A review of bird welfare during controlled atmosphere and electrical water-bath stunning

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Abbreviations	
CAS	Controlled atmosphere stunning
EEG	Electroencephalogram
LAPS	Low atmospheric pressure system
SEP	Somatosensory evoked potential

Slaughter methods are considered humane if they result in a rapid loss of consciousness (ie, loss of individual awareness as a result of blockage or disruption of the brain's ability to integrate information) followed by death with a minimum of pain or distress. At present, there is no consensus on the best methods for slaughtering poultry, and research on methods currently used is limited or has yielded contradictory results.

A variety of stunning methods are used in the poultry industry to induce unconsciousness (and, in some instances, death), but these methods can be divided into 2 broad categories as CAS and electrical water-bath stunning. Each method causes a variety of behavioral and physiologic reactions that must be carefully considered when assessing the humaneness of the method because there is no single reaction that can be used to accurately assess consciousness in poultry.[1] The present review covers behavioral and physiologic reactions to poultry stunning methods and highlights areas in need of further research.

Behavioral and Physiologic Reactions to Stunning

Behavioral reactions—A variety of behavioral reactions have been described as potential indicators of unconsciousness or the onset of unconsciousness in poultry. The assessment of behavioral responses involves direct observation, and such assessments are generally qualitative in nature. The following behavioral reactions have been described relative to the onset of unconsciousness:

- Mandibulation—a distinctive tasting response[2] or mandibular movements involving rapid bill opening and closing.[3,4]
- Headshaking—rapid shaking or lateral movement of the head.[5] Some investigators believe that headshaking may be an indicator of increasing sensory stimulation[6]; however, others believe that it indicates an aversive reaction[7–9] or respiratory distress.[10]
- Respiratory disruption—open-bill breathing with prolonged inspiration or prolonged open-bill gaping with apparent apnea or difficulty inhaling.[3,5]
- Loss of posture—inability to maintain a sitting position and neck tension; in most cases, the bird falls on its side or back.[11] Loss of balance, posture, or both[2] is often used as a way to visually determine loss of consciousness, and it has recently been confirmed that loss of posture is an effective indicator of loss of consciousness.[12] When loss of posture was compared with the alpha-delta wave ratio obtained by means of EEG, there was no statistical difference in their ability to detect unconsciousness.[12]
- Wing flapping—continuous, rapid wing flapping[2] associated with the clonic spasm phase of an epileptiform seizure.
- Corneal or palpebral reflex—a response to touching the eye with a fingertip[13,14] or feather.[15,16] Use of a fingertip may induce a palpebral reflex in addition to the corneal reflex. Blinking or retraction of the eye away from the stimulus is a positive response that, in conjunction with spontaneous blinking and breathing, indicates recovery from stunning.
- Spontaneous blinking—a physical reflex that occurs in birds recovering from electrical stunning.[15] This reflex remains absent in birds that do not recover from stunning.[15–17]
- Resumption of breathing—resumption of spontaneous breathing occurs in birds that do not develop cardiac arrest during stunning. However, this on its own is not an indicator of a return to consciousness.[15,16]

Physiologic reactions—Electroencephalography has been used for many years as an indicator of unconsciousness,[18] but the procedures used to analyze EEG recordings as an indicator of level of consciousness vary widely. Recordings can be analyzed on a raw signal basis or in terms of the component frequencies of the signal (ie, frequency domain analysis) or by evaluating SEPs in the recordings, which reflect the sequential activation of neural structures along various somatosensory pathways.[12]

Electroencephalographic activity is not a direct measure of consciousness; therefore, EEG recordings cannot be used to pinpoint the onset of unconsciousness. However, changes in electrical activity, when

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evaluated alongside clinical observations[18] (ie, loss of posture during CAS or development of tonic seizures with apnea after removal of current during electrical stunning[19]), can still provide useful information. The loss of SEPs is considered by some investigators to be an indicator of effective stunning,[20,21] whereas other investigators define unconsciousness as the point when the EEG shows an isoelectric pattern[1] and death as the point when an isoelectric EEG pattern is paired with nonreversible properties (eg, cessation of respiratory movements).[2,3] Other researchers use the high-amplitude, low-frequency activity of the delta and theta waves to determine unconsciousness in poultry,[22–25] and some consider a profoundly suppressed EEG pattern (< 10% of prestunning brain power)[13,15,26,27] or suppression of the correlation dimension of the EEG (60% of the prestunning brain power)[3] as an indicator of unconsciousness. Finally, some investigators have suggested that an epileptiform EEG recording followed by a quiescent or isoelectric phase is the best evidence of unconsciousness and insensibility.[25,26] Development of a consensus opinion on EEG changes indicative of unconsciousness and death in poultry would be beneficial in evaluating the humaneness of various stunning methods.

