The Old School, Brewhouse Hill, Wheathampstead,
Hertfordshire AL4 8AN, UK
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Assessing pig welfare at stunning in Swedish commercial abattoirs using CO_2 group-stun methods

S Atkinson*†, A Velarde‡, P Llonch‡ and B Algers†

† Department of Animal Environment and Health, Faculty of Veterinary Medicine and Animal Science, Swedish University of Agricultural Sciences, Box 234, 532 23 Skara, Sweden
‡ Animal Welfare Subprogram, IRTA, Finca Camps i Armet s/n Monells, 17121, Girona, Spain
* Contact for correspondence and requests for reprints: Sophie.Atkinson@slu.se

Abstract

While regular monitoring of stun quality in abattoirs is now required by EU law, guidelines specific to species and stun method have not been adequately developed. Carbon dioxide (CO_2) gas stunning of pigs in groups is widely used because of efficiency and reduced pre-slaughter stress. However, some pigs may recover from the stun process if it is not correctly managed. In light of these concerns, this study aimed to develop and implement a standardised assessment for stun quality for use in commercial pig abattoirs. Eight abattoirs and 9,520 slaughter pigs were assessed for stun group size, stick time and stun quality. The stun system, CO_2 concentrations and exposure times were also investigated. A stun-quality protocol (SQP) identified and risk-rated symptoms signifying recovery of consciousness. In abattoirs using paternoster stun-boxes, pigs consistently showed no stun-quality problems despite 65% with stick times between 70 and 100 s. Stun-quality problems were detected in 1.7 to 3.3% of pigs in abattoirs using dip-lift stun-boxes and 75% of stick times were below 60 s. In 36 of 38 cases of inadequately stunned pigs, a combination of symptoms from the SQP was seen. Regular gasping preceded other symptoms in 31 cases and was a valid indicator of inadequate stunning. In response to the stun-quality assessments, two abattoirs serviced the stun machines (increasing CO_2 concentrations and exposure times). All pigs were adequately stunned in follow-up studies. Implementation of stun-quality assessments, such as developed in this study, can assure monitoring of animal welfare at slaughter, beneficial not only to the industry and relevant authorities but also the concerned consumer.

Keywords: *animal welfare, CO_2 stunning, commercial abattoirs, pig welfare, stun-quality assessment, stun-quality protocol*

Introduction

The purpose of stunning animals at slaughter is to ensure they are rendered insensible to bleeding (sticking) and post-slaughter procedures, and it is a statutory requirement of the EU (EC 2009). All major abattoirs in Sweden use group-wise carbon dioxide (CO_2) stun systems where approximately 2.8 million pigs are slaughtered annually (Official Statistics of Sweden 2011). CO_2 stunning is now favoured over electrical or captive-bolt methods due to greater benefits for animal welfare (Stoier *et al* 2000; Barton Gade & Christensen 2002; Terlouw *et al* 2008) and meat quality (Velarde *et al* 2000a; Channon *et al* 2003). The main animal welfare advantage is that pigs can be handled and stunned in groups rather than individually restrained and stunned as with alternative methods. CO_2 systems can also be operated with mechanical push gates that separate pigs into small groups and push them into the stun-box, abolishing the use of electric prodders. When these systems are properly operated, pre-slaughter stress can be reduced (Christensen & Barton-Gade 1997). The depth of unconsciousness (stun quality) from CO_2 gas stunning depends on CO_2 concentration, exposure time and the animal. Due to individual biological variation, some pigs may regain consciousness while others not, even if stunned in the same group (Forslid 1987; Holst 2001). To ensure good animal welfare the stun should ensure unconsciousness is induced for a sufficient duration to include not only the stun-to-stick interval but also the time taken for brain death to occur due to sticking. Anil and McKinistry (1993) found that sticking does not always result in rapid and profuse blood loss in pigs, and the time taken for permanent loss of brain responsiveness varies in commercial practice. Problems with slow bleeding (and consequential delay of death) can occur if the size of the sticking wound is too small (Gregory 1999; Anil *et al* 2000). It is therefore imperative for animal welfare that unconsciousness is closely monitored, and pigs re-stunned when necessary; especially as pigs are hoisted upside down and conveyed to a scalding tank for de-hairing within five minutes after sticking in some abattoirs.

