1-27-2017

Contributing Causes of Injury or Death in Grain Entrapment, Engulfment, and Extrication

Salah Fuad Issa
Purdue University

William E. Field
Purdue University

Charles V. Schwab
Iowa State University, cvschwab@iastate.edu

Fadi S. Issa
King Faisal Hospital and Research Centre

Eric A. Nauman
Purdue University

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Abstract

Objectives: Grain entrapments and engulfments are one of most common hazards associated with grain storage facilities, with over 1,140 such entrapments/engulfments documented since the 1970s. The objective of the study was to determine the factors that contribute to injury or death in grain entrapment, engulfment, and extrication cases. Methods: A literature review, including data contained in the Purdue Agricultural Confined Spaces Incident Database (PACSID), was conducted to determine the conditions that the body experiences during an entrapment or engulfment in grains and during extrication efforts. Results: Based on the review, the conditions a human body faces during an entrapment, engulfment, or extraction can be split into two broad categories—environmental and physiological/psychological. The environmental factors depend on the grain's properties, depth of entrapment or engulfment, position of the victim's body, and characteristics of the storage unit, which include the grain's lateral pressure, vertical pressure, and weight, as well as friction, oxygen availability and diffusion rate, and grain temperature. The physiological and psychological factors are related to the individual's age and physical and psychological conditions, and manifest themselves in terms of oxygen consumption, asphyxiation (including aspiration, lack of oxygen, compression or splinting of the thorax), blood flow, and heart rate. Conclusion: Of all the above factors, a review of fatality data contained in the PACSID indicate that aspiration, asphyxiation, grain weight, and lateral pressure are most likely the primary cause of death for most entrapment victims. Research gaps found by this study include an understanding of the impact of lateral pressure on lung expansion and oxygen availability and consumption rate, and the need for more case studies to accurately determine cause of death.

Keywords

Asphyxiation, aspiration, entrapment depth, lateral grain pressure, physiological conditions

Disciplines

Bioresource and Agricultural Engineering | Occupational Health and Industrial Hygiene | Risk Analysis

Comments

This is the Submitted Manuscript of an article published by Taylor & Francis as Issa, Salah Fuad, William E. Field, Charles V. Schwab, Fadi S. Issa, and Eric A. Nauman. "Contributing Causes of Injury or Death in Grain Entrapment, Engulfment, and Extrication." *Journal of Agromedicine* 22, no. 2 (2017): 159-169. Available online: https://doi.org/10.1080/1059924X.2017.1283277. Posted with permission.

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Conclusion: Of all the above factors, a review of fatality data contained in the PACSID indicate that aspiration, asphyxiation, grain weight, and lateral pressure are most likely the primary cause of death for most entrapment victims. Research gaps found by this study include an understanding of the impact of lateral pressure on lung expansion, oxygen availability and consumption rate, and the need for more case studies to accurately determine cause of death.

Keywords. physiological conditions, lateral grain pressure, asphyxiation, aspiration, entrapment depth

Introduction

Although agriculture has long been recognized as one of the nation's most high-risk industries[1-3], the number of nationally documented fatal incidents in grain production has actually decreased since the 1990s.[4] For instance, in the five-year period 1992-1996, the number of recorded fatalities per year averaged 390; whereas in the five- year period 2010-2014, that number dropped to 253 per year.[4] This significant decrease, however, has not been the case when it comes to incidents involving agricultural confined spaces as the number of these cases have fluctuated. For instance, confined spaces fatalities per year averaged 33 in the 1992-1996 period, peaked with a total of 54 in 2010, then decreased to 31 cases per year over the 2010-2014 period.[5]

One of the risks associated with agricultural confined spaces is grain entrapment and engulfment.[6-9] An entrapment is defined as any situation in which the victim's head remains above the grain mass but is incapable of self-extrication. While an entrapped person is usually buried between chest and shoulder levels[10], one could be buried only up to the knees or waist level and still not be able to get free. An *engulfment* occurs when the victim's head is entirely covered by the grain and/or no longer visible. Grain entrapments and engulfments currently represent about 50% of agricultural confined spaces incidents and 61% of all documented incidents over the last five decades.[5] While entrapments/engulfment represents a significant hazard in confined spaces, there has been no published research exploring the potential environmental and physiological conditions that the human body experiences while entrapped or engulfed, or during extrication efforts by first responders. Thus, the aim of this paper is to review both published studies and data contained in the Purdue Agricultural Confined Spaces Incident Database (PACSID)[9] to gain a deeper understanding of the factors that the body experiences and then to summarize the results.

