical stunning of pigs for slaughter. Why? Hearing on Pre-slaughter Stunning. Kavlinge, Sweden. May 19, 1978.

⁵⁹ Grandin T. (2013). Making slaughterhouses more humane for cattle, pigs and sheep

⁶⁰ Végh A, Abonyi-Tóth Z, Rafai P. (2010). Verification of the technical parameters of head-only electrical stunning of pigs under commercial conditions. *Acta Vet. Hung.* 58:147-58.

carcass. The results showed that in only 128 out of the 145 cases the stunning was effective (88.3%), leaving a rather large amount (11.7%) of the pigs conscious, when stunned at the recommended 1.3 amps⁶¹.

b. Gas stunning

Within the EU, the following gas stunning methods are allowed by Regulation 1099/2009⁶²; carbon dioxide at high concentration, carbon dioxide with associated inert gases, inert gases, carbon monoxide or carbon monoxide associated with inert gases.

i. Carbon dioxide stunning

The other and most commonly used method in the EU is gas stunning using high concentrations of carbon dioxide. Pigs are lowered into a pit with a high concentration of carbon dioxide by using one of the two main stunning systems: a dip-lift system and a paternoster system. The dip-lift system works by lowering a box of small groups (4 to 6 pigs) directly into the maximum carbon dioxide concentration at the bottom of the pit. The box is then brought back up after a certain amount of time (gradient and concentration of gas dependent) and the unconscious pigs are then tipped out ready to be shackled, hoisted and bled out. In contrast, the paternoster system (most commonly used) is based on a Ferris wheel type motion of gondolas which turns continuously, lowering groups of pigs successively into the maximum carbon dioxide concentration with stops to empty the unconscious set of pigs and load a new set of conscious pigs⁶³. According to Regulation 1099/2009, the minimum concentration of 80% carbon dioxide shall be used for pigs⁶⁴ and given that carbon dioxide is heavier than atmospheric air, it shall be admitted from the bottom. The concentration is highest at the bottom and the gradient decreases towards the top as air is mixed up with the atmospheric gas mainly containing nitrogen and oxygen.

ii. Advantages of carbon dioxide gas stunning

One advantage of gas stunning in general (also applicable to stunning with other types of gas mixtures discussed further on in this dissertation) is that pigs do not need to be physically restrained during the stunning other than being ushered into and confined in a gondola, therefore the smooth handling of pigs during the process can be seen as a benefit, in comparison to the physical handling methods required for electrical stunning. Plus, animals can be stunned together in groups and therefore do not need to be lined up in a single-file chute. This ensures consistency in terms of welfare and quality when dealing with high throughput rates in large operations, for example, 800 pigs per hour⁶⁵. This also means that the use of force or electric prods are not necessary while preparing a group of pigs and guiding them through the stunning equipment. In such cases, the start-stop nature of movement into the system is eliminated and the production line can flow better⁶⁶. Note that such advantages are not necessarily beneficial for the animal's welfare, instead they tend to

⁶¹ Végh A, Abonyi-Tóth Z, Rafai P. (2010). Verification of the technical parameters of head-only electrical stunning of pigs under commercial conditions. *Acta Vet. Hung.* 58:147-58.

⁶² Council regulation (CE) No. 1099/2009. Web page: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:303:0001:0030:EN:PDF>

⁶³ Welfare Aspects of Animal Stunning and Killing Methods. EFSA Report 2004

⁶⁴ Council regulation (CE) No. 1099/2009. Web page: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:303:0001:0030:EN:PDF>

⁶⁵ Carbon Dioxide Stunning and Killing of Pigs. The Humane Society Association. Web page: <https://www.hsa.org.uk/downloads/technical-notes/TN19-carbon-dioxide-pigs-HSA.pdf>

⁶⁶ Grandin T., Smith G.C. (2004). Animal Welfare and Humane Slaughter. Web page: <http://www.grandin.com/references/humane.slaughter.html>

favour the speed and efficiency of the process from a production point of view and also the increased quality of the meat produced when using carbon dioxide stunning, making it the preferable method of the industry.

iii. Problems with carbon dioxide gas stunning

1. Aversion to carbon dioxide and physical effects

The humaneness of carbon dioxide stunning is a controversial topic. The use of this stunning method is increasing within the EU due to the ready availability, lower price and high quality of meat produced by using this gas. However, its acceptability on welfare grounds has been questioned by many researchers. In 1996, Raj & Gregory concluded that pigs show profound aversion to a high concentration⁶⁷. Their studies showed that pigs withdrew from an atmosphere of 90% carbon dioxide in less than 5 seconds. This aversion to carbon dioxide atmosphere was found to be greater than the motivation to obtain a reward (apples), even after 24 hours of fasting and 87.5% of pigs preferred to go without water for 72 hours, instead of enduring exposure to carbon dioxide again⁶⁸. When exposed to carbon dioxide in concentrations of 70% in air for 15-20 seconds, they found that this provoked excitation amongst the pigs who exhibited movements resembling escape attempts. Such a behavioural response has been considered unacceptable by Grandin⁶⁹ and Gregory et al.⁷⁰. However, no pigs showed escape attempts at 80-90% carbon dioxide. This lack of escape attempts in pigs exposed to 80-90% could be interpreted as remaining motionless, freezing or a fear-induced inhibition of spontaneous behaviour, or due to the potent analgesic effect of carbon dioxide⁷¹. This could be explained by the research findings of Forslid⁷² and Traeger and Woltersdorf⁷³ based on the electroencephalogram (EEG) recordings which indicated that the animal is unconscious before reaching this phase of behaviour. Induction of unconsciousness prior to the excitatory response should in theory reduce the concern for the welfare of pigs stunned using carbon dioxide, although this still leaves room for a window of pain between the phase of unconsciousness and insensibility to pain. Despite this, earlier research by Hoenderken et al⁷⁴. indicated that the excitation phase starts prior to the onset of unconsciousness, which raised the question of potential distress during this phase of the process. These differing results have sparked confusion in the field, which may be explained by genetic factors playing a large role in determining the averseness of CO₂ gas to pigs. In other words, for some genetic types of pigs, the use of carbon dioxide may be considered humane, whereas for other genetic types, it may be very stressful⁷⁵.

⁶⁷ Raj A.B.M., Gregory N.G. (1996). Welfare implications of the gas stunning of pigs: 2. Stress of induction of anaesthesia. *Animal Welfare* 1996, 5: 71-78.

⁶⁸ Cantieni J. (1976). Ein Beitrag zur carbon dioxide-Betäubung von Schlachtschweinen. *Schweiz Arch Tierheilk*, 119: 255-375.

⁶⁹ Grandin T. (1988). Possible genetic effect on pig's reaction to CO stunning. In: *Proceedings 34th International Congress of Meat Science and Technology*. CSRIO Meat Research Laboratory, Cannon Hill, Queensland, Australia.

⁷⁰ Gregory N.G., Raj A.B.M., Audsley, A.R.S., Daly, C.C. (1990). Effect of CO on man. *Fleischwirtschaft* 70, 2 1173-1174

⁷¹ Welfare Aspects of Animal Stunning and Killing Methods. EFSA Report 2004

⁷² Forslid A. (1987). Transient neocortical, hippocampal and amygdaloid EEG silence induced by one minute inhalation of high concentration of carbon dioxide in swine. *Acta Phys. Scand.* 130, 1-10

⁷³ Troeger K., Woltersdorf W. (1991). Gas anaesthesia of slaughter pigs: 1. Stunning experiments under laboratory conditions with fat pigs of known halothane reaction type: meat quality, animal protection. *Fleischwirtschaft* 71, 1063-1068.

⁷⁴ Hoenderken R. (1983). Electrical and carbon dioxide stunning of pigs for slaughter. In: *Stunning of Animals for Slaughter*. G. Eikelenboom (Ed.), pp. 59-63. Martinus Nijhoff Publishers, Boston.

⁷⁵ Grandin T., Smith G.C. (2004). *Animal Welfare and Humane Slaughter*. Web page: <http://www.grandin.com/references/humane.slaughter.html>

Another issue associated with carbon dioxide stunning is the physiological effects it has on pigs. Raj and Gregory also found that the exposure to the gas stimulates breathing frequency and may lead to severe respiratory distress. The severity of respiratory distress before loss of posture, which is classed as the behavioural indicator of onset of unconsciousness, was studied by recording the sounds occurring during exposure of 20, 30, 40, 50, 60, 70, 80 and 90% concentrations of carbon dioxide in the air. The audio tapes of respiratory sounds expressed during exposure were played to experienced animal physiologists who were asked to categorise the distress sounds as minimum, moderate or severe. The results confirmed that exposure to all concentrations of carbon dioxide in the air induced severe respiratory distress⁷⁶.

The inhalation of carbon dioxide causes acute respiratory distress through irritation of the mucus membranes^{77, 78} which thus provokes hyperventilation, gasping and a sensation of suffocation. In humans, this can be interpreted as dyspnoea or breathlessness which is known to increase when carbon dioxide levels in blood increase⁷⁹. Although hyperventilation is usually considered a sign of panicking and distress, it is thought that the faster and deeper respiration during hyperventilation in high concentration of carbon dioxide in atmosphere leads to increased gas intake and therefore increased efficiency of the stunning method, thus shortening the induction period and time to loss of consciousness⁸⁰. However, this varies depending on the concentration of carbon dioxide the pigs are exposed to.

In addition to this, there is an abundance of scientific evidence demonstrating that carbon dioxide stunning does not guarantee an absence of avoidable pain, suffering and distress in pigs^{81, 82}. Researchers in Denmark and Spain stated that 'the fact these behaviours occur when the animal is conscious is evidence enough that induction to carbon dioxide anaesthesia is not immediate and pigs suffer from fear, pain and/or stress during immersion into the gas'⁸³. The European Food Safety Authority⁸⁴ has concluded that at concentrations above 30%, carbon dioxide is known to be aversive and cause irritation of the mucus membranes that can be painful and elicits hyperventilation gasping before loss of consciousness. Therefore, the EFSA has recommended that the gas used to induce unconsciousness should be non-aversive and that the research into alternative gasses should

⁷⁶ Raj A.B.M., Gregory N.G. (1996). Welfare implications of the gas stunning of pigs: 2. Stress of induction of anaesthesia. *Animal Welfare* 1996, 5: 71-78.

⁷⁷ Raj A.B.M., Gregory N.G. (1996). Welfare implications of the gas stunning of pigs 2. Stress of induction of anaesthesia. *Animal Welfare* 5:71-78. 12

⁷⁸ Peppel P. and Anton F. (1993). Responses of rat medullary dorsal horn neurons following intranasal noxious chemical stimulation: effects of stimulus, intensity, duration, and interstimulus interval. *Journal of neurophysiology* 70:2260-2274.

⁷⁹ Stark R.D., Gambles S.A., Lewis, J.A. (1981). Methods to assess breathlessness in healthy subjects: A critical evaluation and application to analyse the acute effects of diazepam and promethazine on breathlessness induced by exercise or exposure to raised levels of carbon dioxide. *Clinical Science*, 61: 429-440

⁸⁰ Forslid A. (1992). Muscle spasms during pre-slaughter carbon dioxide anaesthesia in swine. *Fleischwirtschaft*, 72: 167-168.

⁸¹ Scientific Report of the Scientific Panel for Animal Health and Welfare on a request from the Commission related to welfare aspects of animal stunning and killing methods. 2004. Welfare aspects of animal stunning and killing methods. The EFSA Journal 1-241. 28

⁸² Velarde A., Cruz J., Gispert M., Carrión D., Torre R.J., Diestre A., Manteca X. (2007). A version to carbon dioxide stunning in pigs: effect of carbon dioxide concentration and halothane genotype, *Animal Welfare* 164:513-522.

⁸³ Rodríguez P., Dalmau A., Ruiz-de-la-Torre J.L, et al. (2008). Assessment of unconsciousness during carbon dioxide stunning in pigs. *Animal Welfare* 17:341-9.

⁸⁴ Opinion of the Scientific Panel on Animal Health and Welfare on a request from the Commission related to welfare aspects of the main systems of stunning and killing the main commercial species of animals (2004). The EFSA Journal 45:1-29

be top priority⁸⁵. In addition, the UK Farm Animal Welfare Council reached the conclusion that the use of high concentrations of carbon dioxide to stun pigs is not acceptable and should be phased out⁸⁶.