Controlled Atmosphere Stunning

Methods for CAS of poultry at slaughter can be divided into 5 groups: anoxia, hypercapnic anoxia, hypercapnic hypoxia, hypercapnic hyperoxygenation, and low atmospheric pressure (**Appendix**). With many CAS systems, birds are stunned while still in their crates and are unconscious when removed from their crates to be shackled. However, some systems require that birds be dumped from their transport crates prior to stunning, creating welfare issues associated with additional handling of the birds while they are conscious.

Anoxia—Controlled atmosphere stunning systems designed to induce anoxia use high concentrations of an inert gas (eg, argon or nitrogen) to displace oxygen from the air the birds breathe. The birds remain conscious until very low oxygen concentrations are achieved. Birds quickly progress beyond recovery after loss of consciousness. Thus, anoxic CAS systems are considered single-stage systems (ie, stun-to-kill systems). However, birds can recover if they are reintroduced to room air prior to death.

Behavioral reactions

Mandibulation has been observed in birds stunned in anoxic systems[2] but may occur less frequently than in birds stunned with other types of CAS systems.[5] Headshaking has also been observed in birds stunned with anoxic systems.[2] Some studies[6,7,11] have found that less headshaking occurs with anoxic systems than with systems that incorporate carbon dioxide; however, 1 study[5] found that headshaking was greater with an anoxic system, with more bouts occurring and bouts lasting for longer durations. Respiratory disruption is significantly less common in birds stunned with anoxic systems, compared with the frequency in birds stunned with hypercapnic anoxic,[2,11] hypercapnic hypoxic,[11] or hypercapnic hyperoxygenation[2,11] systems, and in some instances, no birds stunned with an anoxic system exhibit any respiratory disruption.[7,11] This may be explained by another study[5] that found that an anoxic system had no immediate effects on respiration but that open-bill gaping and apparent apnea were occasionally observed later in the process.

Studies have shown that more bouts of wing flapping occur when birds are stunned with anoxic systems than when birds are stunned with hypercapnic anoxic[2,3,5] or hypercapnic hyperoxygenation[2,3,5] systems and that bouts of wing flapping occur for a longer duration with anoxic systems than with hypercapnic anoxic[2,3] or hypercapnic hyperoxygenation[2,3] systems. One study,[5] which analyzed transformed data by means of a generalized linear mixed model method, rather than comparing median values with a Kruskal-Wallis test as other authors had done, found that wing flapping duration was shorter with anoxic systems, compared with hypercapnic hyperoxygenation systems. Another study[11] found all birds stunned with anoxic, hypercapnic anoxic, or hypercapnic hypoxic systems exhibited severe wing flapping. Analysis of EEG recordings in 1 study[3] suggested that wing flapping occurred when consciousness could not be excluded. The time to loss of posture is similar between anoxic and hypercapnic hyperoxygenation[2] systems.

Physiologic reactions

Time to an isoelectric EEG and time to death are shorter for birds stunned with anoxic systems, compared with times for birds stunned with hypercapnic hyperoxygenation systems,[2] as is time to loss of SEPs.[23] However, time to an isoelectric EEG, time to death, and time to loss of SEPs are all longer for birds stunned with anoxic systems, compared with times for birds stunned with hypercapnic anoxic systems.[2,23]

Summary

Birds stunned with anoxic CAS systems show less respiratory disruption than do birds stunned with other CAS systems but show more wing flapping. It is unclear whether wing flapping begins before or after unconsciousness as determined by EEG.

Hypercapnic anoxia—With hypercapnic anoxic CAS systems, carbon dioxide mixed with an inert gas is used to displace oxygen from the air the birds breathe. As is the case for anoxic CAS systems, hypercapnic anoxic systems are single-stage systems that result in stunning and death.