Stun quality can be assessed under practical conditions by observing animals after stunning for physical symptoms that indicate complete loss of sensitivity or different levels of sustained brain function. Criteria for assessing stun quality are broadly described by Gregory *et al* (1987) and The European Food and Safety Authority (EFSA 2004). Some of the criteria have been applied in stun-quality assessments at commercial slaughter in pigs by Velarde *et al* (2000b), Nowak *et al* (2007) and Van de Perre *et al* (2010). EFSA (2004) mentions the following symptoms in pigs indicative of inadequate stunning with CO_2: rhythmic breathing, attempts to raise the head, vocalisation, corneal reflex, convulsions and spontaneous blinking. The objective assessment of unconsciousness is difficult as some symptoms commonly considered important are indicative only of brain stem activity and do not relate to cortical function (Anil & McKinstry 1991). Recent EU regulations on the protection of animals at the time of killing state that abattoirs should ensure stun quality is regularly monitored by competent staff (EC 1099/2009). External quality assurance schemes are also gaining increasing acknowledgement as a safeguard for animal welfare. However, standardised animal welfare assessments at stunning, specific for species and stun methods, are not adequately developed.

Surveys carried out in Spain and Germany, respectively, revealed percentages of inadequately stunned pigs in the range of 42 to 60% (Velarde *et al* 2000b; Dalmau *et al* 2009) and 6 to 66% (Holleben *et al* 2002; Nowak *et al* 2007; Hartmann *et al* 2010). Velarde *et al* (2000b) looked only at percentage of pigs with righting reflex and pain sensitivity. Both Holleben *et al* (2002) and Hartmann *et al* (2010) only tested corneal reflexes and no other symptoms. Nowak *et al* (2007) and Dalmau *et al* (2009) used more comprehensive criteria, testing for pain and eye reflexes, convulsions and righting reflexes. Differences in the assessment methodology make comparisons in stun quality between the studies difficult.

Even though all major abattoirs in Sweden use Butina® stun systems (Butina Aps, Copenhagen, Denmark), there are variations in size and technical designs related to different models installed. Dip-lift designs have only one box in the system that can be loaded with a nominal capacity of six pigs. The box descends into a 2–4-m deep pit filled with an increasing gradient of CO_2. The box is paused at the pit bottom where concentrations are highest (> 85%), before ascending and tipping the pigs onto a table where shackling takes place. The paternoster designs have up to seven boxes (a nominal capacity to stun eight pigs per group), rotating through the CO_2 gradient in a 3–8-m deep pit, stopping at various intervals for loading of pigs on one side and unloading on the other. The number of pigs per group, the time taken to reach maximum CO_2 concentrations, and total exposure times, vary. These factors are manipulated by the individual abattoirs according to their own discretion, but the manufacturers do provide operational recommendations for each type of system. EU legislation states that sticking must start as soon as possible after stunning but specify no time limit (EC 1993). Swedish regulations stipulate that the stun-to-stick interval (stick time) should not exceed 60 s (SJVFS 2008). Many abattoirs fail to fulfil these requirements, due to the technical design of the slaughter line which cannot transfer animals to sticking within this time constraint. With increasing stun-group size, the time taken to stick the last pigs in the group increases; a potential risk factor to maintaining unconsciousness throughout the slaughter process. Abattoirs can apply to the Swedish authorities for an extension of maximum stick times if it can be verified that there are no concerns for stun quality. This prompted a demand from the slaughter industry and competent authorities for externally conducted assessments of stun quality.

The objective of this study was to develop and implement a practical standardised procedure to assess stun quality in commercial pig abattoirs where CO_2 stunning is used. It also aimed to find the stun-group size and corresponding stick intervals and if times over 60 s negatively affected animal welfare.

Materials and methods

These studies were conducted with the approval of the ethical committee in Gothenburg, Sweden, in accordance with Swedish regulations SJVFS 20011/91. In total, 9,520 pigs (with a slaughter live weight average of 85 [± 20] kg), of halothane negative 'PigHam' strains (Hampshire sire lines with Landrace × Yorkshire sows), were assessed during routine stunning. Ten visits in eight abattoirs were conducted. Each abattoir was numbered numerically from 1 to 8 from largest to smallest processing rate. Abattoirs 1 to 5 and 8 were assessed once and abattoirs 6 and 7 twice (after adjustments in CO_2-stunning parameters). Two full days were spent in abattoirs 6 to 8 (processing 200–250 pigs per day) and one full day in abattoirs 1 to 5 (processing 1,500–3,000 pigs per day).

Stun system

The CO_2 concentration and exposure time (ie total time each stun-box holding pigs had completed a cycle through the CO_2 gradient), were recorded from the digital display monitors mounted on the stun machines. A permanently installed sensor positioned in the pit at a height corresponding to the top of the stun box when in the lowest position (ie approximately 1 m from pit bottom) gave the reading for the CO_2 concentrations. In abattoirs 1 and 2, the CO_2 levels were also checked using an external CO_2 monitor (Butina-85, Copenhagen, Denmark). In abattoirs 1 to 4, rotation times varied according to loading times, therefore, at least ten rotation times were recorded to give an average. In all other abattoirs the CO_2 exposure times were fixed.