2. Genetic factors

Research conducted by Grandin in a Wernberg Compact plant, shows that many of the Hampshire-type pigs started to react in the first few seconds after being exposed to the gas by attempting to rear up in order to avoid it, while fully conscious⁸⁷. In contrast, Grandin observed that Danish pigs (who have a very low incidence of the Halothane gene) remained calm when inhaling the carbon dioxide gas, whereas Irish pigs (high incidence of the Halothane gene) became highly agitated only seconds after sniffing the gas⁸⁸. Similar varying reactions have also been observed in human beings due to genetic factors. For example, people who have panic attacks with a strong genetic basis will react very badly to carbon dioxide as it may induce panic attacks in these people^{89 90}. It has also been observed that it causes anxiety in some people but has little effect on others^{91 92 93}. However, it seems that more research is needed to conclude with such a statement as there may be other factors involved, such as environmental, emotional and spatial elements in which these results were observed, which may contribute to the panic attacks and anxiety caused in these humans. It is not proven that panic attack and anxiety disorders are purely caused by genetics in humans, therefore it seems unfair to draw such a comparison. It is also worth stating that most people found the smell of carbon dioxide to be pungent when inhaled at a 50% concentration⁹⁴.

3. Time to onset of unconsciousness

The main disadvantage of carbon dioxide stunning is that although permitted by EU law, this method departs from the normal legal requirement that stunning must produce immediate unconsciousness⁹⁵ or, in cases where unconsciousness is not immediately caused, the induction of unconsciousness should be non-aversive and avoid causing anxiety, pain, distress or suffering, however, the use of carbon dioxide does not ensure either of these two requirements. Gregory et al. studied the effectiveness of this method and suggested that

⁸⁵ ICAFAW. *Stunning of Pigs with Carbon Dioxide*. SUBMISSION TO THE OIE BY THE INTERNATIONAL COALITION FOR ANIMAL WELFARE. (2016).

⁸⁶ Farm Animal Welfare Council (FAWC). (2003). *Report on the Welfare of Farmed Animals at Slaughter or Killing Part 1: Red Meat Animals*.

⁸⁷ Grandin T. (1998a). The feasibility of using vocalization scoring as an indicator of poor welfare during slaughter. *Appl. Anim. Behavior Sci.* 56:121-128.

⁸⁸ Grandin T. (1988c). Behavior of slaughter plant and auction employees toward animals. *Anthrozoö* 1:205-213.

⁸⁹ Griez E., Zandbergen J., Pols H. (1990). Response to 35% CO₂ as a marker of panic and severe anxiety. *Am. J. Psychiatry* 147:796-797.

⁹⁰ Bellodi L., Perna G., Caldirola D., Arancro C., Bertani A., DiBelle D. (1998). CO₂ induced panic attacks: A twin study. *American Journal of Psychiatry* 155:1184-1188.

⁹¹ Perna, G. et al. (1994). *Psychiatry Research*. 52:159-171.

⁹² Perna G., Bertani A., Caldirola D., Bellodi L. (1996). *American Journal of Psychiatry*. 153:1060-1064.

⁹³ Biber B., Alkin T. (1999). *American Journal of Psychiatry*. 156: 739-744.

⁹⁴ Lambooy E., Sybesma W. (1988). The effect of environmental factors such as preslaughter treatment and electrical stunning on the occurrence of haemorrhages in the shoulder of slaughter pigs. *Proc. International Congress of Meat Science and Technology (Brisbane, Australia)* 34:101-103.

⁹⁵ Stevenson P. (2001). *Welfare Problems in Slaughterhouses*. *Compassion in World Farming*. Web page:

https://www.ciwf.org.uk/includes/documents/cm_docs/2008/a/animal_welfare_problems_in_uk_slaughterhouses_2001.pdf

insensibility is not instantaneous and narcosis began 30 to 39 seconds after the start of the immersion procedure into a concentration of 86% carbon dioxide⁹⁶. The results of this study were obtained by examining the changes in vocalization patterns from a normal tone to a slurred and muffled sound. However, it is worth noting that the pigs in this study were stunned using a compact carbon dioxide stunning unit in which the floor of the gondolas moved away while the pigs descending into the carbon dioxide and their chests were also restrained in V-shaped gondolas. Due to this, there has been speculation over whether the prolonged time to onset of unconsciousness was caused by the compression of the thorax interfering with the full inhalation of the gas. In addition, the restraint used is known to add stress to the situation for the pigs as they may struggle and squeal, however, it cannot be totally ruled out that the screaming was caused by the carbon dioxide. Regardless, since Council Directive 93/119/EC⁹⁷ on the protection of animals at the time of slaughter, the drop floor method of gas stunning had been banned based on animal welfare grounds⁹⁸.

The following studies discussed in this section show that the time to loss of consciousness may vary greatly depending on the individual pig and the strength of the concentration of carbon dioxide. Raj and Gregory reported the time to onset of unconsciousness, indicated by loss of posture, at 25, 17, 22 and 15 seconds after immersion into 60, 70, 80 and 90% carbon dioxide, respectively⁹⁹. Similarly, Ring et al. found that after immersing pigs into 80% carbon dioxide, it took 15-20 seconds for the pigs to be rendered unconscious, which led the researchers to the conclusion that this method is quick and humane. That said, however, Ring et al. also found that Beta activity (13 to 30 Hz) in the EEG increased during this period¹⁰⁰. Such increase in Beta activity is commonly considered correlative with the increase of distress, which, in this case is concerning, from an animal welfare perspective¹⁰¹.

Another study conducted by Raj et al. showed varying results. The study recorded somatosensory evoked potentials (SEPs) in the brain to determine the loss of consciousness during exposure to 80% carbon dioxide and results showed that the average time to loss of SEPs was 21.2 ± 6.5 (SD) seconds, however, one pig took 36 seconds to lose SEP¹⁰². It was also reported by Hoenderken et al., who examined changes occurring in the EEGs, that the time to onset of unconsciousness during exposure of pigs to 80% carbon dioxide could be as long as 35 seconds¹⁰³. This rather large variation in the time it takes for pigs to be rendered insensible using carbon dioxide has not yet been established and raises issues and uncertainty about pigs being totally unconscious when convulsing. The table in Annex 1 shows the extent of these variations studied.

There is no such exposure time required by EU law, as it just establishes that the animal should be unconscious and insensible at the moment of slaughter, but leaves the time of exposure up to the operator. However, in the UK, legislation states that animals must be

⁹⁶ Gregory N., Moss B., Leeson R. (1987). An assessment of carbon dioxide stunning in pigs. *Veterinary Record* 121:517-518.

⁹⁷ Council Directive 93/119/EC on the protection of animals at the time of slaughter. Web page: <http://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX:31993L0119>

⁹⁸ Welfare Aspects of Animal Stunning and Killing Methods. EFSA Report 2004

⁹⁹ Raj A.B.M., Gregory, N.G. (1996). Welfare implications of the gas stunning of pigs 2. Stress of induction of anaesthesia. *Animal Welfare*, 5: 71-78.

¹⁰⁰ Ring C., Erhardt W., Kraft H., Schmidt A., Weinmann H.M., Berner H., Unshelm J. (1988). Zur Betäubung von Schlachtschweinen mittels carbon dioxide (carbon dioxide anaesthesia for slaughter pigs). *Fleischwirtschaft*, 68: 1304-1307 and 1478-1484.

¹⁰¹ Welfare Aspects of Animal Stunning and Killing Methods. EFSA Report 2004

¹⁰² Raj A.B.M., Johnson S.P., Wotton S.B., McInstry J.L. (1997a). Welfare implications of gas stunning of pigs 3. Time to loss of Somatosensory Evoked Potentials and Spontaneous Electrocorticogram of pigs during exposure to gases. *British Veterinary Journal*, 153: 329-340.

¹⁰³ Hoenderken R., Van Logtestijn J.G., Sybesma W., Sapnjaard W.J.M. (1979). Kohlendioxid-Betaubung von Schlachtschweinen. *Fleischwirtschaft*, 59: 1572-1578.

dead before they are removed from the gas chamber to prevent animals regaining consciousness. Taking into consideration the Regulation 1099/2009 minimum requirement of 80% concentration of carbon dioxide exposure for pigs stunned using this method in the EU, it is worth calculating the average time to onset of unconsciousness using the results from the studies in the table at said concentration. This results as a minimum average of 19.8 seconds ranging to a maximum average of 28.14 seconds. Another conclusion that can be made by examining the results presented in this table is that, the exposure of pigs to increasing carbon dioxide concentrations decrease the time to loss of consciousness. Therefore, it is reasonable to say that immersion of pigs into as high carbon dioxide concentration as possible shortens the time it takes for them to lose consciousness and consequently reduces the time spent in a state of stress and hyperventilation. This is shown by the progress made from Council Directive 93/119/EC where the minimum carbon dioxide concentration required was 70%, which was later changed to 80% minimum in the new Regulation 1099/2009. Other studies conducted by Barton-Gade, also confirm, by comparing the speed of immersions into the gas, that the faster the pigs are immersed into high concentrations of carbon dioxide, the faster they may lose consciousness¹⁰⁴. In addition, the EFSA report suggests that the exposure of pigs to a minimum of 80% carbon dioxide is better than lower concentrations and should be achieved within 10 seconds after the pigs leave the atmospheric air, in order to reduce the duration of potential distress and suffering. However, despite 80% being the minimum concentration required by EU law¹⁰⁵, the EFSA states that concentration of carbon dioxide at the bottom of the pit in both the existing stunning systems should be at least 90%¹⁰⁶. In fact, another study¹⁰⁷ carried out on the time to onset of unconsciousness with carbon dioxide stunning using two different gas concentrations also concluded that the 80% concentration required by law is not sufficient to reliably stun pigs. The investigations were carried out under practical conditions by exposing pigs to two different gas concentrations (80% and 90% for 73 seconds) in a gondola stunning system. The EEG measurements, blood constituents such as catecholamines and lactates, and clinical reactions such as corneal reflex and heart beats, were examined. The carbon dioxide concentrations were measured continuously close to the head of the pigs when transported up and down in the gondola in order to effectively measure the EEG in the pigs. The results show that there is strong evidence that carbon dioxide concentrations of 80% applied over 70 seconds are not sufficient to stun pigs properly, given that a large majority of the pigs still showed typical reflexes when leaving the stunning equipment. However, when exposed to an atmosphere of 90% carbon dioxide concentration, most of the pigs had already died before being removed from the pit for bleeding.

4. Stun to stick interval and recovery time

Depending on the gas concentrations and exposure time to carbon dioxide gas, this stunning method may be either reversible or irreversible. It is known that, in humans suffering from hypercapnia (too much carbon dioxide in the bloodstream), rapid decline in blood carbon dioxide levels could lead to post-hypercapnic ventricular fibrillation, which occurs when the lower chambers of the heart quiver preventing the heart from pumping any blood and causing cardiac arrest¹⁰⁸. However, this has not been observed in pigs, therefore,

¹⁰⁴ Barton-Gade P.A. (1999). Preliminary investigations on the effect of immersion of pigs in carbon dioxide gas. Danish Meat Research Institute. Internal report Ref. 02.703. Unpublished data.

¹⁰⁵ Council regulation (CE) No. 1099/2009. Web page: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:303:0001:0030:EN:PDF>

¹⁰⁶ Welfare Aspects of Animal Stunning and Killing Methods. EFSA Report 2004

¹⁰⁷ Hartung J, Nowak B., Waldmann K.H., Ellerbrock S. (2002). CO₂-stunning of slaughter pigs: effects on EEG, catecholamines and clinical reflexes.

¹⁰⁸ Web page:

<http://www.heart.org/HEARTORG/Conditions/Arrhythmia/AboutArrhythmia/Ventricular->

once the pig is removed from the gas chamber, another method must be used to ensure death. Regulation 1099/2009 states that; 'depending on how they are used during the slaughtering or killing process, some stunning methods can lead to death while avoiding pain and minimising distress or suffering for the animals. Other stunning methods may not lead to death and the animals may recover their consciousness or sensibility during subsequent painful procedures. Such methods should, therefore, be completed by other techniques that lead to certain death before the recovery of the animals.'¹⁰⁹ It is also said that some stunning protocols may prove to be sufficiently reliable to irreversibly kill the animals in all circumstances if specific key parameters are applied. In which cases, it would not be necessary to check for effective stunning when there is sufficient evidence that a given stunning protocol provides irreversible death to all animals under certain commercial conditions. The insensibility of a pig exposed to carbon dioxide gas can usually be evaluated by checking for indicators such as corneal reflex, also known as the blink reflex, and respiration. Gregory et al. and Raj have also used brain stem reflexes such as absence of gagging or gasping, as well as corneal reflex, to assess the effectiveness of this gas stunning^{110 111}. During anaesthesia, the corneal reflex is the last reflex to disappear when animals are very deeply anaesthetised, just before vascular collapse and consequent death, since the loss of corneal is the last brain function to lose activity as it drives the most crucial activities in the body, such as breathing. That said, the corneal reflex is the first reflex to reappear when recovering for the very deep anaesthetic state¹¹². In 1987, Gregory et al. found that, after being exposed to a maximum concentration of 92% carbon dioxide for 66 seconds in total, 16% of pigs showed a corneal reflex as they were moved to the sticking point and 5% showed pedal reflex when pinching the hind foot, despite the absence of rhythmic breathing or voluntary movements in all pigs¹¹³.