Behavioral reactions

Mandibulation has been observed in birds stunned with hypercapnic anoxic systems.[2,28] Headshaking has also been observed in birds stunned with hypercapnic anoxic systems[2,10,28] but may occur to a lesser degree than in birds stunned with hypercapnic hyperoxygenation systems.[11] Respiratory disruption tended to be less frequent in birds stunned with hypercapnic anoxic systems, compared with frequency in birds stunned with hypercapnic hyperoxygenation systems,[2,11,28] but was more frequent than in birds stunned with anoxic systems.[2,11]

Studies have shown that fewer bouts of wing flapping occur when birds are stunned with hypercapnic anoxic systems than with anoxic systems[2,3,5] but that more bouts of wing flapping occur than when birds are stunned with hypercapnic hyperoxygenation systems.[2,3,5,28] Overall wing flapping duration following hypercapnic anoxic stunning was shorter than duration following anoxic stunning[2,3] but longer than duration following hypercapnic hyperoxygenation stunning.[2,3] Another study[11] found that all birds stunned with anoxic, hypercapnic anoxic, or hypercapnic hypoxic systems showed severe wing flapping. Time to loss of posture was shorter for birds stunned with hypercapnic anoxic systems than those stunned with anoxic or hypercapnic hyperoxygenation systems.[2,5,10,11]

Physiologic reactions

Time to reach an isoelectric EEG is shorter for birds stunned with hypercapnic anoxic systems, compared with times for birds stunned with anoxic[2] and hypercapnic hyperoxygenation[2] systems. Time to loss of SEPs is also shorter for birds stunned with hypercapnic anoxic systems, compared with time for birds stunned with anoxic,[23] hypercapnic hypoxic,[22] or hypercapnic hyperoxygenation[23] systems.

Summary

Birds stunned with hypercapnic anoxic CAS systems have a shorter time to loss of posture and reach unconsciousness, as determined by means of EEG, more rapidly than do birds stunned with other CAS systems. However, as with anoxic systems, wing flapping occurs at a time when consciousness cannot be ruled out. On the basis of currently available data, hypercapnic anoxic systems may be preferable to anoxic systems but cannot eliminate as many negative experiences for the birds as hypercapnic hyperoxygenation systems do.

Hypercapnic hypoxia—Hypercapnic hypoxic CAS systems mix carbon dioxide with air to achieve an atmosphere capable of stunning or killing. The concentration of carbon dioxide can range from 20% to 80%. Hypercapnic hypoxic systems lend themselves to a multistage approach, whereby unconsciousness can be achieved before the carbon dioxide–induced nociception threshold is reached. After unconsciousness occurs, the carbon dioxide concentration can be increased to a level that kills the birds.

It is thought that carbon dioxide causes unpleasant sensations on the nasal mucosa when administered in high concentrations. A study[7] in turkeys found that 50% of birds would avoid a feeding chamber containing 72% carbon dioxide.

Behavioral reactions

Mandibulation has not been recorded in birds stunned with hypercapnic hypoxic systems. Headshaking has been recorded in birds stunned with hypercapnic hypoxic systems,[6,11,29] but the findings are contradictory, with one study[11] finding that headshaking occurs to a lesser degree with hypercapnic hypoxic systems than with hypercapnic hyperoxygenation systems and another[6] finding that it occurs to a greater degree. Respiratory disruption occurs with hypercapnic hypoxic systems[11,29] with a similar frequency to that reported for birds stunned with hypercapnic anoxic[11] and hypercapnic hyperoxygenation[2] systems. It has also been found that respiratory disruption occurred at a variety of carbon dioxide concentrations and is therefore not dose dependent.[6]

One study[11] found that all birds stunned with anoxic, hypercapnic anoxic, or hypercapnic hypoxic systems developed severe wing flapping. A recent study[29] on 4- and 5-stage incremental carbon dioxide stunning systems found that birds stunned over a 6-minute period with 5 incremental stages in carbon dioxide concentration do not show wing flapping or convulsions prior to loss of posture. The time to loss of posture is similar for birds stunned with hypercapnic hypoxic versus anoxic systems, more rapid for birds stunned with hypercapnic hypoxic systems than for birds stunned with hypercapnic hyperoxygenation systems, and longer for birds stunned with hypercapnic hypoxic systems than for birds stunned with hypercapnic anoxic systems.[11] Another study[30] found that increasing the concentration of carbon dioxide from 35% to 65% reduced the time to loss of posture.

Physiologic reactions

In 1 study,[31] birds began severe wing flapping after achieving a suppressed EEG but before reaching an isoelectric EEG when breathing 45% carbon dioxide. However, loss of SEPs did occur before the onset of severe wing flapping.[31] A study[29] on a 5-stage incremental carbon dioxide hypercapnic hypoxic system found that high-amplitude, low-frequency (transitional) EEG waveforms occurred at 36 seconds on average. This was followed by a suppressed EEG at approximately 60 seconds, with isoelectric or near-isoelectric EEGs by the end of the 6-minute process. In this study,[29] a suppressed EEG indicating unconsciousness was achieved prior to wing flapping.