Group size and stun-to-stick interval

Group sizes in the stun-boxes were recorded by counting the number in each group as they came out of the stun-box. The stun-to-stick interval was timed for every pig in the group using a stopwatch. The time when the 'end' of the stun occurred for all pigs in a group began when the stun-box stopped just before the gate opened to release the pigs. All pigs were chest stuck (severing all major blood vessels in the thorax). Sticking was considered to be the point at which the knife was pushed into the chest and signalled the end of the stun-to-stick time. Stick times were recorded sequentially for each pig in the group. Any incidents or stops or causes for delays in sticking were recorded.

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Table 1 Stun quality protocol (SQP) describing symptoms of inadequate stunning rated for risk to inferior animal welfare from 4 (highest) to 1 (lowest).

Risk level	Interpretation	Symptom	Definition
4	Inadequate stunning and the highest risk to animal welfare due to symptoms signifying consciousness	Righting reflex (RR)	Raising of the head or arching of back in animal's attempt to right itself or recover normal body position
		Pain reflex (PR)	Any response to a painful stimulus such as a severe prick on the nose with a sharp instrument
		Blinking (B)	Animal blinks its eye on its own without stimulation
		Vocalisation (V)	When animal squeals or groans using vocal cords not associated with involuntary sounds during the dying process
3	Inadequate stunning at a lower risk level due to symptoms signifying a recovery risk rather than specific signs of consciousness	Nystagmus (N)	Rapid movements (twitching) of the eyeball from side-to-side
		Corneal reflex (CR)	Animal blinks in response to careful touching of the cornea
		Rhythmic breathing (RB)	Rhythmic air inhalation seen in the form of regular expansion/contraction of chest or flank area or feeling rhythmic air exhalations on the back of the hand
2	If shown independently indicates a low risk and not considered as inadequate stunning but if seen in combination with other symptoms in this rating re-stunning is recommended	Convulsion (C)	Involuntary, violent seizure-like muscle contractions (excluding slight muscle twitches)
		Eyeball rotation (ER)	The eyeball is rotated in a fixed position so the sclera is predominantly seen and little or no iris remaining 40 s after stunning
		Regular kicking (RK)	Multiple movements of the limbs
		Regular gasping (RG)	Opening of the mouth with the sound or appearance of short gasps of air while flexing the head forwards occurring more than 3 times within 10 s intervals
1	If shown independently indicates a low risk of return to consciousness and not considered as inadequate stunning but pigs should be monitored	Irregular gasping (IR)	Occasional opening of the mouth while flexing the head forwards with the sound or appearance of short gasps of air intake at sporadic intervals
		Irregular kicking (IK)	Occasional movements of the limbs

Stun quality

Pigs were continually observed for physical symptoms that could indicate consciousness or a risk that recovery was imminent. When pigs were in a state of whole body relaxation, and there was no evidence of rhythmic breathing, righting reflex, vocalisations, convulsions, blinking, pain or eye responses to stimulation, pigs were considered in a state of deep anaesthesia and adequately stunned. Pigs that showed symptoms outside of the deep stun criteria (Table 1) were more closely examined and the eyes tested by carefully touching the corneal area with a pen tip angled at approximately 45°. If the pig blinked in response it was noted as a corneal reflex. Pain response was tested by pricking the inner snout of the pig with the sharp point of a metal pencil casing and withdrawal response was noted as pain reflex. Every last pig in the group was routinely tested for reflexes. To assist with the practical assessments, a stun-quality protocol (SQP) was designed to identify and categorise symptoms signifying recovery risk of consciousness. Four groups indicated an interpreted risk level (RL) of inferior animal welfare from highest (4) to lowest (1) (Table 1).

Righting reflex (RR), pain reflex (PR), blinking (B) or vocalisations (V) were rated risk level 4 due to the high probability of consciousness (EFSA 2004; von Holleben *et al* 2010). Nystagmus (N), rhythmic breathing (RB) and corneal reflexes (CR) can be displayed just prior to recovery (Holst 2001; Velarde *et al* 2002) but also during light anaesthesia (Rodríguez *et al* 2008; Vogel *et al* 2011) and were therefore rated at risk level 3. It is not certain if convulsions (C), eyeball rotation (ER), regular gasping (RG) and regular kicking (RK) are emanating from a still active neocortex or associated with involuntary nerve responses during deep CO_2 anaesthesia (Forslid 1987; Tranquilli & Thurmon 2007). Therefore, these symptoms were rated risk level 2. Symptoms of irregular gasping (IG) and irregular kicking (IK) were recorded and rated RL 1 because, if shown independently, are not indications of consciousness (EFSA 2004). Any pigs with a single display of symptoms rated RL level 3 or 4, were considered inadequately stunned. Pigs showing a single display of RL 2 symptoms were closely examined and monitored, and only if other RL2 symptoms appeared was inadequate stunning registered. The percentage and frequency of symptoms shown individually or in combination were evaluated for both individual abattoirs and as a total of pooled data.