In 2001, Holst conducted an experiment to examine the efficiency of carbon stunning in pigs where a total of 210 were stunned one by one in a mixture of 90% carbon dioxide in the air. The concentration at the first stop was >70% during a total exposure time of 132 seconds, after which the reappearance of certain reflexes was monitored in each pig. Immediately after the end of exposure to the gas, no pigs showed reflexes. The first reflex to return was the corneal reflex, after an average of 42 seconds. Regular breathing returned after an average of 68 seconds and was confirmed as the first sign of return to consciousness. After an average 76 seconds, convulsions occurred but only in 77% of the pigs. Spontaneous blinking of the eye was used as an indicator of an imminent return of consciousness and was noticed after an average of 93 seconds. The final sign of a complete return to consciousness was observed after 171 seconds through conscious movements of the head or legs. Based on these findings, Holst established the following set of guidelines to be used in order to evaluate the efficiency of carbon dioxide stunning. According to Holst, the following signs are good indicators of a successful stun¹¹⁴:

- Absence of rhythmic breathing

Fibrillation UCM 324063 Article.jsp#.WseP1tPFL-Y

¹⁰⁹ Council regulation (CE) No. 1099/2009. Web page: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:303:0001:0030:EN:PDF>

¹¹⁰ Gregory N.G., Moss B.W., Leeson R.H. (1987). An assessment of carbon dioxide stunning of pigs. *Veterinary Record*, 121: 517-518

¹¹¹ Raj A.B.M. (1999). Behaviour of pigs exposed to mixtures of gases and the time required to stun and kill them: welfare implications. *Veterinary Record*, 144: 165-168.

¹¹² Welfare Aspects of Animal Stunning and Killing Methods. EFSA Report 2004

¹¹³ Gregory N.G., Moss B.W., Leeson R.H. (1987). An assessment of carbon dioxide stunning of pigs. *Veterinary Record*, 121: 517-518.

¹¹⁴ Holst S. (2001). Carbon dioxide Stunning of Pigs for Slaughter- Practical Guidelines for Good Animal Welfare. Proc. 47th International Congress of Meat Science and Technology, Krakow, Poland. Vol. I, pp. 48-54

- Absence of gagging or gasping (may be present briefly)
- Absence of convulsions
- Absence of spontaneous blinking of the eye
- Absence of corneal reflex (may be present briefly in a low frequency (<5%) of the total number of pigs, provided that other reflexes are absent)

Regulation 1099/2009 states that the loss of consciousness and sensibility must be maintained until the brain death of the animal, which determines the complete loss of sensibility. It also states that business operators must ensure that persons responsible for stunning or other nominated staff carry out regular checks to ensure that the animals do not present any signs of consciousness or sensibility in the period between the end of the stunning process and death. In addition, those checks must be carried out on a sufficiently representative sample of animals and their frequency must be established taking into account the outcome of previous checks and any factors which may affect the efficiency of the stunning process. The regulation goes on to state that, when the outcome of the checks indicates that an animal is not properly stunned, the person in charge of stunning must immediately take the appropriate measures as specified in the standard operating procedures drawn up in accordance with Article 6 of the regulation¹¹⁵.

In another study, Holst used the corneal reflex as an indicator to show that, as the duration of carbon dioxide exposure increases, the time it takes to regain consciousness is delayed¹¹⁶. The pigs were stunned in a paternoster stunner, also known as a gondola, with >70% carbon dioxide at the first stop position, which was reached within 10 seconds after immersion, and 90% carbon dioxide at the bottom position, reached within 40 seconds. Different but increasing exposure times varying between 112 and 192 seconds in intervals of 10 secs were tested to find that, as the stunning time increase from 112 to 192 seconds, the time to the earliest reappearance of the corneal reflex increased from 20 to 102 seconds respectively. From these results, it can be concluded that, as the exposure time increases, the duration and depth of unconsciousness also increases, therefore meaning that the stun-to-stick interval can be increased without affecting the animal's welfare during that time. Holst proposed a stun-to-stick interval of up to 90 seconds to be adequate enough to ensure the animal's welfare is not put at risk. Based on the findings of this study, the EFSA report established the following guidelines for stun-to-stick intervals using group carbon dioxide stunning equipment with a minimum of 70-80% gas concentration in the air at the first stop of the gondola and 90% concentration at the bottom¹¹⁷.

Total time of exposure (sec)	Sticking within (sec)
120	30
130	45
140	60
150	75
160	90

The EFSA report also pointed out that the information shown in the above table is purely a guideline for stunning times, not a strict requirement or regulation. Therefore, it is advised that, if the recommended exposure times cannot be met then it must be ensured that

¹¹⁵ Council regulation (CE) No. 1099/2009. Web page: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:303:0001:0030:EN:PDF>

¹¹⁶ Holst S. (2001). Carbon dioxide Stunning of Pigs for Slaughter- Practical Guidelines for Good Animal Welfare. Proc. 47th International Congress of Meat Science and Technology, Krakow, Poland. Vol. I, pp. 48-54

¹¹⁷ Welfare Aspects of Animal Stunning and Killing Methods. EFSA Report 2004

no pigs regain consciousness before or during bleeding, by either increasing the gas concentration or increasing the dwell times. It must also be taken into consideration the number of pigs being stunned at one time, for example, it is common to stun 2-3 pigs in each gondola or even up to 7-8 pigs in the new group-wise stunning systems. So, this means that the time required for shackling, hoisting and sticking the last pig in a group, increases with the group size and thus the overall stun-to-stick interval also increases¹¹⁸.

Similarly, another study conducted by Holleben et al. in 2002 established the following guidelines for recommended stun-to-stick interval, as shown in the table below¹¹⁹:

Exposition in +/- 84 %	100 sec	Maximum stun-to-stick time 35 sec
Exposition in >84 %	100 sec	Maximum stun-to-stick time 45 sec
Exposition in >84 %	150 sec	Maximum stun-to-stick time 60 sec

In England, the 2015 Welfare of Animals at the Time of Killing legislation¹²⁰ actually requires pigs to be killed by carbon dioxide before they emerge from the gas. As with many gas killing systems, this works by carbon dioxide partly displacing oxygen so that the brain cannot function and brain death ensues¹²¹. This killing by gas is required due to the fact that although stunned pigs may emerge from the stunning equipment appearing flaccid and unconscious, there is still a possibility that sensitivity may return since exposure to carbon dioxide is reversible, depending on the duration. Compassion in World Farming reported that the problem with carbon dioxide stunning is that although the pig may appear unconscious, they may in fact still be sensible and able to feel pain, indicated by eye blinking and return to rhythmic breathing. CIWF states that, in practice, pigs are generally only exposed to high concentrations of carbon dioxide for approximately 90 seconds, however, 90 seconds is not sufficient to kill all pigs. Consequently, the pigs who have not been killed by the gas can regain consciousness, therefore, it is recommended that pigs should be kept in the gas for longer than 90 seconds and the stun-to-stick interval should be no longer than 15 seconds, in order to avoid the possibility of sticking pigs who have since regained consciousness¹²². The Welfare of Animals at the Time of Killing legislation of England also requires that once immersed in the gas stunner, pigs must be conveyed to the point of maximum concentration of the 80% or more, within a maximum period of 30 seconds. Most stunning systems will involve at least one stop before the animals reach maximum concentration, therefore meaning that each part of the cycle should be no more than 25 seconds and to ensure that animals cannot return to consciousness, a dwell time of 2.5 minutes is required¹²³.

iv. Effects of carbon dioxide stunning on meat quality

¹¹⁸ Welfare Aspects of Animal Stunning and Killing Methods. EFSA Report 2004

¹¹⁹ Holleben K.V., Schütte A., Von Wenzlawowicz M.V., Bostelmann N. (2002). Call for veterinary action in the slaughterhouses - Deficient welfare at carbon dioxide stunning of pigs and captive bolt stunning of cattle. *Fleischwirtschaft Int.* (3), 8-10.

¹²⁰ Welfare of Animals at the Time of Killing (England) Regulations 2015

Web page: http://www.legislation.gov.uk/ukxi/2015/1782/pdfs/ukxi_20151782_en.pdf

¹²¹ Humane Slaughter Association. (2007). Carbon Dioxide Killing and Stunning of Pigs. Web page: <https://www.hsa.org.uk/downloads/technical-notes/TN19-carbon-dioxide-pigs-HSA.pdf>

¹²² Stevenson P. (2001). Welfare Problems in Slaughterhouses. *Compassion in World Farming*. Web page: https://www.ciwf.org.uk/includes/documents/cm_docs/2008/a/animal_welfare_problems_in_uk_slaughterhouses_2001.pdf

¹²³ Humane Slaughter Association (2007). Carbon Dioxide Killing and Stunning of Pigs. Web page: <https://www.hsa.org.uk/downloads/technical-notes/TN19-carbon-dioxide-pigs-HSA.pdf>

As mentioned briefly in the section on electrical stunning, the major negative effect on meat quality of inappropriately administered stunning methods is that they affect the incidence of petechial haemorrhages or blood splash in the flesh. Blood splash is a cosmetic defect that occurs when small capillaries in the muscle of the animal's body ruptures while the circulatory system is still intact and can appear as small red spots or as a bruise when covered by a large area. Such an effect is purely aesthetic and is said to have no effect on animal welfare¹²⁴. Research conducted by Lambooy and Sybesma in 1988 compared the effects on meat quality between the two most commonly used stunning methods. A group of pigs were stunned with 70 volts or 475-volt electricity in the fattening pen and in a restrainer, while another group were stunned with carbon dioxide. They concluded that a high voltage and stunning in a pen resulted in lower incidences of blood splash, however, carbon dioxide stunning showed no blood splash in the pigs¹²⁵.

Similarly, research by Channon et al. confirmed that carbon dioxide stunning will produce less blood splash than the average electrical stunner¹²⁶. In another study by Channon et al., it was found that pigs stunned with carbon dioxide had the lowest incidence of ecchymosis (the escape of blood into the tissues from ruptured blood vessels) in the shoulder and middle primals and concluded that the supply of carbon dioxide stunned pig carcasses to end-users with fewer blemishes can improve both customer satisfaction as well as reduce labour costs associated with the trimming of ecchymosis affected meat from the affected areas of the body¹²⁷. In addition, research by Larsen concluded that carbon dioxide stunning has been proven to be highly effective in terms of decreasing the incidence and extent of ecchymosis and improving worker safety by reducing the kicking actions typically induced by electrical stunning. This is due to the fact that the carbon dioxide stunned pigs remained motionless for up to 60 seconds following exposure to the gas¹²⁸. Barton-Gade reported that carbon dioxide stunning does not reduce the incidence of pale, soft and exudative pork (PSE) but given that the immediate pre-slaughter handling of the pigs may be less stressful in a carbon dioxide stunning system, this may result in better meat quality than with pigs stunned with electricity¹²⁹.

Blood splash in the meat product has been proven to be a problem for the meat industry since audits of pork and beef packing plants by the National Pork Producers Council and the National Cattlemen's Association in the United States indicate that blood splash is costing the pork industry almost 50 cents for every pig marketed¹³⁰ and is costing the beef industry about 12 cents for every slaughter steer or heifer marketed¹³¹. In total, such damages

¹²⁴ Grandin T., Smith G.C. (2004). *Animal Welfare and Humane Slaughter*. Web page: <http://www.grandin.com/references/humane.slaughter.html>

¹²⁵ Lambooy E., Sybesma W. (1988). The effect of environmental factors such as pre-slaughter treatment and electrical stunning on the occurrence of haemorrhages in the shoulder of slaughter pigs. *Proc. International Congress of Meat Science and Technology (Brisbane, Australia)* 34:101-103.

¹²⁶ Channon H.A., Trout G.R., Pengelly A.M., Warner R.D. (1998). *Stunning of pigs: Effect of method, current level and duration on carcass quality of pigs. Manipulating Pig Production VI*, p. 125, Pig Research and Development Corporation, Australia.

¹²⁷ Channon H.A., Payne A.M., Warner R.D. (2002). Comparison of CO₂ stunning with manual electrical stunning (50 Hz) of pigs on carcass and meat quality.

¹²⁸ Larsen H. K. (1982). Comparison of 300 volt manual stunning, 700 volt automatic stunning and CO₂ compact stunning with respect to quality parameters, blood splashing, fractures and meat quality. In G. Eikelenboom (Ed.), *Stunning of animals for slaughter* (pp. 73–81). The Hague: Martinus Nijhoff Publishers.