Summary

Stunning with traditional hypercapnic hypoxic systems does not show a clear advantage over stunning with other CAS methods because it is unclear, given the mixed EEG results that have been reported, whether wing flapping begins before birds are unconscious. However, recent modifications to this CAS system resulting in a 5-stage incremental scheme appear to have resolved this issue with a seemingly smoother induction of unconsciousness prior to death.

Hypercapnic hyperoxygenation—Controlled atmosphere stunning systems that use a mixture of carbon dioxide, oxygen, and an inert gas result in hypercapnic hyperoxygenation. These types of gas mixtures can stun but not kill poultry; therefore, they generally are used in 2-stage systems whereby high concentrations of carbon dioxide are used to kill the birds after they have become unconscious.

Behavioral reactions

Mandibulation has been observed in birds stunned with hypercapnic hyperoxygenation systems.[2,28] Headshaking has also been observed in birds stunned with hypercapnic hyperoxygenation systems,[1] and 1 study[11] found it occurred to a greater degree than with anoxic, hypercapnic anoxic, and hypercapnic hypoxic systems. However, another study[5] found that less headshaking occurred with hypercapnic hyperoxygenation than with hypercapnic hypoxic systems. Respiratory disruption was greater in birds stunned with hypercapnic hyperoxygenation systems, compared with frequency in birds stunned with hypercapnic anoxic or anoxic systems.[2,3,11,28]

Fewer bouts of wing flapping occurred when birds were stunned with hypercapnic hyperoxygenation, compared with number of bouts when birds were stunned with either hypercapnic anoxic or anoxic systems.[1–3,5,11] Studies have also found that the total amount of time that wing flapping occurred was less when birds were stunned with hypercapnic hyperoxygenation systems, compared with total time when birds were stunned with anoxic,[2,3,11] hypercapnic anoxic,[2,3,5,11,28] or hypercapnic hypoxic[11] systems. Another study[3] found that hypercapnic hyperoxygenation systems eliminated the possibility of severe wing flapping occurring during a period of consciousness for the birds. Although it has been shown that significantly fewer wing fractures occur with hypercapnic hyperoxygenation than hypercapnic anoxic systems,[5,28] more wing fractures occur with hypercapnic hyperoxygenation systems than with low-frequency alternating current electrical stunning systems (120 V; 50 Hz).[5] The time to loss of posture was longer with hypercapnic hyperoxygenation systems than with anoxic,[11] hypercapnic anoxic,[2,11] or hypercapnic hypoxic[2,11] systems.

Physiologic reactions

Time to an isoelectric EEG and time to death are longer for birds stunned with hypercapnic hyperoxygenation systems, compared with times for birds stunned with anoxic or hypercapnic anoxic systems.[2,3] Time to loss of SEPs is also longer for birds stunned with hypercapnic hyperoxygenation systems, compared with time for birds stunned with anoxic or hypercapnic anoxic systems.[22]

Summary

Birds stunned with hypercapnic hyperoxygenation systems take longer to lose consciousness (as determined by EEG results) than do birds stunned with most other CAS systems. This reflects the fact that hypercapnic hyperoxygenation systems are 2-phase stunning systems which, by design, take longer to achieve their outcome. In addition, respiratory disruption is greater in birds stunned with hypercapnic hyperoxygenation systems than in birds stunned with other CAS systems. However, less wing flapping occurs than with other CAS systems and it appears that wing flapping does not begin until after the birds are unconscious. When a hypercapnic hyperoxygenation system was compared with a low-frequency alternating current electrical stunning method, there were fewer wing fractures with the latter method.

Low atmospheric pressure—Atmospheric depressurization is also known as vacuum stunning. This type of system reduces the atmospheric PO_2 by evacuating air from an airtight chamber. Rapid decompression is an unacceptable method of euthanasia because pain and distress may occur as a result of gases trapped within the body. Recently, however, a LAPS was developed for stunning broilers whereby negative pressure is applied slowly over time, resulting in a hypoxic state followed by anoxic death.[32,33]

Behavioral reactions

Mandibulation, headshaking, and respiratory disruption have not been observed in birds stunned with a LAPS.[32] However, there were periods when birds were considered light-headed. This was defined by the researchers as the time from the first head movement to the time of the first wing flap.[32]

Observation of > 10,000 birds in an experimental commercial LAPS found approximately 6% of birds showed wing flapping. However, the percentage of birds with wing damage was greater for birds stunned with the LAPS than for those stunned electrically.[32] The mean time to loss of posture was approximately 65 seconds.[32] A more recent study[33] found EEG suppression began around 30 seconds and the onset of movement (as determined by the first EEG artifact) occurred at a mean of 39 seconds. The researchers concluded that this first, brief artifact was likely related to loss of posture,[33] which is associated with loss of consciousness.[12] This was longer than times reported for other CAS systems with the exception of 30% carbon dioxide.