Table 2 Description of the eight abattoirs and ten study visits including: box type, loading mechanism, number of boxes, average group size/box, CO_2 concentration and exposure times, average stick time for last pig (LP), and number and percentage of inadequately stunned pigs.

Abattoir	Box type	Loading method	No boxes	Mean (± SD) pigs per box	CO_2 (%) pit base	Mean (± SD) exposure time (s)	Mean (± SD) stick time last pig (s)	Number inadequately stunned (n/N) (%)
1	Paternoster	Auto	7	7 (± 1.2)	93	282 (± 44)*	117 (± 13)	0/3,444 (0)
2	Paternoster	Auto	6	4 (± 1)	93	238 (± 42)*	117 (± 9)	1/2,325 (0.04)
3	Paternoster	Auto	4	3 (± 0.4)	93	250 (± 34)*	96 (± 8)	0/500 (0)
4	Paternoster	Auto	3	3	91	240 (± 10)*	68 (± 15)	0/700 (0)
5	Paternoster	Auto	3	3	93	240	70 (± 4)	0/507 (0)
6a	Dip-lift	Auto	1	7	91	172	86 (± 13)	10/602 (1.6)
6b**	Dip-lift	Auto	1	7	93	180	67 (± 3.2)	0/252 (0)
7a	Dip-lift	Manual	1	5	93	208	60 (± 8)	19/582 (3.3)
7b**	Dip-lift	Manual	1	5	94	224	65 (± 10)	0/200 (0)
8	Dip-lift	Manual	1	4	92	224	66 (± 9)	8/408 (2)

* Taken as an average of 40 box rotations in abattoirs 1 and 2, and 10 in abattoirs 3 and 4, due to variations in time taken to load pigs effecting CO_2 exposure times (exposure times in abattoirs 5 to 8 never varied). ** 6b and 7b are reassessments. N is the total number of pigs studied in each abattoir and n is the portion of pigs of that number.

Table 3 Mean (± SD) stick time (s) and, beneath these figures, the total number (N) of pigs in each group for all abattoirs.

	Abattoir number									
Pig number	**1**	**2**	**3**	**4**	**5**	**6a**	**6b***	**7a**	**7b***	**8**
Pig 1	68 (± 7) 502	58 (± 10) 53	45 (± 6) 161	41 (± 14) 174	36 (± 4) 169	27 (± 3) 122	24 (± 2) 36	32 (± 5) 158	33 (± 5) 42	51 (± 8) 102
Pig 2	75 (± 7) 502	69 (± 10) 553	63 (± 6) 161	55 (± 15) 174	53 (± 4) 169	36 (± 4) 122	33 (± 3) 36	39 (± 6) 158	41 (± 6) 42	56 (± 9) 102
Pig 3	80 (± 8) 502	80 (± 10) 551	81 (± 8) 161	68 (± 15) 174	70 (± 4) 169	45 (± 5) 122	39 (± 3) 36	46 (± 7) 158	49 (± 8) 42	61 (± 9) 102
Pig 4	90 (± 8) 500	91 (± 11) 505	96 (± 8) 16			53 (± 6) 122	47 (± 3) 36	53 (± 8) 158	57 (± 9) 42	66 (± 9) 102
Pig 5	96 (± 8) 493	102 (± 10) 155	103 (± 0) 11			62 (± 7) 122	55 (± 4) 36	60 (± 8) 158	65 (± 10) 42	
Pig 6	96 (± 9) 438	117 (± 9) 8				72 (± 11) 122	62 (± 3) 36			
Pig 7	101 (± 9) 306					81 (± 14) 122	67 (± 3) 36			
Pig 8	106 (± 9) 148									
Pig 9	111 (± 12) 42									
Pig 10	117 (± 13) 11									

Abattoirs 1 to 6 are paternoster stun systems and abattoirs 6 to 8 dip-lift systems. * Abattoir 6b and 7b are reassessments.