¹²⁹ Barton-Gade P.A. (1993). Effect of stunning on pork quality and welfare: Danish experience. *Allen D. Leman Swine Conference*, 20, 173–178.

¹³⁰ Morgan, J.B., Cannon F.K., McKeith D., Meeker D., Smith, G.C. (1993). *National Pork Chain Quality Audit (Packer-Processor-Distributor)*. Final Report to the National Pork Producers Council. Colorado State University, Fort Collins, and University of Illinois, Champaign-Urbana.

¹³¹ Smith G.C., Morgan J.B., Tatum J.D., Kukay C.C., Smith M.T., Schnell T.D., Hilton G.G., Lambert C., Cowman G., Lloyd B. (1994). Improving The Consistency And Competitiveness Of Non-Fed Beef; *Derecho Animal. Forum of Animal Law Studies*, vol. 9/4 87

to pig carcasses is costing approximately 43 million dollars annually to the pork industry. Such a large economic loss caused by electric stunning indicates the reason why the focus has shifted to carbon dioxide stunning, despite the latter being more harmful to animal welfare, as shown in the studies discussed in this section¹³².

v. Gas mixtures

Although described in the list of stunning methods table in Regulation 1099/2009, at present, alternative gas mixtures are not used under commercial conditions for stunning or killing pigs¹³³ and whilst an alternative non-aversive gas mixture would be preferable, no such alternatives are currently commercially available¹³⁴. In fact, the Regulation states that carbon monoxide as a pure source and carbon monoxide associated with inert gases are only to be used for piglets in situations other than slaughter, leaving carbon dioxide associated with inert gases (such as argon or nitrogen) or inert gases as the only other alternatives for slaughtering pigs.¹³⁵

vi. Advantages of gas mixtures

It has been suggested that oxygen deprivation is a more humane method of stunning than carbon dioxide inhalation¹³⁶. This can be accomplished by using inert gases such as argon that displace oxygen in the air, which are non-aversive. Oxygen deprivation results in hypoxia which leads to loss of consciousness and subsequent death as neurons become starved of oxygen¹³⁷. Plus, due to the fact that argon is an odourless, non-irritant gas, it is believed that loss of consciousness through argon or nitrogen induced anoxia, for example, may occur with little or no aversion or distress.

vii. Problems with gas mixtures

1. Aversion to gas mixtures and physical effects

There is presently considerable interest in the use of either 90% argon in air or a mixture of 30% carbon dioxide and 60% argon in air for stunning/killing pigs, however, although the carbon dioxide/argon mixture is preferable to the use of high concentrations of carbon dioxide, it causes distress to pigs nonetheless¹³⁸. Research conducted by Raj and Gregory in 1995 used passive avoidance tests in the presence of a reward (an apple) to

And, Improving The Salvage Value Of Cull Cows And Bulls. The Final Report of the National Non-Fed Beef Quality Audit—1994. Final Report to the National Cattlemen's Beef Association. Colorado State University, Fort Collins.

¹³² Morgan, J.B., Cannon F.K., McKeith D., Meeker D., Smith, G.C. (1993). National Pork Chain Quality Audit (Packer-Processor-Distributor). Final Report to the National Pork Producers Council. Colorado State University, Fort Collins, and University of Illinois, Champaign-Urbana.

¹³³ Welfare Aspects of Animal Stunning and Killing Methods. EFSA Report 2004

¹³⁴ Humane Slaughter Association (2007). Carbon Dioxide Stunning and Killing of Pigs. Web page: <https://www.hsa.org.uk/downloads/technical-notes/TN19-carbon-dioxide-pigs-HSA.pdf>

¹³⁵ Council regulation (CE) No. 1099/2009. Web page: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:303:0001:0030:EN:PDF>

¹³⁶ Freed D.L.J. (1983). CO₂ euthanasia. *Nature* 1983, 304, 482.

¹³⁷ American Veterinary Medical Association. AVMA Guidelines for the Euthanasia of Animals: 2013 edition. Web page: <https://www.avma.org/KB/Policies/Documents/euthanasia.pdf> (accessed on 1 October 2014).

¹³⁸ Stevenson P. (2001). Welfare Problems in Slaughterhouses. *Compassion in World Farming*. Web page: https://www.ciwf.org.uk/includes/documents/cm_docs/2008/a/animal_welfare_problems_in_uk_slaughterhouses_2001.pdf

determine aversion to the initial inhalation of argon or carbon dioxide. The results showed that, when exposed to 90% argon concentration (with 2% residual oxygen) in a feeding chamber, all the pigs spent most of their allocated time (3 minutes) feeding on apples. All 6 pigs in trial 1 and 3 out of 6 pigs in trial 2 either became unsteady or lost their posture while they were still feeding on apples presented inside the chamber but none of the pigs showed signs of hyperventilation whilst inhaling argon inside the chamber. Contrastingly, when exposed to 90% carbon dioxide in the feeding chamber, the pigs immediately withdrew their heads and they also spent significantly less time in the feeding box. When 30% carbon dioxide was presented in the feeding chamber, the pigs withdrew their heads either immediately upon smelling the gas or when they started to hyperventilate¹³⁹.

Given that the inhalation of concentrations greater than 30% carbon dioxide by volume in atmospheric air causes aversion in pigs, LLonch et al. conducted a study in 2012 to assess the pigs' aversion to the following three gas mixtures: 70% nitrogen with 30% carbon dioxide (70N30C), 80% nitrogen with 20% carbon dioxide (80N20C) and 85% nitrogen with 15% carbon dioxide (85N15C). Pigs were placed individually at the starting point of the test facility and allowed to enter the crate of a dip-lift stunning system during one control session with atmospheric air, and three treatment sessions with one of the gas treatments in each group. When exposed to the gas mixtures, the majority of pigs (85.80%) performed attempted retreats in the crate, 22.22% exhibited escape attempts and 7.91% vocalized, without differences between gas mixtures. The percentage of pigs gasping increased when exposed to 70N30C compared to 80N20C and 85N15C¹⁴⁰, which confirms that pigs do show aversion to the inhalation of 15-30% carbon dioxide with nitrogen gas mixture compared to the atmospheric air.

In fact, EFSA has stated that hypoxic stunning (oxygen deficiency in the blood) induced with 90% argon in the air is less aversive than hypercapnic (high levels of carbon dioxide in the blood) hypoxia induced with 30% carbon dioxide in argon or nitrogen or stunning with 80-90% carbon dioxide in the air¹⁴¹. Similarly, Raj has expressed that, based on their research, 'from the point of view of the animals' welfare, 90% argon in the air would be the first choice and a mixture of 30% carbon dioxide and 60% argon would be preferable to 80-90% carbon dioxide'¹⁴².

In 1996, Raj and Gregory conducted research to determine the severity of respiratory distress occurring prior to loss of consciousness (indicated by the behavioural change of loss of posture) during exposure to the following concentrations: 90% argon in air, 20, 30, 40, 50, 60, 70, 80 or 90% carbon dioxide in air or a mixture of 30% carbon dioxide and 60% argon. In order to determine the severity, the respiratory sound was used to categorise the distress as either minimum, moderate or severe. The results were as follows: exposure to 90% argon induced minimal respiratory distress prior to loss of consciousness, whereas, exposure to all the concentrations of carbon dioxide in the air induced severe respiratory distress and exposure to the carbon dioxide-argon mixture induced moderate distress¹⁴³.

Another alternative gas stunning method is the use of helium gas, however, very little

¹³⁹ Raj A.B.M., Gregory N.G. (1995). Welfare implications of the gas stunning of pigs 1. Determination of aversion to the initial inhalation of carbon dioxide or argon. *Animal Welfare*, 4: 273-280.

¹⁴⁰ Llonch P, Dalmau A., Rodríguez P., Manteca X, Velarde A. (2012). Aversion to nitrogen and carbon dioxide mixtures for stunning pigs. Web page: <https://www.ufaw.org.uk/downloads/awj-abstracts/v21-1-llonch.pdf>

¹⁴¹ Opinion of the Scientific Panel on Animal Health and Welfare on a request from the Commission related to welfare aspects of the main systems of stunning and killing the main commercial species of animals. 2004. *The EFSA Journal* 45:1-29

¹⁴² Raj A.B.M. (1999). Behaviour of pigs exposed to mixtures of gases and the time required to stun and kill them: welfare implications. *Veterinary Record* (1999) 144: 165-168

¹⁴³ Raj A.B.M., Gregory N.G. (1996). Welfare implications of the gas stunning of pigs 2. Stress of induction of anaesthesia. *Animal Welfare*, 5: 71-78.

research has been conducted into this method and only one study exploring helium stunning in comparison to carbon dioxide stunning has been found online. The objective of this study, carried out by Machtolf et al. in 2013¹⁴⁴, was to determine the stunning properties on the inert gas helium. A total of 80 pigs were stunned in an experimental facility; of which 40 were immersed in a helium enclosure (> 95% concentration) and the other 40 in a commercial carbon dioxide (90% concentration) dip-lift system. Animal welfare implications such as behavior observations, stress hormones and sound level analyses, as well as carcass and meat quality parameters such as analyses of petechial hemorrhages, pH values, sensory evaluation etc. were investigated. In order to evaluate the different stunning procedures from an animal welfare standpoint, each animal was filmed with a video camera and sound levels of vocalization were recorded during the process. The behavior of the pigs was analysed by measuring the time required to overbalance and the duration of uncontrolled muscular excitation and convulsions. The convulsions were graded in the following classifications: (0) negligible, (1) up to five running motions, single head movements, (2) continuous running motions, head movements, (3) massive running motions, recurring movements of the whole body.

The results of this study showed that the pigs stunned with helium showed no aversive behavior inside the gas atmosphere and the pigs overbalanced after 20 seconds which is in accordance with the results obtained by applying the inert gas argon. All pigs (including the pigs stunned with carbon dioxide) showed uncontrolled muscular excitation, lying in side position, however, the pigs stunned with helium gas exhibited grade 1 convulsions whereas the pigs stunned with carbon dioxide showed grade 2. Despite this, the convulsion duration during helium stunning was actually longer than during carbon dioxide stunning. The helium exposure time of 180 seconds was sufficient to ensure a state of unconsciousness and insensibility, until the pigs died of exsanguination and immediately after stunning, during the bleeding process, reflex tests were negative for all animals¹⁴⁵. However, although this study concluded that ‘this research shows the feasibility to stun pigs with helium’ it did not explore the time it takes to loss of consciousness, the physical effects of the gas and the reversibility of the stunning, which are the main concerns from an animal welfare standpoint.

2. Time to onset of unconsciousness by gas mixtures

Research done by Raj and Gregory in 1995 concluded that the time to loss of unconsciousness, indicated by the behavioural change of loss of posture, was on average 35, 24 and 15 seconds in 30kg piglets after exposure to 90% argon, carbon dioxide and argon mixture and 80-90% carbon dioxide, respectively¹⁴⁶. In a similar study conducted by Raj et al., the time to loss of somatosensory evoked potentials (SEPs), and thus unequivocal loss of consciousness was determined and found that the times to loss of SEPs were 9-21, 11-20 and 16-36 seconds after exposure to 90% argon in the air, 30% carbon dioxide with 60% argon in the air and 80-90% carbon dioxide in the air, respectively¹⁴⁷. The longest times recorded for the onset of an isoelectric electrocorticogram (ECoG) were 86, 47 and 44 seconds following exposure to 90% argon in the air, 30% carbon dioxide with 60% argon in the air

¹⁴⁴ Machtolf M., Moje M., Troeger K., Bulte M. (2013). Stunning slaughter pigs using the inert gas helium.

¹⁴⁵ Machtolf M., Moje M., Troeger K., Bulte M. (2013). Stunning slaughter pigs using the inert gas helium.

¹⁴⁶ Raj A.B.M., Gregory N.G. (1995). Welfare implications of the gas stunning of pigs 1. Determination of aversion to the initial inhalation of carbon dioxide or argon. *Animal Welfare*, 4: 273-280

¹⁴⁷ Raj A.B.M., Johnson S.P., Wotton S.B., McInstry J.L. (1997a). Welfare implications of gas stunning of pigs 3. Time to loss of Somatosensory Evoked Potentials and Spontaneous Electrocorticogram of pigs during exposure to gases. *British Veterinary Journal*, 153: 329-340

and 80-90% carbon dioxide in the air, respectively. These results suggest that the exposure time required to kill pigs with this method of anoxia would be longer than the required time for hypercapnic stunning (with carbon dioxide)¹⁴⁸.