Previous Research Efforts

Schmecta and Matz[11] carried out some of the earliest documented research regarding grain entrapments, studying the depth at which one can no longer extricate himself and the speed at which one can become entrapped in flowing grain. They found that when the grain reached hip depth, self-rescue was no longer possible, and when at shoulder depth not only was extrication impossible, but also the harness worn (rated for 150 kg) was even damaged during attempts made to extricate via rope. They also found that it took about 30 seconds for a human subject to get entrapped to shoulder level in a gravity unloaded bin with grain flowing from a bottom outlet at 25 metric tons per hour (925 bushels per hour); and when entrapped to chest level, breathing was difficult. Schwab et al.[12] built upon this early study by measuring the force required to vertically extricate a mannequin (wearing body harness) entrapped and engulfed in various levels of grain (results discussed in subsequent section). No other physical stresses aside from the pull forces were measured.

In 1977, the Purdue University Agricultural Safety and Health Program (PUASHP) created—and continues to manage—a national database on grain entrapment and engulfment injuries and fatalities. This on-going effort has stimulated subsequent research on such topics as: entrapments in grain transport vehicles[13], entrapments in commercial grain facilities[14], on-farm fatalities[15], contributing factors to grain entrapments[16], incidents involving grain vacuums[17], impact of grain rescue tubes on the forces needed to extricate[18], entrapments involving youth and beginning workers[19], incidents in agricultural confined spaces[9], and auger entanglements inside agricultural confined spaces.[20]

Extrication methods

Three rescue strategies have been documented as most commonly employed in attempting to extricate those entrapped or engulfed primarily in grain bins and grain transport vehicles (GTV). The first involves removing grain from around a victim so he can be freed, which is attempted either by cutting holes in the wall of the storage facility (if fabricated from steel panels) in order to lower the grain level, vacuuming the grain out of the structure (lower the level of grain)[17], placing retaining walls (a coffer dam) around the victim then removing the grain from inside the coffer dam walls freeing the victim, or a combination of all three.[21] The second strategy, which has been used for entrapments or engulfments inside a GTV, involves opening the outlet door(s) or tipping the GTV in hopes the victim will flow out with the grain (PACSID, unpublished results). The third strategy involves pulling the victim up and out of the grain mass using a harness and/or rope being pulled manually by first responders or attached to some type of powered or manually operated mechanical winch.[12,18]

Relative to this third method, attempting to forcefully extricate someone from a grain mass has historically been considered highly dangerous due to the large amount of force needed to do so. For instance, Schwab et al.[12], found that, to pull out an adult size 75 kg (165 lbs.) mannequin required about 1,900 N (430 pound-force) if entrapped at waist level and 4,000 N (900 pound-force) if entrapped up to the neck. Roberts et al.[7] found that extricating a mannequin after placement of a coffer dam around it actually increased the force required by 22-26%. Also, a case has been reported in which first responders, using a rope and truck to pull the victim out of a grain mass, resulted in the victim's injury or fatality.[21]

Snow-avalanche case studies

Similar types of entrapment/engulfment cases involving victims buried in snow avalanches have been studied extensively and should be considered since the bulk density of snow is within the same magnitude of many grains (i.e., about 800 kg/m^3). When engulfed, the victims tend to be submerged from 0.5 to 3 m beneath the surface of the snow, with the survival rate being only 19%.[22,23] In a review of 136 avalanche fatality cases, Stalsberg et al.[23] found 67.6% were caused by suffocation, 13.2% by mechanical trauma, 3.7% by hypothermia, 2.9% by suffocation and mechanical trauma, and 11% unknown. In another study of avalanche engulfments in Utah, McIntosh et al.[24] reported 85.7% caused by asphyxiation, 5.4% by mechanical trauma, and 8.9% by a combination of trauma and asphyxiation. The variability in percentages was likely due to local typography, such as the presence of thick forests, cliffs, or rocks.[25] Stalsberg et al.[23] uses the term suffocation to include aspiration, low oxygen concentration in surrounding air pocket, and thorax compression. McIntosh et al.[24] asphyxiation cases are reported to be due to breathing air with low concentration of oxygen.