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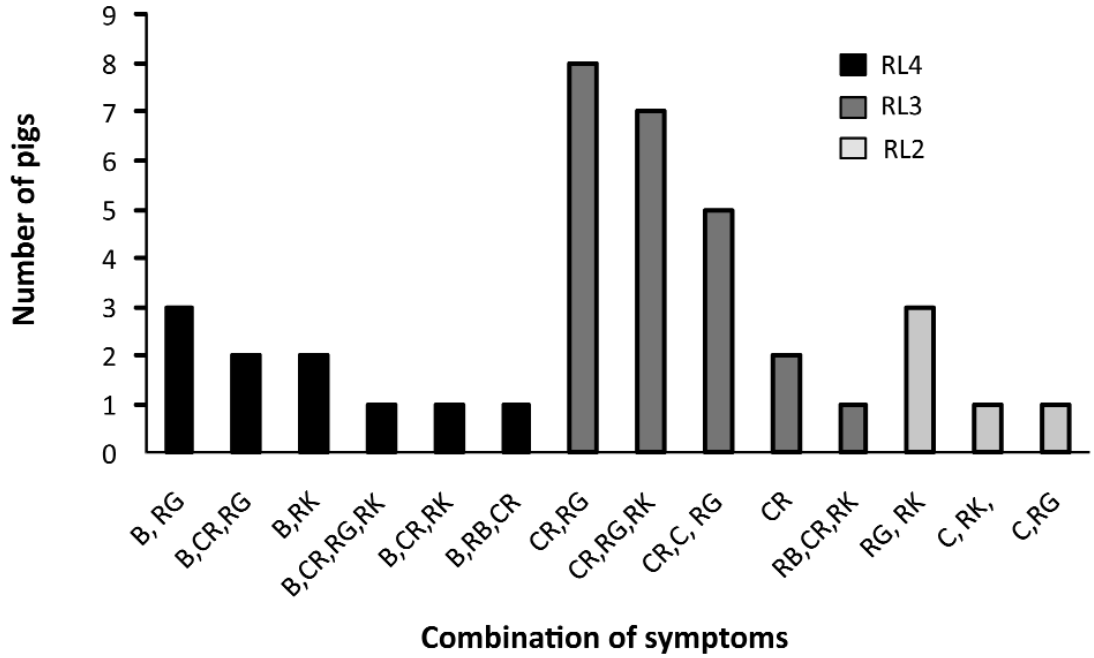
Figure 1



The combinations of symptoms seen in inadequately stunned pigs (n = 38), grouped in the category of the symptom with the highest risk level (RL). B: Blinking, RB: Rhythmic breathing, CR: Corneal reflex, C: Convulsions, RG: Regular gasping, RK: Regular kicking.

Data analysis

Descriptive data analysis was used with Microsoft Excel version 2007. For the statistical analysis, the Statistical Analysis System software (SAS 9.2, SAS Institute Inc, Cary, NC, USA 1999–2001) was used. Differences in the prevalence of the different risk levels (RL1, RL2, RL3 and RL4) and of the different symptoms assessed (RR, PR, B, V, N, RB, CR, C, ER, RG and RK) were analysed with a general linear model analysis of variance (PROC GENMOD) following a binomial distribution. The 'time of exposure', 'box type', 'group size' and 'stun-to-stick interval' were taken as fixed effects whereas the 'CO_2 concentration' was taken as a covariate. The correlation (PROC CORR) using the Fisher's exact test between all the different symptoms of recovery were analysed. Also, the correlation between the time of exposure and the number of pigs in each group was assessed. In all comparisons, results were taken to be statistically significant when $P < 0.05$.

Results

Five abattoirs used the Butina® paternoster (abattoirs 1–5) and the other three (6–8) used the Butina® dip-lift stun systems. The number of boxes in the stun machine, group size, stun-to-stick intervals, CO_2 concentrations, CO_2 exposure times and stun quality varied in each abattoir (Table 2).

Stun system

In abattoirs 1 and 2, the CO_2 concentrations measured with the external monitor, registered 81 and 83% in the first stop and 91 and 93% in the bottom stop, respectively, which corresponded to slightly higher concentrations than that displayed on the stun-box monitor. In the other abattoirs the machines displayed CO_2 concentrations between 91 to 94%. The abattoirs with the longest stick times (1 and 2) also had the longest CO_2 exposure times, averaging 282 (± 44) s and 238 (± 42) s, respectively. In abattoir 1 (seven boxes), it took 13 s to reach each stop, in which the CO_2 levels at the first stop exceeded 80%. The boxes stopped five times for 40 s during the rotation. The boxes were in the pit bottom for a minimum of 80 s where CO_2 concentrations were above 90%.

Group size and stun-to-stick interval

Five abattoirs (4 and 5 with paternoster and all the dip-lift systems), had consistent group sizes ranging from three to seven pigs. Abattoirs 1 to 3 had varying group sizes from a minimum of three to a maximum of 10 pigs. In the paternoster systems, the average stick time for the last pig in the group, varied from a minimum of 70 (± 4) s to a maximum of 117 (± 12) s and in the dip-lift systems, from a minimum of 60 (± 8) s to a maximum of 86 (± 13) s (Table 3). Of 7,476 pigs in the paternoster systems, 80% had stick times greater than 60 s, 62% greater than 70 s and 42% greater than 80 s. In abattoirs 1 and 2, 30% were stuck after 90 s. In the dip-lift systems, 75% of the pigs were stuck within 60 s, but 71% of the last pigs in each group were stuck over 60 s and 50% over 70 s.

Table 4 In each abattoir the number of pigs and percentage in brackets that displayed certain symptoms from the SQP.