Investigations under commercial conditions have been carried out by Raj in 1999 to determine whether the use of other gas mixtures using the Combi system. The concept for this system is based on the pigs being driven forward to the stunning equipment in groups in a manual driveway. The pigs are then divided into smaller groups and driven into the stunning boxes, which are lowered into a carbon dioxide atmosphere by a gondola or lift system. After stunning, the pigs are tipped out from the stunning boxes for shackling and sticking. According to the manufacturer Butina's website, the advantages of this system are 1) high level of consideration for animal welfare 2) handles groups of two pigs in each box 3) utilizes the natural curiosity of the pigs 4) less stressed pigs gives improved meat quality and 5) better working environment for operating and mechanical personnel¹⁴⁹. However, with this Combi system, the main disadvantage is that only one pig at a time can enter the stunning box, compared to the paternoster for example, where pigs can enter the crate in groups, keeping their natural will to stay in groups and therefore reducing stress ante-mortem. In the study conducted by Raj, 2 or 3 pigs were loaded per cradle and immersed in either 90% argon in the air or a mixture of 30% carbon dioxide and 60% argon in the air and exposed to each of the mixtures for 3, 5 and 7 minutes to determine the proportion of pigs killed and the ideal stun-to-stick intervals for the pigs that survived after exposure¹⁵⁰.

The approximate time elapsed between the pigs leaving the gas chamber and sticking was 25, 35 and 45 seconds, respectively, for the first, second and third pig hoisted from a single batch of three. The animals were examined when exiting the gas and again 5 seconds after sticking (in total, 50 seconds after exiting the gas) for the presence of gagging, corneal reflex, response to a nose prick and any convulsions in the body during bleeding. The results of this study concluded that after exposure of pigs to either argon-induced anoxia or the carbon dioxide-argon mixture for 3 minutes, recovery can be avoided in pigs by sticking them with 25 seconds from exiting the alternative gas mixtures, however, carcass convulsions occurred during bleeding. In addition, exposure to the same mixture for 5 minutes and bleeding with 45 seconds prevented the resumption of consciousness in pigs and carcass convulsions during bleeding. And finally, exposure to only argon-induced anoxia for 7 minutes resulted in death in the majority of pigs, however, to the carbon dioxide-argon mixture for 7 minutes resulted in death in all pigs¹⁵¹.

It is worth noting that, after exposing pigs to the mixtures for 3 minutes, the convulsions that occurred during bleeding may be a sign of the pigs regaining consciousness and is therefore not recommended that this amount of time be used for stunning with these gas mixtures in practical slaughterhouse conditions. Warriss and Wotton suggested that pigs could be exposed to either argon or a carbon dioxide-argon mixture for 3 minutes to stun them and then immediately kill them when returned to atmospheric air by inducing cardiac arrest with an electric current across the chest, for example 90V, 50 Hz sine wave AC for 5 seconds, within 25 seconds of leaving the gas mixture¹⁵². It has also been suggested in the EFSA report that cardiac arrest could be induced when the pigs are still inside the chamber in the gas mixture, which would eliminate all chances of recovery due to stun-to-stick interval

¹⁴⁸ Raj A.B.M., Johnson S.P., Wotton S.B., McInstry J.L., (1997a). Welfare implications of gas stunning of pigs 3. Time to loss of Somatosensory Evoked Potentials and Spontaneous Electrocardiogram of pigs during exposure to gases. *British Veterinary Journal*, 153: 329-340

¹⁴⁹ Web page: <http://www.butina.eu/products/combi/>

¹⁵⁰ Raj A.B.M. (1999). Behaviour of pigs exposed to mixtures of gases and the time required to stun and kill them: welfare implications. *Veterinary Record*, 144: 165-168.

¹⁵¹ Raj A.B.M. (1999). Behaviour of pigs exposed to mixtures of gases and the time required to stun and kill them: welfare implications. *Veterinary Record*, 144: 165-168.

¹⁵² Warriss P.D., Wotton S.B. (1981). Effect of cardiac arrest on exsanguination in pigs. *Research in Veterinary Science*, 31: 82-86.

delays¹⁵³. The report also concluded that, the available scientific evidence clearly suggests that stunning pigs with inert gas mixtures such as nitrogen and/or argon is the best option from an animal welfare standpoint. Similarly, Raj et al. stated in 1997 that 'killing pigs with argon-induced anoxia must be the first choice on welfare grounds and a mixture of 30% carbon dioxide and 60% argon in the air appears to be more humane than using a high concentration of carbon dioxide.'¹⁵⁴

However, in commercial practice there could be problems with both argon and a mixture of carbon dioxide and argon due to the fact that neither lead to rapid death and the duration of unconsciousness induced by a given exposure time of minimum 3 minutes to alternative gas mixtures is a lot shorter than that achieved by stunning with high concentrations of carbon dioxide. Therefore, given this short duration, EFSA recommends that pigs must be either killed in the gas mixtures or subsequently killed by inducing electrical cardiac fibrillation¹⁵⁵. In fact, Compassion in World Farming (CIWF) has stated that pigs must be left in the gas chamber until 100% of the animals are dead, since pigs can recover consciousness relatively quickly after stunning if they are not left in the gas long enough to kill them. Therefore, CIWF states that it is essential that pigs are kept in the gas for a sufficient amount of time to cause death and also, that there is a short stun-to-stick interval to prevent any that are not killed from the gas from regaining consciousness¹⁵⁶. Based on the findings of Raj, it was only after 7 minutes of exposure to a carbon dioxide-argon mixture that all of the pigs were killed¹⁵⁷, which is a considerable period of time to be immersed in a gas mixture before death is caused. For this reason, CIWF fears that, under commercial conditions and with such a fast production line and high numbers of pigs to slaughter within a set amount of time, the animals may not be immersed in the gas for sufficiently long or, the stun-to-stick intervals may be too long to avoid problems.

To conclude, although neither loss of consciousness nor death are immediate even with inert gas mixtures, the studies discussed show that it takes longer for pigs to lose brain responsiveness when exposed to high levels of carbon dioxide than in the case of argon or a mixture of carbon dioxide and argon, which implies that the use of high levels of carbon dioxide should be abandoned and replaced with other gas mixtures. Despite this, due to the lack of purpose built equipment, inert gases are not implemented under field conditions and the Farm Animal Welfare Committee (FAWC) recommended that the government and industry should fund research and development to achieve this. In an ideal situation proposed by the FAWC in 2003, such a system should incorporate the following principles to maximize the pigs' welfare at slaughter¹⁵⁸:

- Pigs should be maintained in a stable social group with the minimum of restraint;
- Pre-slaughter handling facilities should be designed to minimise stress;
- The gas used to induce unconsciousness should be non-aversive;
- All pigs should be rendered rapidly unconscious in the gas;

¹⁵³ Welfare Aspects of Animal Stunning and Killing Methods. EFSA Report 2004

¹⁵⁴ Raj A.B.M., Johnson S.P., Wotton S.B., McKinstry J.L. (1997). Welfare implications of gas stunning pigs: 3. The time to loss of somatosensory evoked potentials and spontaneous electrocorticogram of pigs during exposure to gases. *Veterinary Journal* 153: 329-340.

¹⁵⁵ Welfare Aspects of Animal Stunning and Killing Methods. EFSA Report 2004

¹⁵⁶ Stevenson P. (2001). Welfare Problems in Slaughterhouses. *Compassion in World Farming*. Web page:

https://www.ciwf.org.uk/includes/documents/cm_docs/2008/a/animal_welfare_problems_in_uk_slaughterhouses_2001.pdf

¹⁵⁷ Raj A.B.M. (1999). Behaviour of pigs exposed to mixtures of gases and the time required to stun and kill them: welfare implications. *Veterinary Record*, 144: 165-168.

¹⁵⁸ FAWC (Farm Animal Welfare Council), 2003. Report on the welfare of farmed animals at slaughter or killing. Part 1: Red meat animals, June 2003 (www.fawc.org.uk).

- An irreversible state of unconsciousness must be reached in all pigs prior to sticking, however if this cannot be accomplished, the stun-to-stick interval should be as short as possible (less than 25 seconds); and,
- There should be adequate monitoring of the system and efficient evacuation in the event of any system failure.

viii. Effects of gas mixtures on meat quality

Increased physical activity or stress immediately before slaughter is associated with a faster pH decline in the meat because of increase ATPase activity and lactate accumulation in the muscle^{159 160 161}. Troeger et al.¹⁶² showed that pigs stunned with mixtures of argon and carbon dioxide with low concentrations of oxygen resulted in a longer and more intense muscle excitation phase compared with pigs exposed to high concentrations of either argon or carbon dioxide, which causes an acceleration of the muscle glycolytic process at death. Such muscular contractions during and after stunning have been suggested to have a negative effect on pork quality¹⁶³. This is because they cause a more rapid drop in pH and a reduced water-holding capacity due to the increase of post-mortem protein denaturation¹⁶⁴ and it is believed that an increase in the rate of post-mortem pH fall increases the incidence of PSE meat¹⁶⁵.

Having said that, the results of a study conducted by Llonch et al., which aimed to assess the effect of exposure to various concentration mixtures of nitrogen and carbon dioxide, compared to the commercial stunning of 90% carbon dioxide, showed that although aversion occurred several seconds after the beginning of exposure to the gas mixtures, until the loss of balance (approximately 28 seconds), the stress response at this time might have been too weak to cause metabolic changes at the muscle level, which would usually result in poor meat quality¹⁶⁶. Their results also showed that animals stunned with a mixture of 80% nitrogen with 20% carbon dioxide (80N20C) and 85% nitrogen with 15% carbon dioxide (85N15C) showed a longer muscular excitation and had a lower pH45 than the other groups (70N30C and 90C), suggesting that there was a negative correlation between duration of muscular excitation and pH45. No PSE pork was found in their study, however, the higher prevalence of RSE meat (meaning red, soft and exudative, which is considered a milder form of PSE pork¹⁶⁷) was found in animals stunned with 85N15C followed by 80N20C and 70N30C. The results of the study concluded that, as the carbon dioxide concentration of gas

¹⁵⁹ Monin G. (1988). Stress d'abattage et qualités de la viande. *Recueil de Médecine Vétérinaire* 164, 835–842.

¹⁶⁰ D'Souza D.N., Dunshea F.R., Warner R.D., Leury B.J. (1999). Comparison of different dietary magnesium supplements on pork quality. *Meat Science* 51, 221–225.

¹⁶¹ Terlouw C. (2005). Stress reactions at slaughter and meat quality in pigs: genetic background and prior experience. A brief review of recent findings. *Livestock Production Science* 94, 125–135.

¹⁶² Troeger K., Machold U., Moje M., Behrschmidt M. (2005). Gas stunning of pigs. A comparison of carbon dioxide, argon, a nitrogen/argon mixture and argon/carbon dioxide under meat quality aspects. 3. Summary and discussion of results; conclusions. *Fleischwirtschaft* 5, 109–111

¹⁶³ Van der Wal P.G. (1997). Causes for variation in pork quality. *Meat Science* 46, 319–327

¹⁶⁴ Warris P.D., Brown S.N. (1987). The relationship between initial pH, reflectance and exudation in pig muscle. *Meat Science* 20, 65–74.

¹⁶⁵ Troeger K., Woltersdorf W. (1991). Gas anaesthesia of slaughter pigs. Stunning experiments under laboratory conditions with fat pigs of known halothane reaction type: meat quality and animal protection. *Fleischwirtschaft* 71, 1063–1068

¹⁶⁶ Llonch P., Rodríguez P., Gispert M., Dalmau A., Manteca X., Velarde A. (2011). Stunning pigs with nitrogen and carbon dioxide mixtures: Effects on animal welfare and meat quality, <https://www.ncbi.nlm.nih.gov/pubmed/22436284>

¹⁶⁷ Faucitano L., Ielo M.C., Ster C., Lo Fiego D.P., Method S., Saucier L. (2010). Shelf life of pork from five different quality classes. *Meat Science* 84, 466–469.

mixture was decreased, the prevalence of exudative pork increased as exposure to 90C reduces muscular excitation compared to the nitrogen and carbon dioxide mixtures, leading to a lower incidence of RSE meat.