Research Objectives

Unlike snow-avalanche fatalities, the causal factors involved in grain entrapments, engulfments, and extrication resulting in victim injury or death have not been extensively researched. The objective of the study presented here, therefore, is to determine what those factors may be by analyzing the literature and PASCID database documented causative factors. To simplify the results, the potential factors involved were split into two main categories—environmental-related and physiological/psychological-related.

Environmental ones are any that act upon the body, such as friction, pressure, and temperature. Physiological/psychological ones are those that affect internal responses by the body like asphyxiation and heart rate (physiological) and/or those that relate to the mental capacity of the victim to respond to his/her circumstances (psychological).

Research Questions Explored

Following are three research questions that guided this analysis, from documented incidents, about the causes of fatalities and injuries in grain entrapments, engulfments, and extrication.

1. What are the likely injury/fatality percentage differences in entrapment, engulfment, and extrication cases?
2. What are the environmental factors potentially impacting injury/fatality and survival rates in entrapment, engulfment, and extrication cases?
3. What are the physiological and psychological factors potentially impacting the injury/fatality and survival rates in entrapment, engulfment, and extrication cases?

Methodology

The literature review was conducted using the ASABE Technical Library, Google Scholar, and Purdue University article databases; and the extensive collection of resources related to grain entrapment maintained by PUASHP was likewise reviewed. The list of keywords applied in accessing these sources included: avalanche, psychogenic shock, suspension trauma, asphyxiation, grain pressure, grain entrapment, grain engulfment, extraction, vertical pull force, grain lateral pressure, hypothermia, heart rate, oxygen consumption rates, and any term that might be useful in understanding the impact of grain entrapment, engulfment, and extrication on the human body. Several published individual case studies on grain entrapments and engulfments were reviewed as well. In addition, all cases reported in the PACSID were analyzed to: (a) gain a better understanding of the factors that could potentially cause grain entrapment and engulfment injury or death, and (b) to address the questions regarding rate of entrapment or engulfment, and extrication methods used. For an extensive summary of how cases were collected and analyzed, see Riedel[26] and Issa et al.[9] The final list of factors was developed based on the case studies found in the PACSID, similar case studies from litigation documents and other research studies.

Findings

Research Question 1

What are the likely injury/fatality percentage differences in entrapment, engulfment, and extrication cases?

As of 2015, PACSID database contained 1,873 confined spaces incidents dating from 1956 to 2015; 1,143 of which were grain entrapment and engulfment cases. Of those, 766 were fatal (67%). In the five-year period 2011-2015, the fatality percentage of grain entrapment and engulfment cases decreased to 42%, likely because of the increased reporting of non-fatal cases. This increase in reporting was probably due to multiple factors, including better surveillance efforts and more awareness of this issue.[5] Again, of the 1,143 PACSID grain entrapment and engulfment cases, 570 were identified as engulfments, of which only 68 victims survived. That represents only a 12% survival rate which is lower than what is reported for snow-avalanche engulfments. In 15 of the 210 identified entrapment cases (7%), the victim still died, even though his head was above the grain surface when discovered.

In the vast majority of the PACSID entrapment/engulfment-related fatality cases, no autopsies had been conducted or cause of death was merely speculated. Where cause of death was reported, 21 had been attributed to asphyxiation, four to crushing of the body or head, three to inability to breathe or lack of oxygen (anoxic encephalopathy), and one each attributed to loss of blood, seizure, heart attack, heat stress, and spinal injury. Of those 21 asphyxiation cases, eight were directly linked to aspiration (airways and/or lungs blocked with grain) and five to crush asphyxiation. As to surviving grain engulfments, seven of the 68 cases attributed survival with covering of the mouth and nose during engulfment. In addition, 11 of the survivors were unconscious before being resuscitated. All the resuscitated victims were less than 16 years of age and represented 50% of those under 16 who survived engulfment (22 cases total).

When it came to the grain entrapment cases, depth of entrapment varied considerably. Of the 174 cases in which the depth of the victim was reported, the surface of the grain was at face, head, or neck level in 66 cases (36%), at chest or shoulder level in 60 cases (34%), at waist or torso level in 36 cases (21%), at legs level (ankles/knees) in four cases and one case in which only the ankles were visible because the victim had gotten entrapped upside down. Lastly, in seven cases, survival victims of entrapment reported trouble breathing while entrapped.

Research Question 2

What are the environmental factors potentially impacting injury/fatality and survival rates in entrapment, engulfment, and extrication cases?