Physiologic reactions

In a study[33] of birds stunned with an LAPS system, cross-referencing of the EEG and ECG data indicated that the EEG recordings displayed largely high-amplitude, low-frequency activity before movements indicating loss of posture were observed and that this activity was suppressed during periods of convulsion. At the end of the 280-second LAPS cycle, the EEG was isoelectric.[33]

Summary

Birds stunned with a LAPS appear to have longer times to loss of posture and unconsciousness than do birds stunned with anoxic or hypercapnic anoxic systems, possibly because the design of the LAPS requires a long cycle time. However, headshaking and respiratory disruption have not been observed in birds stunned with a LAPS. Wing flapping does not occur until after the birds are unconscious as determined on the basis of loss of posture and EEG results; however, the incidence of wing damage is greater in these birds than in birds stunned electrically. This is likely due to the fact that LAPS-stunned birds have loose muscles and open wings during periods of wing flapping, as opposed to the rigid posture of birds leaving a water-bath stunner, which includes tightly closed wings characteristic of a tonic spasm. Finally, there was no damage to the inner ear of LAPS-stunned birds, which can be seen with rapid decompression.[33]

Electrical Stunning

Electrical stunning is accomplished by passing an electrical current through the CNS of birds for a set time. Unconsciousness results from the inhibition of impulses arising from the reticular activating and somatosensory systems. In many cases, the stunning current reaching the brain is enough to induce an epileptic seizure but is lower than what is required to cause ventricular fibrillation and death. Thus, once birds are unconscious as a result of electrical stunning, a separate method (eg, exsanguination) is needed to induce death. The effectiveness of an electrical stunning system is dependent on the electrical variables used (ie, waveform, current, voltage, frequency, and duration) as well as the biological factors of the bird (ie, size, weight, sex, composition, and feather cover).[34] Electrical water-bath stunning involves contact of the bird's head with an electrified water bath. The electric current flows through the body of the bird while it is suspended upside down by the legs in moving shackles. Depending on the size of the water bath, several birds may contact the bath simultaneously. The water bath is electrically live so that each bird is stunned from the moment it makes contact with the water.[34] The presence of several birds contacting the water bath at the same time can create parallel pathways of resistance, altering the current delivered to individual birds.[35] Resistance can be variable owing to bird resistivity and shackle condition, and this variation can influence the efficacy of electrical water-bath stunning so that some birds receive insufficient current to induce unconsciousness and insensibility. Recent research has found a significant difference in efficacy of electrical stunning on the basis of sex, regardless of the electrical stunning waveform used.[16,36] Female broilers receive a significantly lower stunning current, compared with males, which results in a lower stunning efficiency for females. This could be due to differences in resistivity of the abdominal fat or the fact that females have thinner legs, leading to loose contact with the shackle, which lessens conductivity.[36] This variation creates concern for bird welfare in that birds may fail to lose consciousness or may recover prior to exsanguination.[34] Low stunning efficiency with conventional electrical water-bath systems has led the Netherlands to begin to phase these systems out.[29]

In addition to general efficiency issues associated with electrical water-bath stunning, prestunning electric shocks can occur if the birds' wings make contact with the water bath before their heads do[8] or if wing flapping occurs at the entrance to the stunner. One study[37] has shown that 66% of birds flap their wings during any unevenness they experience on the shackle line. Shackling itself is a painful[38] and stressful process for a bird, as shown by increased blood cortisol concentrations[39,40] and wing flapping.[39] It has been suggested that there should be a minimum time lapse of 12 seconds between shackling and stunning to allow birds to stop wing flapping[41] and a maximum time lapse of 60 seconds, after which a major stress response is seen.[40] The incidence of wing flapping and prestunning shocks may be reduced on a shackle line with the implementation of a breast support conveyor.[42] However, these conveyors can cause more distress to the birds if there are sharp bends in the shackle line.[42]

During electrical water-bath stunning, some birds may completely miss the electrified water bath because of wing flapping, struggling, lifting their head, or incorrect adjustment of the stunner. The use of rump bars to limit movement and breast support may help prevent birds from missing the water bath[34]; however, particularly small birds may reach the neck slitter while still conscious.