Another observation found in the study was that the presence of ecchymosis in the meat was also affected by the duration of muscular excitation. The results showed that increased muscular excitation during exposure to nitrogen and carbon dioxide mixtures caused a higher incidence of ecchymosis compared to the 90C exposure. In theory, this could be explained by the suggestion from Troeger et al.¹⁶⁸ that the low concentration of residual oxygen in the atmosphere also contributes to the occurrence of ecchymosis in the carcasses of pigs stunned with hypoxia, given that the lack of oxygen in the blood vessels induces the release of catecholamines¹⁶⁹ and causes vasodilation¹⁷⁰, resulting in increased blood supply and pressure. However, in this study, the range of oxygen concentration in the gas mixtures (from 1% to 2% of volume in atmosphere air) didn't show any significant differences between the groups tested. Consequently, the differences in the incidence of ecchymosis cannot definitely be put down to the differences in oxygen concentrations. Therefore, other than vasodilatation, it could be that ecchymosis was caused by the rupture of muscle capillaries induced by the vigorous muscular contractions, especially given the superficial location of the blood splashes, since blood vessels on the surface are easier to tear due to muscle contraction and blood pressure rise compared to those location inside the muscle¹⁷¹. Results of the study showed that 25% of pigs exposed to nitrogen and carbon dioxide mixtures had ecchymosis in their carcasses, whereas no ecchymosis was present in animals stunned with 90C. Therefore concluding that, although nitrogen and carbon dioxide stunning exhibit fewer signs of aversion than 90C, their induction time to unconsciousness is longer and this may negatively affect meat and carcass quality¹⁷² and hence dissuade the industry from employing such methods.

c. Alternative methods

Alternatives to the commonly used gas and electric stunning methods also exist but are not commercially used or accepted.

i. Waterjet and electro-immobilisation stunning

One of these alternatives is the waterjet stunning method which was developed in Switzerland to stun/kill pigs but was later discontinued¹⁷³. This method works by using high pressure water droplets which are shot in the head and brain of pigs by a water gun applied to the frontal bone¹⁷⁴. The immediate death of the animal is ensured but it causes frequently

¹⁶⁸ Troeger K., Machold U., Moje M., Behrschmidt M. (2005). Gas stunning of pigs. A comparison of carbon dioxide, argon, a nitrogen/argon mixture and argon/carbon dioxide under meat quality aspects. 3. Summary and discussion of results; conclusions. *Fleischwirtschaft* 5, 109–111

¹⁶⁹ Machold U., Troeger K., Moje M. (2003). Gas stunning of pigs – a comparison of carbon dioxide, argon, a nitrogen–argon–mixture and argon/carbon dioxide, (2 steps-system) under animal welfare aspects. *Fleischwirtschaft* 83, 109–114.

¹⁷⁰ Wadsworth R.M. (1994). Vasoconstrictor and vasodilator effects of hypoxia. *Trends in Pharmacological Sciences* 15, 47–53.

¹⁷¹ Troeger K., Machold U., Moje M., Behrschmidt M. (2005). Gas stunning of pigs. A comparison of carbon dioxide, argon, a nitrogen/argon mixture and argon/carbon dioxide under meat quality aspects. 3. Summary and discussion of results; conclusions. *Fleischwirtschaft* 5, 109–111

¹⁷² Llonch P., Rodríguez P., Gispert M., Dalmau A., Manteca X., Velarde A. (2011). Stunning pigs with nitrogen and carbon dioxide mixtures: Effects on animal welfare and meat quality, <https://www.ncbi.nlm.nih.gov/pubmed/22436284>

¹⁷³ Welfare Aspects of Animal Stunning and Killing Methods. EFSA Report 2004

¹⁷⁴ Schatzmann U., Howard J., Pittino U., Fuchs P. (1993). Jet injection for stunning slaughter pigs

heavy destruction of the rear parts of the head, resulting in very severe carcass convulsions which leads to safety problems during the handling of the carcass. It is worth noting that electro-immobilisation must not be confused with electric stunning as it involves the passing of low voltage current through the body, by the application of two electrodes to the body in different ways depending on the degree or area of immobilisation required. The effect is to cause tetanic contracture of the skeletal muscles either of the entire body or of a body region, when the current is applied and the effect disappears immediately after the current is removed¹⁷⁵. It does not make the animal unconscious and insensible to pain, it just paralyses the animal, who may not be able to vocalise or struggle, given the fact that their muscles are paralysed. Research in many different laboratories has shown that electrical immobilisation is very aversive and should not be used as a substitute for a well-designed restraint device¹⁷⁶.

Experiments to explore waterjet suitability were conducted under laboratory conditions with post-mortem material such as pig heads and live pigs, by Lambooji and Shatzmann¹⁷⁷. Immediate unconsciousness, as determined by electroencephalogram, was initiated by a rapid penetration of the skin and skull which caused the destruction of brain tissue between 0.2–0.4 seconds. However, as mentioned, a common problem associated with waterjet stunning is convulsions given that, when an animal is decerebrated (removal of the cerebrum), convulsions of the carcass occur, mainly in the hind limbs¹⁷⁸ ¹⁷⁹. To avoid such convulsions, an immobilizing current of 40V (100 mA) may be used throughout the body, making the method applicable in a slaughterhouse. In this study by Lambooji and Shatzmann, a pressure of 3900 bar was applied via tubes to a fixed nozzle in the head restraining device of an automatic stunner, at a speed of 2ml of water injected per 50ms. The pigs were restrained and stunned with the waterjet, then as soon as possible the pigs were exsanguinated under vacuum, using a hollow knife stuck into the heart, while lying on their backs on electrodes to immobilize them with 40V (100 mA) during the bleeding out process. Another group of pigs used as the ‘control’ were stunned using the head-only electric stunning method and were not electro-immobilised. The results showed that fewer haemorrhages were observed in the shoulders of pigs stunned with the waterjet when combined with electro-immobilisation¹⁸⁰, however, although electro-immobilisation would reduce carcass movements and thus haemorrhages, the disadvantages from an animal welfare standpoint are great¹⁸¹. Grandin has even expressed that the use of electricity to immobilise and paralyse animals to hold them still is very aversive, bad for animal welfare and it should be forbidden¹⁸².

A study carried out by Lambooji¹⁸³ using calves, sheep and pigs, found that breathing was impaired in all animals during administration of an electrical current using an electro-

tested on a slaughter line. *Fleischwirtschaft* 73, 126-128.

¹⁷⁵ Animal Welfare Standards, 2013. Cattle Electro-immobilisation discussion paper public consultation version 1.3.13. Web page: <http://www.animalwelfarestandards.net.au/files/2011/02/Cattle-Electroimmobilisation-discussion-paper-1.3.13.pdf>

¹⁷⁶ Grandin T. Electro-immobilisation is not a humane method of restraint. Web page: <http://www.grandin.com/humane/electro.html>

¹⁷⁷ Lambooji E., Schatzmann U. (1994). The use of a high pressure waterjet combined with electroimmobilization for the stunning of slaughter pigs: Some aspects of meat quality.

¹⁷⁸ Leuenberger Th. (1989). Jet-injektion beim Schwein; Untersuchungen i~ber die Anwendbarkeit einer Hochdruckwasserstrahls zur Bet~tubung von Schlachtschweinen. Thesis, Bern.

¹⁷⁹ Schatzmann U., Leuenberger Th., Fuchs P., Howald M., Howard, J. (1990). *Fleischwirtschaft.*, 70, 890

¹⁸⁰ Lambooji E., Schatzmann U. (1994). The use of a high pressure waterjet combined with electroimmobilization for the stunning of slaughter pigs: Some aspects of meat quality.

¹⁸¹ Welfare Aspects of Animal Stunning and Killing Methods. EFSA Report 2004

¹⁸² Grandin T. Electro-immobilisation is not a humane method of restraint. Web page: <http://www.grandin.com/humane/electro.html>

¹⁸³ Lambooji E. (1985). Electroanaesthesia or electroimmobilisation of calves, sheep and pigs by the Feenix Stockstill. *The Veterinary Quarterly* 7 (2): 120.

immobilisation device and that body temperature, plasma cortisol and pulse rate were raised and the pulse rate was irregular, including ECG recordings showing unspecified pronounced changes in cardiac activity. In addition, particularly at the higher currents, electro-immobilisation (followed by water jet or any other killing method) scientifically affects respiration so the incidence and duration of apnoea and asphyxia is a major concern for animal welfare. Deaths associated with electro-immobilisation have even been reported, presumably from hypoxia due to the respiratory paralysis, combined with tachycardia¹⁸⁴.

The use of electro-immobilisation is not banned by the European Union, however, some individual member states such as the United Kingdom and Ireland have banned its use. Compassion in World Farming have categorised this stunning method as a ‘bad system and practice’ given the fact that it does not render the animal insensible to pain or unconscious due to the low currents used¹⁸⁵. The 2005 Irish report on the use of electro-immobilisation stated that ‘it is quite a cruel form of restraint, causing distress and aversive reactions, and may increase the likelihood of minor surgical procedures being carried out cruelly, i.e. without analgesia’¹⁸⁶.

ii. High energy microwave irradiation

This alternative method involves raising the brain temperature to the point at which insensibility occurs¹⁸⁷ and was tested in pigs by Lambooji et al.¹⁸⁸ in 1990. The study involved irradiation of pigs’ heads (obtained post mortem) with a power output of 6 kW delivered using 2450 MHz for 1.5 to 2.5 seconds. It was concluded that an output of 45 to 70 kW would be necessary to kill pigs, however, the results were the same as a previous report on rats regarding the uneven distribution of temperature within the brain. This uneven heat distribution occurring in the brain during microwave irradiation poses a threat to animal welfare, however, it is believed that this risk could be reduced or alleviated by a simultaneous application of high energy electromagnetic fields, also known as transcranial magnetic stimulation (TMS), as reported in rats¹⁸⁹. Although little investigation has been done on this particular method in pigs, other studies have been conducted with sheep and cattle. A 2017 study by McLean et al.¹⁹⁰ looked at the development of a microwave energy delivery system for the reversible stunning of cattle. This study looked at developing a stunning method which would be suitable for certain markets such as Kosher and Halal in which stunning is disallowed due to the fact that, in both Judaism and Islam it is believed that the animal must be ‘whole and undamaged’. In this experiment, cadaver heads were used to demonstrate that brain temperature could be raised to a point at which insensibility would be expected to occur (44 degrees Celsius) and to calculate the power and time combinations require to achieve this in a range of cattle weights. It was noted that the main difficulty in administering this method of stunning is penetrating the brain with waves and reducing excessive surface

¹⁸⁴ Animal Welfare Standards (2013). Cattle Electro-immobilisation discussion paper public consultation version 1.3.13. Web page: <http://www.animalwelfarestandards.net.au/files/2011/02/Cattle-Electroimmobilisation-discussion-paper-1.3.13.pdf>

¹⁸⁵ Compassion in World Farming (2014). CIWF Policies on Animal Welfare. Web page: <https://www.ciwf.org.uk/media/5471512/ciwf-policies-on-animal-welfare.pdf>

¹⁸⁶ Sub-committee to the Scientific Advisory Committee on Animal Health and Welfare, 2005. The use of electro-immobilisation on live farm animals in Ireland.

¹⁸⁷ Web page: <https://faanalytics.org/using-microwave-energy-better-welfare-slaughter/>

¹⁸⁸ Lambooji E., Lagendijk J.J.W., Van Rhooen G.C. (1990). Feasibility of stunning slaughter pigs with microwaves at 434 MHz. *Fleischwirtschaft*, 2: 3-5.

¹⁸⁹ Welfare Aspects of Animal Stunning and Killing Methods. EFSA Report 2004

¹⁹⁰ McLean D., Small A.H., Meers L., Owen J.S., Ralph J. (2017). Development of a microwave energy delivery system for reversible stunning of cattle

heating of the skin. Another study by Small et al., performed on four anaesthetised sheep confirmed this finding in a live animal model where brain temperatures between 43 and 48 degrees Celsius were achieved with 20 seconds of microwave energy application¹⁹¹. None of the studies conducted have examined the physical effects that this method would have on the animals, however, it can be assumed that microwaving the brain of a live animal to at least 43 degrees would involve consequences from an animal welfare perspective.

iii. Lethal injection

The killing method of lethal injection is commonly used to euthanise or ‘put down’ pets with terminal illnesses, behavioural problems or old age and is generally believed to be the most humane and ‘kind’ thing to do in certain circumstances. The animal is injected intravenously with a lethal dose of anaesthetic drugs following, in some cases, initial injection of a sedative to prevent movement during the injection. The animal rapidly loses consciousness and dies. The most commonly used drugs for this are barbiturates in combination with other drugs and the animal should always be restrained to guarantee that the administration of the drug is effective. Intravenous administration is preferred, however, intraperitoneal or intramuscular administration are also options, although they are very painful not recommended. In addition, the animal should always be monitored throughout the administration and the following period to ensure that the drug have been effectively administered and death can be confirmed by the absence of brainstem reflexes¹⁹².