		Abattoir number									
Risk level	**Symptom**	**P1 (n = 3,444)**	**P2 (n = 2,325)**	**P3 (n = 500)**	**P4 (n = 700)**	**P5 (n = 507)**	**D6 (n = 602)**	**D6b (n = 252)**	**D7 (n = 582)**	**D7b (n = 200)**	**D8 (n = 408)**
4	Righting reflex	0	0	0	0	0	0	0	0	0	0
4	Pain reflex	0	0	0	0	0	0	0	0	0	0
4	Blinking	0	0	0	0	0	0	0	3 (0.5)	0	7 (1.7)
4	Vocalise	0	0	0	0	0	0	0	0	0	0
3	Nystagmus	0	0	0	0	0	0	0	0	0	0
3	Corneal reflex	0	1 (0.04)	0	0	0	9 (1.5)	0	15 (2.6)	0	3 (0.7)
3	Rhythmic breathing	0	0	0	0	0	0	0	1 (0.2)	0	1 (0.2)
2	Eye rotation	0	0	0	0	0	0	0	0	0	0
2	Convulsions	0	0	0	0	0	6 (1)	0	1 (0.2)	0	0
2	Regular kicking	0	0	0	0	0	3 (0.5)	0	12 (2)	0	4 (1)
2	Regular gasping	2 (0.05)	60 (2.5)	0	0	0	14 (2.3)	0	20 (3.4)	0	6 (1.5)
1	Irregular gasping	0	0	0	0	0	0	0	1 (0.2)	0	5 (1.2)
1	Irregular kicking	0	1 (0.04)	0	0	0	0	0	1 (0.2)	0	0
Inadequate stun		0	1 (0.04)	0	0	0	10 (1.7)	0	19 (3.3)	0	8 (2)

P: paternoster stun-box type; D: dip-lift stun-box type. * 6b and 7b are reassessments. n = total number of pigs studied in each abattoir.

Stun quality

When pooling data, a total of 38 pigs displayed symptoms of inadequate stunning from the SQP. Pigs were consistently adequately stunned in the five abattoirs using paternoster systems (only one of 7,476 pigs showed corneal reflex at sticking). In all three dip-lift systems, pigs were found inadequately stunned with 1.5% of pigs in abattoir 6a, 3.3% in 7a, and 2% in abattoir 8 during the first study (Table 2). A re-investigation was completed in abattoirs 6 and 7 after service of the stun systems and an increase in CO_2 exposure times (from 172 to 180 s in abattoir 6b and 208 to 224 s in abattoir 7b). The second stun-quality assessment found all pigs properly stunned in both abattoirs. The total proportion of pigs inadequately stunned in the paternoster systems was lower (0.01%) compared to the dip-lift systems (1.8%) ($P < 0.001$). The number of pigs in the group increased significantly ($P < 0.001$) the stun-to-stick interval.

The probability that pigs displayed symptoms rated risk level 3 or 4 increased significantly when the CO_2 exposure time decreased ($P > 0.01$) and when the CO_2 concentration decreased ($P = 0.05$). The symptoms rated as risk level 3 were significantly more frequent when the CO_2 concentration and the time of exposure decreased ($P = 0.03$ and $P = 0.046$, respectively) and when the stun-to-stick interval increased ($P = 0.028$). Most inadequately stunned pigs (95%) showed more than one symptom. The most frequent symptom observed was the corneal reflex, present in 74% (28) of the 38 pigs in total that were inadequately stunned. It was observed in 1.5, 2.6 and 0.7% of the total pigs assessed in abattoirs 6, 7 and 8, respectively (Table 4). In 26 cases of corneal reflex (RL3) there were also RL2 symptoms shown and the most frequent combination was corneal reflex with regular gasping (Figure 1). Blinking was seen in 0.5% of pigs in abattoir 7, 1.7% in abattoir 8 (Table 4), and in 26% (10) of the 38 inadequately stunned pigs. The symptoms pain reflex, righting reflex (RL4), nystagmus and eyeball rotation (RL3) were never observed. There was a significant correlation between the appearance of blinking and corneal reflex ($r = –0.31$, $P = 0.048$). All pigs in the study that were inadequately stunned were promptly re-stunned with back-up devices, such as electrical stun (six abattoirs) and captive-bolt gun (two abattoirs). In abattoirs 7 and 8 (dip-lift systems), most of the stick times of inadequately stunned pigs (21/28) remained under 60 s and all under 68 s. The longest stick times in abattoirs 1 to 8 were 160, 145, 119, 245, 83, 145, 104 and 116 s, respectively, and all these pigs were adequately stunned.