Some believe an epileptiform EEG recording followed by a quiescent or isoelectric phase is currently the best evidence of unconsciousness and insensibility following electrical stunning and that this pattern is, therefore, the best measure of an effective electrical stun.[26,27]

The waveforms, currents, voltages, and frequencies used in electrical stunning vary widely. However, the waveforms used for stunning poultry at slaughter can be broadly classified into 3 categories: alternating current (sinusoidal and rectangular), direct current (pulsed), and the US model. When sinusoidal (50 Hz) and rectangular (70 Hz) alternating current were compared with pulsed direct current (70 Hz) at constant voltages (60, 80, and 120 V) at a shortened stun time of 4 seconds, it was found that the minimum stunning currents needed to achieve 90% stunning efficiency (as determined by a profoundly suppressed EEG) were 70, 90, and 130 mA, respectively.[36]

Alternating current—Alternating current may be used for electrical water-bath stunning of poultry and is commonly used in Europe. Slaughter plants can use clipped or rectified waveforms; however, a sinusoidal waveform is traditional for alternating current. Modern commercial stunners now use a rectangular waveform. The application time for stunning of poultry under commercial conditions is approximately 10 seconds.[15]

Behavioral reactions

A decrease in the number of positive corneal reflexes from 20 seconds after alternating current stunning to 40 seconds after stunning has been correlated with progressive brain death, as determined by means of EEG.[15] Some authors suggest that there should be a maximum of 30% of birds with a poststunning corneal reflex.[15] A corneal reflex, in addition to spontaneous blinking that is regular and periodic, likely indicates recovery and consciousness of the birds, and spontaneous blinking has been linked to EEG results indicative of ineffective stunning.[15] Use of higher voltage can decrease the incidence of spontaneous blinking.[36] Resumption of spontaneous breathing occurs in birds that do not develop cardiac arrest during stunning; however, on its own, it is not an indicator of returning consciousness.[15] Recovering birds have been shown to resume breathing within 20 seconds of stunning[15]; use of a higher voltage can decrease the number of birds that resume spontaneously breathing. Wing flapping after electrical stunning is not indicative of consciousness in birds. It appears to be associated with electrically induced convulsions when leaving the water bath.[15] When low-frequency alternating current stunning (125 V; 50 Hz) was compared with hypercapnic anoxic and hypercapnic hyperoxygenation systems, there were significantly fewer wing fractures with the electrical stunning method.[5] When sinusoidal wave alternating current stunning (60, 80, and 120 V; 50 Hz) was compared with rectangular wave alternating current stunning (60, 80, and 120 V; 70 Hz) and pulsed direct current stunning (60, 80, and 120 V; 70 Hz), a corneal reflex, spontaneous blinking, and resumption of spontaneous breathing were less likely to occur with sinusoidal wave than with rectangular wave or pulsed direct current stunning. However, birds stunned with sinusoidal wave alternating current systems showed significantly more wing flapping than did those stunned with rectangular wave alternating current or pulsed direct current systems.[36]

Physiologic reactions

Some authors have found the best means of achieving a profoundly suppressed EEG is with low-frequency, high-amperage stunning.[13,15] Studies have shown that unless a current ≥ 150 mA is used, frequencies > 400 Hz are not suitable to render ≥ 90% birds unconscious, defined as reaching < 10% of the prestunning total EEG power[15,27,43] and abolishment of SEPs[27,43] for 40 seconds after stunning. Currents < 120 mA were also unable to render ≥ 90% of the birds unconscious for 40 seconds after stunning.[15] Additionally, when sinusoidal wave alternating current (60, 80, and 120 V; 50 Hz) was compared with rectangular wave alternating current (60, 80, and 120 V; 70 Hz) and pulsed direct current (60, 80, and 120 V; 70 Hz), development of an isoelectric EEG was more likely with sinusoidal wave alternating current than with rectangular wave alternating current or pulsed direct current.[36]

Summary

Studies[13–16] have found that current frequency has the most impact on stunning efficiency with alternating current systems. These same studies[13,15] concluded that frequencies > 400 Hz cannot be recommended with a maximum current of 150 mA and that stunning currents < 100 mA do not induce an adequate level of unconsciousness in birds. When these nonrecommended parameters are used, < 90% of the birds are effectively stunned for 40 seconds after leaving the water bath. With the highest frequencies (800 and 1,500 Hz), all birds survived the stunning process regardless of the current used (maximum current, 150 mA).[15] However, a more recent study[36] found that sinusoidal wave alternating current of 50 Hz and rectangular wave alternating current of 70 Hz achieved 90% stunning efficiency when 70 or 90 mA, respectively, of current was used. Spontaneous blinking combined with an increase in corneal reflexes indicates recovery of birds.[15] Finally, a ventral neck cut severing the common carotid arteries and external jugular veins on both sides of the neck is critical to avoid a return to consciousness in stunned birds.[13]

Direct current—Pulsed direct current is also often used for electrical water-bath stunning of poultry. Various combinations of currents, frequencies, and stunning times are used throughout the industry. Direct current has a faster rate of voltage change and a shorter excursion distance than sinusoidal wave alternating current.