Once injected into the vein, the barbiturate depresses the central nervous system, removing awareness and causing the animal to fall into a state of unconsciousness similar to anaesthesia. In this state of deep anaesthesia, within seconds the animal stops breathing and succumbs to cardiac arrest. Generally, according to the Humane Society of the United States Euthanasia Reference Manual, after 5 seconds the animal is unconscious, within 10 seconds the animal is in deep anaesthesia, within 20 seconds the animal stops breathing, within 40 seconds the heart stops circulating blood and finally, within 2 minutes the animal is clinically dead meaning that all voluntary and involuntary functions cease, apart from the occasional muscle twitch¹⁹³. To many this may seem like the most obviously humane way to kill an animal and therefore should be the preferred method of choice at slaughter, however, when an animal is killed by lethal injection, there may be restrictions on how the carcass can be disposed of since the carcass cannot be used for human or animal consumption if it has been killed by lethal injection.

v. Future alternatives

In 2017, it was announced that the Department for Environment, Food and Rural Affairs (DEFRA) and the Humane Slaughter Association (HSA) are jointly offering up to £400,000 of research funding for a project to develop of more humane way to stun pigs during commercial slaughter. This research project has been introduced due to the fact that HSA expressed that research has shown that pigs find direct exposure to high concentrations of carbon dioxide aversive and a 2003 report by the Farm Animal Welfare Council (FAWC) recommended that this method should be phased out. The following year a report by EFSA confirmed the effectiveness of the method but noted that it resulted in respiratory distress in pigs. Similar concerns were expressed for poultry and alternative controlled atmosphere

¹⁹¹ Small A.H., McLean. D, Keates H.L., Owen J.S., Ralph J. (2013). Preliminary investigations into the use of microwave energy for reversible stunning of sheep.

¹⁹² The Humane Slaughter Association. Lethal Injection. Web page: <https://www.hsa.org.uk/lethal-injection/lethal-injection-1>

¹⁹³ Farricelli A.J. (2018). Understanding Dog Pain during Euthanasia. Web page: <https://pethelpful.com/dogs/Understanding-Dog-Pain-During-Euthanasia>

systems are now in use in the poultry industry due to this, as reported by HSA. Both Defra and HSA have said that they are committed to improving the welfare of animals at slaughter and that the funding aimed to develop and or validate a ‘more humane method which could replace high-concentration carbon dioxide stunning of pigs’. The project aims to ensure that any proposed method is not only more humane but also practically and economically viable so that it is likely to be widely adopted by the pig industry¹⁹⁴.

6. ENFORCEMENT OF LAWS ON STUNNING METHODS

i. Implementation of monitoring procedures

Regulation 1099/2009 includes two articles (16 and 17)¹⁹⁵ which describe the monitoring procedures at slaughterhouses and the designation of an animal welfare officer to ensure the correct enforcement of the Regulation. Article 16 states that business operators shall put in place and implement appropriate monitoring procedures in slaughterhouses for each slaughter line. The frequency of the checks shall take into account the main risk factors, such as changes regarding the types or the size of animals slaughtered or personnel working patterns and shall be established so as to ensure results with a high level of confidence. Article 17 states that;

1. Business operators shall designate an animal welfare officer for each slaughterhouse to assist them in ensuring compliance with the rules laid down in this Regulation.
2. The animal welfare officer shall be under the direct authority of the business operator and shall report directly him or her on matters relating to the welfare of animals. He or she shall be in a position to require that the slaughterhouse personnel carry out any remedial actions necessary.
3. The responsibilities of the animal welfare officer shall be set out in the standard operating procedures of the slaughterhouse and effectively brought to the attention of the personnel concerned.
4. The animal welfare officer shall hold a certificate of competence issued for all the operations taking place in the slaughterhouse for which he or she is responsible.
5. The animal welfare officer shall keep a record of the action taken to improve animal welfare in the slaughterhouse in which he/she carries out his/her tasks. This record shall be kept for at least one year and shall be made available to the competent authority upon request.
6. Paragraphs 1 to 5 shall not apply to slaughterhouse slaughtering less than 1000 livestock units of mammals or 150000 birds or rabbits per year¹⁹⁶.

The national authorities responsible for implementing slaughter regulations must ensure that the people involved in the handling of animals from the moment of arrival to the act of slaughter have the necessary skills to perform their tasks humanely and efficiently¹⁹⁷. For example, in the UK, Defra is responsible for enforcing the EU Regulation 1099/2009

¹⁹⁴ The Humane Slaughter Association. Funding Opportunity – Development of an alternative method to high concentration CO2 for the commercial stunning of pigs. Web page: <https://www.hsa.org.uk/grants-awards/hsa-defra-funding-opportunity>

¹⁹⁵ Council regulation (CE) No. 1099/2009. Web page: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:303:0001:0030:EN:PDF>

¹⁹⁶ Council regulation (CE) No. 1099/2009. Web page: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:303:0001:0030:EN:PDF>

¹⁹⁷ Animal Welfare Intergroup (2010). Analysis of Animal Welfare Issues in the European Union. Web page: <http://www.animalwelfareintergroup.eu/wp-content/uploads/2011/10/EurogroupForAnimals-AreasOfConcern2010.pdf>

and monitors slaughterhouses to make sure that the animals are protected before and during slaughter. Certificates of competence for slaughterers and other operatives working with animals such as handlers or shacklers to make sure the right training has been done for the appropriate duties. According to the UK Government website¹⁹⁸, specially trained Official Veterinarians carry out the checks to make sure that there have been no issues concerning the welfare of animals presented for slaughter, however it does not state how often these checks are carried out, although it does say that business operators will receive ‘reasonable notice of an inspection’¹⁹⁹. Such checks are made:

- On the unloading and handling of animals
- Where they are kept prior to slaughter
- Restraining of animals
- Positioning of the stunning equipment
- On the effectiveness of the stun
- The efficiency of the bleeding

Despite this, Compassion in World Farming has stated in their report on the ‘Welfare of pigs in the European Union’ that current EU legislation on the welfare of pigs is inadequate to protect welfare and is poorly enforced²⁰⁰. CIWF has also expressed that ‘regulations on animal welfare at slaughter are too often ignored and slaughter personnel are poorly trained. Many, or even most, countries fail adequately to inspect slaughterhouses or to enforce the law sufficiently rigorously. Investigations continue to reveal illegal and inhumane practices.’²⁰¹ Furthermore, over recent years, European Commission Veterinary inspections in several member states revealed various animal welfare problems due to poor implementation and enforcement of existing legislation. Some inspections were undertaken as a result of complaints from animal welfare societies and the most frequent problem has been shown to be inadequate stunning, with slaughterhouse staff not knowing how to use stunning equipment, which is frequently poorly maintained²⁰².

During a session in 2015, the intergroup ‘Eurogroup for Animals’²⁰³ called on the Commission to phase out killing methods which cause intense suffering to animals, such as the use of carbon dioxide stunning pigs, given that most citizens believe that the new Council Regulation 1099/2009 has improved the conditions and welfare of animals at the time of killing, when in fact it has been demonstrated that the improvements have been very limited and that methods which are a major source of suffering, pain and distress such as this one, are still widely used. The Senior Policy Officer for farm animals at Eurogroup for Animals, Michel Courat, analysed the regulation and highlighted some of the positive points, such as the obligation for staff to receive training and for slaughterhouses to have an Animal Welfare officer, however, he also denounced the negative points such as the possibility of still using carbon dioxide stunning for pigs. He went on to state that ‘poor implementation and enforcement has been reported by the Food and Veterinary Office (FVO) inspectors but

¹⁹⁸ Web page: <https://www.food.gov.uk/business-guidance/animal-welfare>

¹⁹⁹ DEFRA (2015). Slaughterhouses, knacker's yards and farms: inspections and penalties. Web page: <https://www.gov.uk/guidance/slaughterhouses-knackers-yards-and-farms-inspections-and-penalties>

²⁰⁰ Compassion in World Farming. The Welfare of pigs in the European Union report. Web page: <https://www.ciwf.org.uk/media/3818889/welfare-of-pigs-in-the-european-union.pdf>

²⁰¹ Compassion in World Farming (2009). Slaughter factsheet. Web page:

<https://www.ciwf.org.uk/media/3818632/slaughter-factsheet.pdf>

²⁰² Animal Welfare Intergroup (2010). Analysis of Animal Welfare Issues in the European Union. Web page: <http://www.animalwelfareintergroup.eu/wp-content/uploads/2011/10/EurogroupForAnimals-AreasOfConcern2010.pdf>

²⁰³ Eurogroup for Animals (2015). Commission must ensure proper implementation and enforcement of the slaughter regulation immediately. Web page: <http://www.eurogroupforanimals.org/commission-must-ensure-proper-implementation-and-enforcement-of-the-slaughter-regulation-immediately>

despite the clear failure of member states to respect the law, the European Commission instead of launching infringement procedure prefers to start a three-year training programme allowing millions of animals to continue to suffer unnecessarily.” A speaker from Eyes on Animals, Margeet Steendijk, also criticized the current legislation by stating that “carbon dioxide stunning is, from the point of view of animal welfare, a torturous stunning method, as the pigs suffer pain and panic for up to 60 seconds. Already 10 years ago, the European Food Safety Authority asked Member States to phase out carbon dioxide stunning as it is an inhumane method.” Moreover, it is clear from the Food and Veterinary Office audits conducted since 2013 in 14 Member States that the regulation is not being correctly implemented and enforced anyway²⁰⁴.

The overview report on ‘Animal welfare at slaughter in Member States’ summarises the 13 audits completed by the Food and Veterinary Office on the official controls and other measures taken by Competent Authorities (CAs) to implement Council Regulation (EC) 1099/2009 which were carried out to evaluate the effectiveness of official controls on business operators to ensure animals are spared any avoidable pain, distress or suffering during their killing and related operations as required by the Regulation. The report shows that in a majority of Member States the FVO audits uncovered monitoring systems which did not adequately address the requirements of Article 16 of the Regulation. Although EFSA has published guidance for monitoring stunning and for selecting appropriate sample sizes to confirm the effectiveness of stunning, none of the food business operators (FBOs) had made use of this guidance in developing their own checks and neither had the CAs promoted the use of the EFSA tools. Hence, it would be more valuable to integrate this into the European legislation, rather than being just a tool for guidance. In five Member States, operators’ own checks did not include adequate monitoring for signs of consciousness prior to electrical stimulation or signs of life prior to scalding/dressing which gave rise to a small number of serious animal welfare problems. Particularly in the small to medium size establishments, there were not always registers of the animal welfare officers’ activists to improve animal welfare²⁰⁵.

ii. CCTV footage

A measure that would help monitor the correct enforcement of the Regulation is mandatory CCTV footage in slaughterhouses. In 2017, the French Assembly voted for the compulsory installation of surveillance cameras in slaughterhouses from 2018 after several investigations into French abattoirs carried out and released by L214 revealing horrific animal suffering. Although this measure must still be adopted by the Senate after a trial period, it is a positive initial step which the majority of the French public strongly supports, with 85% voting in favour of the measure in a Ifop poll²⁰⁶.

To this day, France is the first and only country within the European Union to make CCTV footage mandatory in slaughterhouses. CIWF has expressed that previous investigations in the UK have also shown terrible suffering of animals in abattoirs, when slaughter is not carried out humanely and according to standards of best practice, and although an increasing number of slaughterhouse operators have installed CCTV cameras in all or part of their premises, without a law to enforce installation, it currently remains

²⁰⁴ Eurogroup for Animals (2015). Commission must ensure proper implementation and enforcement of the slaughter regulation immediately. Web page: <http://www.eurogroupforanimals.org/commission-must-ensure-proper-implementation-and-enforcement-of-the-slaughter-regulation-immediately>

²⁰⁵ Food and Veterinary Office (2015). Overview report on Animal welfare at slaughter in Member States.