A total of six environmental-related factors were determined to impact the rates of injury and fatalities in entrapment or engulfment cases (including injuries occurring during extrication)—lateral pressure, vertical pressure, friction, oxygen availability, oxygen diffusion rate, and grain temperature. Lateral and vertical pressure have direct impacts on the body's ability to breath, friction impacts the ability to extricate a person, oxygen availability and diffusion rates impact accessibility of oxygen in the surrounding grain, and grain temperature impacts the body's ability to maintain its core temperature.

Lateral pressure

If the person is entrapped at least at chest depth or engulfed in an upright position, the grain's lateral force would compress his chest (although it's unclear at which depth he could no longer breathe). Thompson et al.[27] found the lateral pressure of corn against the grain bin wall at a depth of 1.5 m (5 ft) was 5-7 kPa (kilo Pascal), at 12.2 m (40 ft) was 20-30 kPa, and did not increase beyond that depth. In a more recent experiment, Moore and Jones[28] found that the torso experiences 2.8 kPa when corn is at shoulder level and 3.9 kPa when buried at about 0.9 meters (3 ft) below shoulder level. Compared to what a scuba diver faces underwater (i.e., 15 kPa at 1.5 m and 121 kPa at 12.2 m), the pressures experienced in grain are relatively low.

It is important to note that load cells used to measure lateral pressures might not correctly measure or estimate actual pressure on the human chest; that's because these cells are designed to measure the active pressure in grain or pressure the grain applies to a wall. However, when one breathes, the chest is pushing against the grain mass and thus should experience a pressure closer to the grain's passive pressure or wall pushing against the grain mass (pushing the grain upwards against gravity).[29] The pressure on the cylindrical part of a grain bin with a hopper bottom is active while the hopper portion is considered passive.[30] By definition, passive pressure is larger than active and might restrict a person's ability to breathe; there are no known studies that confirm the magnitude of passive pressure at various entrapment and engulfment depths. Only one case of an entrapment resulting in death reported the cause to be asphyxiation due to chest compression.[14] However a medical record verifying either cause of death or injuries caused by the pressure on the chest could not be accessed. The placement of a coffer dam around the victim and removing the grain has been demonstrated as an effective extrication strategy by reducing the grain pressure on the victim. However, as shown by Roberts et al.,[18] the process of installing the coffer dam may actually increase the forces on the victim.

Vertical pressure

A victim will experience substantially more pressure if he happens to be engulfed in a horizontal position. Thompson et al.[27], using a load cell to measure the pressure from a column of grain, found it to be about 30 kPa at 1.5 m (5 ft) and about 90 kPa at 12.2 m (40 ft). This is significantly higher than the lateral pressure of grain (5-7 kPa at 1.5 m and 20-30 kPa at 12.2 m). Even when fully engulfed in a vertical position beneath the surface, the grain mass above the person acts as a barrier to pulling him out and increases the total load on him.

Friction

While not a major force during the process of entrapment or at steady-state condition, friction can be significant when the victim is being extricated up and out of the grain. The total force on a temperature cable, for example, when being pulled from grain can be calculated by summing the force of friction and weight of grain above the cable.[31] Schwab et al.[12] demonstrated that a person weighing 75 kg (165 lbs.) buried completely under grain would experience about 7,000 N (newton) or 1,574 pound-force if pulled directly out of the grain and about 3,000 N or 674 pound-force if entrapped up to his shoulders.

If a person is harnessed when being entrapped, he will experience friction forces as he is being pulled into the grain mass against the tension of the safety line. A basic temperature cable in the grain mass could experience up to two times as much force when grain is flowing than when in a steady-state condition[31]. Schwab et al.[12] found no statistical difference in force measured between extricating a mannequin from static grain and suspending a mannequin in flowing grain. Depending on how deep the victim sinks before there is no slack in his lifeline, the force generated could be enough to cause the mounting brackets of a ladder attached to the grain bin wall to fail or cause structural deformity or collapse of the roof beams, depending on where the rope was attached.[21]