Behavioral reactions

When direct current stunning is used, birds stunned with either lower frequencies or higher currents are less likely to have a corneal reflex. Birds with an absence of corneal reflexes 20 seconds after stunning also had isoelectric EEGs, an indicator of unconsciousness.[16,17] In 1 study[16] (stunning duration, 10 seconds), males were shown to be more likely to have a corneal reflex 20 seconds after stunning than were females, although no difference was found between sexes 40 seconds after stunning; another study[36] (stunning duration, 4 seconds) found females more likely to have a corneal reflex. Birds stunned with either lower frequencies or higher currents are also less likely to spontaneously blink, although males are more likely to blink after stunning than females.[16] Blinking is absent in birds that do not recover from stunning.[16,17] Resumption of spontaneous breathing occurs in birds that do not develop cardiac arrest during stunning; however, this on its own is not an indicator of returning consciousness.[16] It has been shown that recovering birds typically resumed breathing within 20 seconds after stunning and that males were more likely to resume breathing after stunning than females.[16] Wing flapping after electrical stunning is not indicative of consciousness in birds and appears to be associated with convulsions when leaving the waterbath.[16] Wing flapping does not occur in birds that experience cardiac arrest.[16] When pulsed direct current (60, 80, and 120 V; 70 Hz) was compared with sinusoidal wave alternating current (60, 80, and 120 V; 50 Hz) and rectangular wave alternating current (60, 80, and 120 V; 70 Hz), a corneal reflex, spontaneous blinking, and resumption of spontaneous breathing were more likely to occur with the use of pulsed direct current with a stunning duration of 4 seconds. However, birds stunned with pulsed direct current showed significantly less wing flapping than did those stunned with sinusoidal wave alternating current or rectangular wave alternating current.[36]

Physiologic reactions

One study[16] found that frequencies > 200 Hz are not suitable to render ≥ 90% of birds unconscious for 40 seconds after stunning at a current of 150 mA. Female birds were shown to be less likely to obtain a profoundly suppressed EEG than were male birds in the first 20 seconds after stunning.[16]

Summary

Studies[13–16] have found that with direct current stunning, current frequency has the greatest effect on stunning efficiency. One study[16] concluded that frequencies > 200 Hz cannot be recommended even when a maximum current of 150 mA is used because under these conditions, < 90% of birds were effectively stunned for 40 seconds after leaving the water bath. With the highest frequencies (800 and 1,500 Hz[16]; 800 and 1,400 Hz[14]) studied, all birds survived the stunning process regardless of the current used (maximum current, 150 mA[16] or 200 mA[14]). Spontaneous blinking combined with a return of corneal reflexes is indicative of rapid recovery of birds.[15,16] Additionally, when pulsed direct current (60, 80, and 120 V; 70 Hz) was compared with sinusoidal wave alternating current (60, 80, and 120 V; 50 Hz) and rectangular wave alternating current (60, 80, and 120 V; 70 Hz), the incidence of an isoelectric EEG was lower with pulsed direct current than with sinusoidal wave or rectangular wave alternating current.[36]

As with alternating current, a ventral neck cut (as opposed to a unilateral neck cut) is critical to avoiding a return to consciousness in stunned birds.[14] Finally, there appear to be some differences in the effectiveness of stunning on the basis of bird sex.

US model—Contrary to the European model, electrical stunning in the United States involves pulsed direct current with low current (25 to 45 mA/bird),[44] low voltage (10 to 25 V),[44–46] and high frequency (approx 500 Hz).[44–46] This type of system became possible with advances in electrical circuitry and changes to the length of the water-bath cabinet that increase dwell time of the birds and decrease the total resistance in the water bath.[44] In a survey of 329 US poultry plants, 92.1% reported using electrical stunning and 77.4% of those plants used low-voltage (10 to 25 V), high-frequency (500 Hz) systems.[47]