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Discussion

Stun system

Pigs were consistently adequately stunned in the paternoster systems despite most stick times exceeding 60 s. The shortest CO_2 exposure time recorded in the paternoster systems was 238 s; indicating pigs were exposed to CO_2 concentrations higher than 80% for at least 192 s. Studies in Germany and Spain on similar Butina® paternoster systems, reported shorter CO_2 exposure times coupled with much higher percentages of inadequately stunned pigs. Hartmann *et al* (2010) reported exposure times of 120 and 90 s in 90% CO_2, with 6.2 and 17% pigs displaying corneal reflex, respectively. Velarde *et al* (2000b) reported 25 and 28% pigs with pain and righting reflex when stunned in 83% CO_2 for 103 s. The CO_2 exposure times and concentrations should be high enough to ensure all pigs in the group remain unconscious during sticking and until death. In this study, at least 200 stick times in the smaller abattoirs and 500 in the larger ones, were considered an adequate sample size to gauge the stick-time variations. Swedish regulations state that pigs should be exposed to a minimum of 70% CO_2 for 140 s, of which 60 s of that time, the CO_2 concentration should increase to 90%. In the paternoster systems where 80% of the pigs were stuck > 60 s, these recommendations may not provide suitable stunning, especially in abattoirs 1 and 2 where 98.5% of the pigs had stick times > 60 s.

Group size and stun-to-stick interval

Four abattoirs (1, 2, 4 and 7a) had several stops in the system causing delayed stick intervals related to slaughter-line congestion, shackles derailing, jams in the stun gate when releasing pigs at the system exit, or pigs flipping over the edge of the stun crate (requiring a separate pulley to attach them to the shackle line). Abattoirs with few stops or interruptions in the system had less variable stick times. Many stick times of the inadequately stunned pigs in abattoir 6 were extended due to re-stunning prior to sticking. In the second study assessment, however, stick times were more efficient because no pigs required re-stunning. In abattoirs 6a and 7a re-stunning occurred after sticking because the symptoms were detected post sticking.

Stun quality

Abattoir 6 had a larger group size (and longer stick times) than abattoirs 7 and 8. Therefore, it was unexpected to record shorter CO_2 exposure times than the other abattoirs using dip-lift stun-boxes. Despite using longer CO_2 exposure times and having shorter stick times, abattoir 7a had a two-fold higher percentage of inadequately stunned pigs compared to abattoir 6a. However, by increasing the CO_2 exposure times and concentrations, all pigs were properly stunned in follow-up assessments. Abattoir 8 used an exposure time of 224 s and 91% CO_2 at the pit base, yet 2.4% pigs were inadequately stunned. These exposure times should have consistently stunned all pigs. Although the stun machine registered a CO_2 concentration higher than 90% CO_2, air draughts, cold gas, or excess water in the stun-pit base, may have reduced individual CO_2 consumption thus preventing proper stunning in some pigs. In abattoirs 6 and 7, gas-transfer pipes were insulated and valves upgraded to ensure the CO_2 entered the stun-box at no less than at 20°C, possibly improving stun efficiency found in the second assessments.

In abattoir 8, none of the pigs with blinking or corneal reflex had pain responses. When showing a blink response, the eyelid slowly closed and opened. The corneal reflex response also occurred only once when tested repetitively. Pigs in abattoir 7a, however, opened the eyelid fully and quickly on repeat tests. This suggests that these pigs were in a more shallow state of stun than in abattoir 8. Danish Meat Association guidelines (Danish Meat Research Institute 2011) for CO_2 group-wise stunning, do not consider a corneal reflex response unless it occurs twice and EFSA (2004) states that the corneal reflex is positive if the eyelid closes after touching once. Vogel *et al* (2011) considered the corneal reflex as any blink or twitch of the eyelid in association with physical touch. Rodríguez *et al* (2008) reported corneal reflex in stunned pigs that showed brain activity values indicating unconsciousness, therefore they doubted the effectiveness of the corneal reflex in accurately assessing consciousness. Panella-Riera *et al* (2008) found corneal reflex in 20% of pigs immediately after stunning in a Butina® dip-lift system, which disappeared after 40 s. According to Hall *et al* (2001), the presence of the corneal reflex may be present for a short time after cardiac arrest has occurred. It can also be the first symptom to appear after recovery from CO_2 stunning (Forslid 1987; Anil 1991; Holst 2001), and therefore it can be difficult to interpret if the pig showing corneal reflex is close to death or recovery. In

Table 5 Suggested risk level of certain symptoms and relevant actions to take where 0 indicates no level of risk and 4 the highest risk level for inferior animal welfare.