Oxygen availability and diffusion rate

Porosity values depend significantly on the type of grain and its moisture content and generally range from 39% to 65%.[32] Overall, porosity values for specific grains are as follows: 39% for alfalfa, 39-48% for yellow corn, 41-44% for soybeans, 43-46% for grain sorghum, 43-46% for wheat, 49% for rye, 52-59% for barley, 52-59% for sweet corn, and 58-65% for oats, indicating that 40-60% of a grain mass is potentially filled with air.[32,33] While in theory this might mean that if a person's airway remains unrestricted, he could still breathe under grain. What might limit the ability for one to breathe in these situations includes: low initial oxygen levels in the mass (due to mold, foreign material, or insect activity), the actual porosity of grain, diffusion rate of the oxygen, and amount of dust/fines in the mass. Turning ventilation fans can be a lifesaving method by creating an airflow around the victim.[34] Less than 16% oxygen is considered an immediate danger to life, while between 16-19% is considered dangerous but not life threatening.[6] The following case study highlights that, in cases where the mouth and nose are protected, an individual can survive under grain.

In 2013, a 23-year-old man entered an 80,000 bushel grain bin in Iowa to unplug the outlet in the floor to allow the corn to flow. Due to asthma suffered since childhood, he entered the bin wearing a battery-powered respirator and a rope. (The respirator uses a battery-operated fan to circulate and filter out dust and mold from the surrounding air supply.) While trying to loosen the crusted material, he broke through and was drawn into the grain, being fully buried 46-61 cm (18-24 inches) below the grain surface. Without other workers nearby, the victim was engulfed for about an hour before a truck driver realized he was missing. The driver tried to pull on the rope to no avail because the victim was so far underneath the surface. By the time rescue was completed.(via draining the grain from the bin), he had been engulfed for four to five hours. During the engulfment, he had drifted in and out of consciousness but was able to shout, alerting the emergency rescue crew that he was alive. The respirator had continued to function throughout the engulfment period. After rescue, his heart rate was 173 beats per minute (bpm); he had suffered an injured foot, a rope burn, and minor scratches and ended up spending two days in a hospital.[35] This type of successful survival of victims fully engulfed in grain are rare but continue to be documented.

Temperature

Grain is harvested during the fall often under low daily temperatures. In addition, farmers are encouraged to lower grain temperature in the bin to around 4°C (39°F) through operating ventilation fans, utilizing the low ambient temperatures during the fall to reduce microbial and insect activity.[36] As spring approaches and ambient temperature warms, the grain in the center of the bin can remain significantly cooler (>10°C) than the outside temperature, depending on the bin's size.[37] For example, at the end of May, the average temperature in Winnipeg, Canada, is about 15°C, while the grain in the center of a 9 m bin would be about 4°C.[37] This means that one entrapped or engulfed in grain could be exposed to relatively low temperatures and potentially experience hypothermia.

This is important to understand because it impacts the discussion of what extrication methods are best suited for rescue. In water at about 4°C, a person can survive between 30 and 90 minutes.[38] This is because water is 25 times more thermally conductive than air (0.6 W/m K [watts per meter Kelvin] for water versus 0.024 W/m K for air); thus, the body cools down 25 times faster in cold water than in air.[39] While it is not known how long a person would survive in grain at lower temperatures, the thermal conductivity of grain ranges from 0.16 to 0.20 W/m K, which is about 7-8 times greater than air.[40] This means that a person exposed for multiple hours buried in cold grain could experience hypothermia, although not as quickly as one would experience in water.

In one case study, the victim was buried up to his armpits in grain at 0°C temperature. At the time of attempted rescue, he was conscious and experiencing no pain. The emergency first responders initially tried to free him by shoveling the grain out of the way. When this proved ineffective, they placed a harness around his upper body in order to pull him out. As they were pulling, he complained of chest pain and developed breathing problems. Although analgesic drugs were administered to reduce the pain, the pull-force required caused him such unbearable pain that the rescue attempt could not be continued.

Eventually, the rescuers placed a cylinder around him, removed the grain between his body and the cylinder wall, and then pulled him out. Once extricated, his chest pain stopped completely. The rescue took about four hours; and by the time it was completed, the victim had developed mild hypothermia and had a body core temperature of 35.1ºC. He was provided a blanket and hot fluids then taken to the hospital, where he was discharged the next day.[10]

Research Question 3

What are the physiological and psychological factors potentially impacting the injury/fatality and survival rates in entrapment, engulfment, and extrication cases?

Factors identified influencing the rate of injury and fatalities were oxygen consumption, asphyxiation, blood flow, heart rate, and a psychological-related one. Oxygen consumption and asphyxiation impact the body's ability to breathe; blood flow and heart rate impact its ability to maintain bodily functions; and the psychological factor impacts how one responds to entrapment or engulfment.