Behavioral reactions

Efficacy of the stunning in US slaughter plants has been determined by assessing corneal and comb reflexes.[47] Typically, a bird is considered stunned by plant personnel when it becomes unresponsive to stimulation of the cornea or comb with its eyes wide open, an arched neck, and tucked wings.[47] One study[48] evaluated a 2-phase step-up stunner, with a first phase consisting of low-voltage (12 and 15 V), high-frequency (550 Hz) pulsed direct current for 10 seconds and a second phase consisting of sinusoidal wave alternating current (50 Hz at 40, 50, and 60 V for 5 seconds).[48] The best results for this combination occurred in male birds at the highest voltage settings (phase one, 15 V; phase two, 60 V).[48] Under these conditions, only 22% of the birds had corneal reflexes, 18% had spontaneous blinking, and < 10% had wing flapping.[48]

Physiologic reactions

One study[48] that evaluated a 2-phase step-up stunner, with a first phase consisting of low-voltage (12 and 15 V), high-frequency (550 Hz) pulsed direct current for 10 seconds and a second phase consisting of sinusoidal wave alternating current (50 Hz at 40, 50, and 60 V for 5 seconds), found that 45% of the birds did not achieve an isoelectric EEG. Contradicting this, another research group evaluating a similar 2-phase step-up stunner (phase one, 23 V [550 Hz direct current for 10 seconds]; phase two, 15 V [60 Hz alternating current for 5 seconds]) found that the poststunning EEG had a brief period of high-amplitude spikes that progressively decreased in amplitude over time.[a] These investigators found the EEG recording of the brain activity to be very similar to that seen with the European model of electrical stunning.[a]

Summary

Results of studies of birds stunned with the low-voltage US model indicate that the birds are unresponsive to stimuli. However, the physiologic data are contradictory, and it is unclear whether birds truly reach a state of unconsciousness. As noted by others,[48,49] further research is needed to evaluate the effectiveness and humaneness of electrical stunning with low-voltage settings in 1- and 2-phase stunning systems.

Conclusions

The biological variability of birds makes it difficult to construct recommendations for optimal parameters for electrical stunning of poultry at slaughter. Inadequate electrical variables can result in a return to consciousness before birds enter the neck slitter. However, use of electrical frequencies that are too high results in an increase in blood spotting,[34] leading to larger amounts of carcass waste and an overall increase in the number of birds needed to yield the same amount of end product.

Compared with electrical stunning methods, CAS presents some welfare advantages because manual handling, shackling, and transport cage dumping (depending on the design and implementation of the system) of concious birds are eliminated. However, CAS methods have their own welfare disadvantages. Hypercapnic hyperoxygenation and incremental hypercapnic hypoxic systems appear to result in a smoother induction of unconsciousness and a reduction in the incidence of convulsions. Traditional hypercapnic hypoxic systems may invoke involuntary (unconscious) motor activity in birds, such as flapping of the wings or other terminal movements, which can damage tissues and be disconcerting for observers; however, wing flapping is less with these systems than with anoxic systems.

Compared with CAS methods that require dumping birds from their transport crates while they are still concious and with electrical stunning methods, LAPS appears to have welfare advantages because it does not require dumping concious birds onto the conveyor line and removes the need for manual handling and shackling of concious birds prior to electrical stunning. Also, LAPS seems to result in a quiet transition to unconsciousness without escape behaviors and with minimal physical activity and wing flapping.

All stunning methods cause a variety of behavioral and physiologic reactions that must be carefully considered. The American Association of Avian Pathologists–American College of Poultry Veterinarians position statement asserts that low-voltage alternating current, pulsed direct current, and CAS systems are viable and acceptable methods of stunning poultry at slaughter.[50]

No matter which system is used, it is important that stunning eliminate consciousness as rapidly and painlessly as possible. For many of the methods currently available, further research is needed to ensure that unconsciousness occurs prior to development of distressing behavioral reactions to the stunning method or entry to the neck slitter and scalder. A uniform definition of unconsciousness and death is necessary to achieve this goal.

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Appendix

Classification of methods for CAS of poultry at slaughter.

Category	Description
Anoxia	A high concentration of an inert gas (eg, argon or nitrogen) is used to displace oxygen from the air
Hypercapnic anoxia	A mixture of carbon dioxide and an inert gas is used to displace oxygen from the air
Hypercapnic hypoxia	A mixture of carbon dioxide and air is used to displace oxygen from the air
Hypercapnic hyperoxygenation	A mixture of carbon dioxide, oxygen, and an inert gas is used to stun the birds; a high concentration of carbon dioxide is then used to kill the birds (2-step process)
Low atmospheric pressure	Negative pressure is applied slowly over time, resulting in a hypoxic state followed by anoxic death