Risk level	Symptoms	Action
0	Deep stun symptoms (none of the below)	OK, no action needed
1	Irregular gasping or kicking	OK, but observe for other symptoms
2	Irregular convulsions Corneal reflex once Regular gasping or kicking	OK, but reflex test and monitor closely for other symptoms
3	Any combination of risk level 2 symptoms Full eyeball rotation Repeated convulsions Nystagmus Slow blink Rhythmic breathing	Re-stun immediately
4	Corneal reflex repeated response Vocalisation Rapid blink Righting reflex Pain reflex	

0 → 4, decreasing stun quality and increasing risk to animal welfare.

abattoirs 7 and 8, many pigs displayed corneal reflex, blinking or regular gasping after sticking, but most symptoms disappeared quickly; probably due to rapid blood loss from sticking causing death. However, when one pig with rhythmic breathing prior to shackling was tested for reflexes it failed to show any. Regular kicking symptoms began and the pig showed corneal reflex upon repeat tests, 55 s after sticking (115 s after stunning). Three pigs initially showed no symptoms, but 50 to 60 s after sticking, regular gasping and corneal reflex appeared, indicating some form of recovery of consciousness despite sticking. This may have been due to poor sticking procedures. Anil and McKinstry (1993) also found a return of rhythmic breathing, and Vogel *et al* (2011) corneal reflex in some pigs after sticking. Any delay in the rate of blood loss from ineffective sticking could result in sustained perfusion of the brain by cerebral blood supply, thereby prolonging brain activity and pig consciousness, potentially compromising animal welfare (Anil *et al* 2000).

The symptom regular gasping appeared to indicate different levels of stun quality in different abattoirs. In abattoir 2 it appeared in up to 2.5% of pigs without any other symptoms. In abattoir 6, 7 and 8, however, most pigs showing regular gasping showed other symptoms indicating inadequate stunning according to the SQP. Gregory *et al* (1987) reported 75% pigs with gasping of which 16% had corneal reflex after short exposure to CO_2 (66 s in 86% CO_2); therefore gasping was probably a symptom of recovery. Forslid (1987) and Holst (2001) found that gasping occurred before normal breathing resumed when pigs were allowed to recover after CO_2. Grandin (2010), however, mentions that gasping is a symptom of a dying animal, but Raj (1999) refers to it as a rudimentary brainstem reflex. Regular gasping and regular kicking in abattoirs 6, 7 and 8 were good indicators to initiate a closer examination to assess the stun quality and, in fact, 18 pigs with corneal reflex first showed symptoms of regular gasping while on the shackle line. This highlights the importance of continual monitoring of pigs during a stun-quality assessment, and not just checking them at one point after stunning. It is not clear scientifically what risk level of recovery there is if pigs display RL2 symptoms. In this study, however, it was decided that pigs displaying a combination of these symptoms (convulsions, regular gasping or regular kicking), should be considered inadequately stunned and re-stunned to eliminate any risk for animal welfare. It seemed a reasonable level of risk grading since 82% (31 of 38) inadequately stunned pigs with RL2 symptoms also showed RL3 or 4 symptoms (Figure 1). Stun-quality assessments could be enhanced by recording when (eg on the stun crate, shackle or after sticking) and to what degree (eg single/repeated, weak/strong), the symptoms were displayed. Table 5 suggests appropriate actions to take when pigs display certain symptoms according to the risk level for animal welfare.

According to EFSA (2004), it is acceptable to see 5% of pigs with corneal reflex at the time of sticking. The highest percent of pigs with corneal reflex in this study was 2.6% and in all but two cases other symptoms occurred from the SQP. Using the corneal reflex as the only indicator for assessing stun quality is not recommended. The use of the SQP in this study ensured that all symptoms that could indicate possible inadequate stunning were considered. This also helped to reduce inconsistencies despite variations in the stun systems, and comparisons could be made between the stun-quality standards of the different abattoirs. When presented with the results, abattoirs 6 and 7 did not find the stun-quality results of 1.6 and 3.2% acceptable, and worked to have all pigs properly stunned in the follow-up studies. It is therefore not unrealistic to expect that abattoirs have no more than 1.5% of pigs with rate 3 symptoms and certainly not more than 1% with rate 4 from the SQP.

Animal welfare implications and conclusion

The use of a stun-quality protocol (SQP) specific for CO_2 gas stunning of pigs helped formulate a standardised method for deciding when pigs were inadequately stunned. In abattoirs using paternoster systems, pigs were consistently adequately stunned, and stick times up to 100 s compared to 60 s, did not increase the risk to animal welfare. Stun-quality problems were detected in abattoirs using dip-lift systems, although 75% of the stick times were below 60 s. Regular gasping was an important indicator of inadequate stunning in these abattoirs. Blinking and corneal reflex symptoms were sometimes displayed prior to or after sticking, once or on repeated occasions. These symptoms could therefore be more accurately defined in the SQP. Symptoms of inadequate stunning sometimes appeared while pigs were on the shackle line sometime after sticking. It is therefore important to monitor stun quality continuously and not just at one point after stunning. In some pigs corneal reflex was seen as long as 60 s after sticking. While prompt sticking can reduce recovery risk, it should not be the means which animals are rendered unconscious while the slaughter procedure is performed.

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