²⁰⁶ Compassion in World Farming (2017). CCTV footage to be mandatory in French slaughterhouses. Web page: <https://www.ciwf.org.uk/news/2017/01/cctv-to-be-mandatory-in-french-slaughterhouses>

voluntary²⁰⁷. On the UK Government website, it is stated ‘we enforce zero tolerance towards animal cruelty. You must have appropriate systems in place to comply with the legal requirements and achieve the required standards of animal welfare. We support the use of CCTV in slaughterhouses as an effective monitoring tool for animal welfare as this helps both the food business operator and their management team ensure the necessary standards are being met at all times.’²⁰⁸ In addition, each year a survey is carried out on CCTV in slaughterhouses in England and Wales. For example, in 2016, as part of its animal welfare programme, the Food Standards Agency (FSA) carried out a survey in which all 278 operating slaughterhouses voluntarily took part. The results showed that 102 out of 207 red meat slaughterhouses (49.3%) and 50 out of 71 white meat slaughterhouses (70.4%) in England and Wales have some form of CCTV in use for animal welfare purposes and it is estimated that 96% of pigs throughput comes from premises with some form of CCTV in use²⁰⁹.

iii. Numerical scoring system for auditing

Another measure which could be put in place to facilitate monitoring, auditing and enforcement of laws in the European Union, is the system of numerical scoring and animal based measurements, developed by Temple Grandin. This system has five numerically scored animal based outcome standards and is now used as a private standard by major restaurant companies and has been incorporated into a USDA direction for meat inspectors in the USA^{210 211}. The five animal based measures are:

1. Percentage of livestock animals stunned effectively on the first attempt
2. Percentage of livestock animals that remains insensible after they are hung on the rail
3. Percentage of livestock animals that fall during handling
4. Percentage of cattle and pigs that vocalise (squeal, bellow) during handling and stunning
5. Percentage of livestock animals moved with an electric goad

Each one of these critical control points measures the outcome of many problems and is a practical standard that can be easily implemented in both large and small pork slaughter plants²¹². In fact, legislation should enforce a maximum percentage of failures for each of these critical points and the corrective measures required. These measurements also provide the advantage of greater consistency between different auditors and inspectors since vague wording in either regulations or industry standards leads to inconsistent enforcement

²⁰⁷ Compassion in World Farming (2017). CCTV footage to be mandatory in French slaughterhouses. Web page: <https://www.ciwf.org.uk/news/2017/01/cctv-to-be-mandatory-in-french-slaughterhouses>

²⁰⁸ Web page : <https://www.food.gov.uk/business-guidance/animal-welfare>

²⁰⁹ Food Standards Agency, 2016. Results of 2016 CCTV survey in slaughterhouses in England and Wales. Web page:

<http://webarchive.nationalarchives.gov.uk/20171207164502/https://www.food.gov.uk/enforcement/sectorrules/animal-welfare/animal-welfare-survey>

²¹⁰ Grandin T. (2006). Progress and challenges in animal handling and slaughter in the U.S.. *Applied Animal Behaviour Science*, 100, 129–139.

²¹¹ FSIS/USDA (2009). FSIS Directive 6910.1 Revision 1, District Veterinary Medical Specialist (DVMS) Work methods, United States Department of Agriculture, Food Safety, and Inspection Service, December 7, 2009. Web page: <http://www.fsis.usda.gov/OPPDE/rdad/FSISDirectives/6910.1Rev1.pdf>. (accessed December 19, 2009).

²¹² Grandin T. (2000). Effect of animal welfare audits of slaughter plants by a major fast food company on cattle handling and stunning practices. *Journal of the American Veterinary Medical Association*, 216, 848–851.

as they can be interpreted differently by different inspectors and auditors. This lack of specific and clear information is a crucial problem of welfare legislation. For example, a survey conducted by the Government Accountability Office (GAO) in 2010 indicated that enforcement of humane slaughter regulations was very variable between different Federal meat inspectors in the USA²¹³. At the slaughterhouse, by using this numerical scoring system, animals can also be assessed for many conditions that are detrimental to animal welfare that are due to problems during transport or poor conditions on the farm for example, poor body condition, lameness, death losses, animal cleanliness, serious injuries and obvious neglected health problems²¹⁴.

7. CONCLUSION

It is commonly believed that the term 'humane' means 'without pain, distress or suffering' however the Oxford English dictionary defines the term humane as 'having or showing compassion or benevolence'²¹⁵. Similarly, the term 'compassion' is defined as 'sympathetic pity and concern for the sufferings or misfortunes of others'²¹⁶. Typical examples of showing compassion (concern for the sufferings) to animals would include, rescuing a dog or a cat from an abusive home, cutting a dolphin free from being trapped in a tangled net, taking an injured bird with a broken wing to a vet, and so forth. However, when discussion turns to animals raised for human consumption, it seems that the actual meaning of the word humane becomes distorted, as these animals are often submitted to the very opposite of the typically compassionate scenarios described. Taking into account these two definitions, how can one be concerned for the sufferings of another when that same person is the one inflicting said sufferings? Surely it would be paradoxical for one to both pity and cause suffering at the same time. In any other situation, putting the terms 'humane' (showing compassion) and 'slaughter' together in one sentence would seem like an oxymoron. Going by the true definition of the word humane, none of the methods discussed in this thesis can be classed as humane, for example, loading pigs into a gas chamber, knowingly causing them to suffer, proven by the studies discussed, cannot be classified as a compassionate act and therefore cannot be considered humane.

However, even if the word humane were to mean 'without pain, distress or suffering', still, none of the methods discussed can truly be considered as such. For example, the first and most commonly used method of stunning pigs is carbon dioxide gas, however, it has been proven that the time to onset of unconsciousness is not immediate. In fact, studies by Gregory et al. found that insensibility is not instantaneous and narcosis began 30 to 39 seconds after the start of the immersion procedure into a concentration of 86% carbon dioxide. And the average time to onset of unconsciousness during exposure to 80% carbon dioxide (required by Regulation 1099/2009), calculated from the 6 different studies presented in Table 2 of this paper, results as a minimum average of 19.8 seconds ranging to a maximum average of 28.14 seconds. It has also been proven by Raj and Gregory that during this time, the exposure to the gas stimulates breathing frequency and may lead to severe respiratory distress. There is also the possibility, if not left in the chamber to die, of pigs regaining consciousness before they are stuck and bled. Therefore, it can be concluded that the carbon dioxide stunning method is neither immediate nor pain-free and causes pigs to suffer greatly

²¹³ Grandin T. (2010). Auditing animal welfare at slaughter plants Web page: http://ssu.ac.ir/cms/fileadmin/user_upload/Mtahghighat/tfood/ARTICLES/meat/Auditing_animal_welfare_at_slaughter_plants.pdf

²¹⁴ Grandin, T. (2010). Auditing animal welfare at slaughter plants Web page: http://ssu.ac.ir/cms/fileadmin/user_upload/Mtahghighat/tfood/ARTICLES/meat/Auditing_animal_welfare_at_slaughter_plants.pdf

²¹⁵ <https://en.oxforddictionaries.com/definition/humane>

²¹⁶ <https://en.oxforddictionaries.com/definition/compassion>

for up to an average of 28.14 seconds and potentially more. In addition, it seems more than just a coincidence that the most commonly used method to stun and kill pigs in the European Union is also the most profitable for the industry since it is the cheapest method and results in a product of the highest quality out of all stunning methods explored. In fact, this is clear to see as it is even stated in Regulation 1099/2009 that ‘improving the protection of animals at the time of slaughter contributes to higher meat quality’.

The other most commonly used method in the EU is electrical stunning, which is generally considered to be more humane than carbon dioxide stunning. However, one of the main problems with the conventional head-only electric stunning methods is that there is a possibility the stunning fails to induce an unconscious state on the first attempt, which may be extremely stressful for the animal. In addition to the pain caused by the failed seizure on the first attempt, the animal will then be submitted to further stress by being handled and stunned for a second time. Furthermore, in large facilities, electric prods may be deemed necessary to move pigs down the single-file chute into the restrainer for electric stunning which may induce stress and instant pain, caused by the electric shock from the prod. In addition, since this method causes violent kicking and spasms due to the induction of an epileptic seizure, the animals are more likely to be stuck and bled incorrectly and thus lead to pigs regaining consciousness before brain death. A practical solution to this it thought to be head-body (cardiac arrest stunning) since it takes away the risk of pigs regaining consciousness before sticking, however, there is still the possibility that, if not performed correctly and the electric current doesn't pass through both the brain and the heart, instantaneous unconsciousness will not be induced and the cardiac arrest will, of course, be painful. Plus, research has shown that the minimum required current of 1.3 amps for electrical stunning methods is not ideal and does not reliably render pigs unconscious. In fact, a study from 2010 showed that in only 128 out of the 145 cases the stunning was effective (88.3%), leaving a rather large amount (11.7%) of the pigs conscious, when stunned at the recommended 1.3 amps. Therefore, a pain-free and stress-free stun/death cannot be guaranteed by electrical stunning either.

Finally, the other most discussed stunning method is using gas mixtures. Exposure to inert gas mixtures such as argon and nitrogen are preferable to high concentrations of carbon dioxide as they are thought to be non-aversive, however, a study by Llonch et al. confirmed that pigs still show aversion to the inhalation of 15-30% carbon dioxide with nitrogen gas mixture compared to the atmospheric air. Other studies have also shown that certain levels of respiratory distress are still caused by a variety of gas mixtures. For example, research conducted by Raj and Gregory concluded that exposure to 90% argon induced minimal respiratory distress prior to loss of consciousness and the carbon dioxide-argon mixture induced moderate distress. However, although inert gas mixtures cause less respiratory distress than carbon dioxide, the time to onset of unconsciousness is longer therefore the pigs are forced to endure such distress for a longer period of time. In addition, the duration of unconsciousness induced by a given exposure time of minimum 3 minutes to alternative gas mixtures is a lot shorter than that achieved by stunning with high concentrations of carbon dioxide, which increases the risk of pigs regaining consciousness when being stuck. Therefore, stunning using inert gas mixtures cannot reliably ensure a totally pain-free death without suffering either.

To conclude, according to the scientific research discussed in this thesis, the stunning methods permitted by current European legislation cannot be considered humane.

Annex 1

Table 2 - Time (in seconds) to loss of consciousness measured by different methods after exposure to different concentrations of carbon dioxide²¹⁷

Carbon dioxide concentration (%)	(%) Time to loss of sensibility (EEG)	Time to loss of brain responsiveness (AEP/SEP)	Average time to loss of posture	Number of animals tested	Reference
95	11.8±0.3			4 (x2)*	Forslid, 1992 ²¹⁸
90		14		6 (x2)*	Martoft et al. 2001 ²¹⁹
90			15±3	5	Raj and Gregory 1996 ²²⁰
85			22±2	42	Holst 2002 ²²¹
80	21-30			6 (x2)*	Forslid 1987 ²²²
80	Max. 35				Hoenderken et al. 1979 ²²³
80	15-20			44	Ring et al. 1988 ²²⁴
80		21.2±6.5		12	Raj et al. 1997 ²²⁵
80			22±6	5	Raj and Gregory 1996
76-80			26±6	16**	Dodman 1977 ²²⁶
75			25±3	42	Holst 2002
71-75			29	16**	Dodman 1977
70			17±4	5	Raj and Gregory 1996
66-70			34±9	16**	Dodman 1977
65			27±3	42	Holst 2002
61-65			38	16**	Dodman 1977
60			25±2	5	Raj and Gregory 1996
55			32±4	36	Holst 2002
50			34±8	5	Raj and Gregory 1996

²¹⁷ Welfare Aspects of Animal Stunning and Killing Methods. EFSA Report 2004²¹⁸ Forslid A. (1992). Muscle spasms during pre-slaughter carbon dioxide anaesthesia in swine. *Fleischwirtschaft*, 72: 167-168.²¹⁹ Martoft L., Lomholt L., Kolthoff C., Rodriguez B.E., Jensen E.W., Jørgensen P.F., Pedersen H.D., Forslid, A. (2001). Effects of carbon dioxide anaesthesia on central nervous system activity in swine. *Lab Animal*, 36: 115-126.²²⁰ Raj A.B.M., Gregory N.G. (1996). Welfare implications of the gas stunning of pigs 2. Stress of induction of anaesthesia. *Animal Welfare*, 5: 71-78.²²¹ Holst S. (2002). Behaviour in pigs immersed into atmospheric air or different carbon dioxide concentrations. Danish Meat Research Institute. Internal report Ref.no. 02.709 7295. Unpublished data²²² Forslid A. (1987). Transient neocortical, hippocampal and amygdaloid EEG silence induced by one-minute inhalation of high concentration carbon dioxide in swine. *Acta Physiol. Scand.*, 130: 1-10.²²³ Hoenderken R., Van Logtestijn J.G., Sybesma W., Sapnjaard W.J.M. (1979). Kohlendioxid-Betaubung von Schlachtschweinen. *Fleischwirtschaft*, 59: 1572-1578.²²⁴ Ring C., Erhardt W., Kraft H., Schmidt A., Weinmann H.M., Berner H., Unshelm J., (1988). Zur Betäubung von Schlachtschweinen mittels carbon dioxide (carbon dioxide anaesthesia for slaughter pigs). *Fleischwirtschaft*, 68: 1304-1307 and 1478-1484.²²⁵ Raj A.B.M., Johnson S.P., Wotton S.B., McInstry J.L. (1997a). Welfare implications of gas stunning of pigs 3. Time to loss of Somatosensory Evoked Potentials and Spontaneous Electrocorticogram of pigs during exposure to gases. *British Veterinary Journal*, 153: 329-340.²²⁶ Dodman N.H. (1977). Observations on the use of the Wernburg dip-lift carbon dioxide apparatus for pre-slaughter anaesthesia of pigs. *Br. Vet. J.*, 133: 71-80.

Table notes:

* Each pig was tested twice

** Each of the 16 pigs in total tested several times in different concentrations

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