Oxygen consumption

A person engulfed in grain will likely struggle to get enough oxygen to his lungs from the surrounding grain mass. Likely exacerbating the situation are one's age, general health, and respiratory health. For example, the lung disease, chronic obstructive pulmonary disease (COPD), makes it hard to breathe and can cause coughing, tightness of chest, wheezing, and excessive mucus production. The leading cause of COPD is cigarette smoking.[41] Those with the disease have significantly smaller oxygen peak consumption rates than those who don't, thus experience a much higher level of dyspnea, or shortness of breath.[42] This means that a COPD subject entrapped or engulfed in grain will likely experience significant obstacles in breathing; and if he experiences uncontrollable coughing and wheezing, the risk of aspirating grain will be even greater. In addition, a person who panics due to a natural fear of being buried alive[43] will use up most of the available oxygen in a relatively short time (versus one who remains calm), thus further reducing his odds for survival.

Asphyxiation

There are three main ways in which a victim can experience asphyxiation in grain—aspiration, crush or traumatic asphyxiation, and postural asphyxiation. The primary one is aspiration, and there are a multitude of case studies of engulfed victims with their lungs filled with grain.[44-46] The flowability of grain may be enough to fill the victim's mouth, nose, and lungs, leading to asphyxiation, as long as there is no barrier (e.g., a mask) between his face and the grain and/or he responds to being pulled into the grain by opening his mouth to shout or breathe. Crush or traumatic asphyxiation occurs when the rib cage or abdomen are fixated, as is often the case in a mining incident or if a trench collapses and buries the victim to neck level.[47] The tell-tale sign of crush asphyxiation is the distribution of petechiae (small red/purple spots) across the body and face and in the eyes.[48] Due to a lack of studies, it's unclear whether the passive grain pressure alone could cause crush or traumatic asphyxiation.[28]

The third type is postural or positional asphyxiation, where the body gets wedged in a specific position that prevents movement of the chest.[49] Having the arms and hands behind the back or above the head reduces the victim's ability for chest expansion; and the fear or stress associated with asphyxia can, in and of itself, cause death by cardiac arrest.[50]

Blood flow

A person entrapped or engulfed in grain loses the ability to move legs and torso, which might lead to physiological conditions similar to being suspended in a harness (regardless if they were wearing a harness or not). Weems and Bishop[51] reported that a healthy adult suspended in a vertical position for as few as 5 minutes with no body movement can lose consciousness and, if not placed in a horizontal position, can die. The reason is that blood quickly starts pooling in the legs due to lack of muscle movement, thus reducing the supply to the heart; and straps around the thighs further cut off blood flow[52]—a physiological condition subsequently confirmed by Pasquier et al.[53]

In an earlier-cited case study by Bahlmann et al.[10], the victim experienced chest pain until he was fully extricated, the authors suggested that mild hypothermia may have contributed to the pains, since hypothermia is known to cause angina (Angina is the chest pain one feels when not enough blood flows to a part of the heart due to temporary blockage of the arteries; and the pain tends to dissipate quickly[54]). The victim's sudden relief from chest pain after rescue indicates that, while hypothermia and his heart disease might have played a role in the pain's severity, the primary cause might have been reduced blood flow similar to what one experiences during suspension trauma. In addition, if the pain had been caused solely by the pressure of the grain on his chest, the subject should have experienced relief as soon as the grain level was below his chest. Lastly, a study on how boa constrictors kill their prey revealed that they induced circulatory arrest in their victims, causing a cardiac electrical dysfunction[55]. This is contrary to previous understanding that victims of boa constrictors die due to suffocation.

Heart rate

There are potentially multiple factors impacting the heart rate of a person engulfed in grain. The first is the availability of oxygen in the surrounding grain. A study by Dripps and Comroe[56] to measure the impact of oxygen supply on heart rate found that decreasing the supply to 8-10% for 6-8 minutes increased heart rate of the test subjects by 20 bpm up to approximately 90 bpm. The study participants were first rested on a bed for 45-60 minutes in order to stabilize their heart rates then provided oxygen at a specific concentration through a rubber mask.

Another factor could be the surrounding grain pressure. While no studies were uncovered specifically on the impact of grain pressure on a person's heart rate, Butler and Woakes[57] found that, when test subjects were submerged under water and remained inactive for 30 seconds, their heart rates dropped from 70 bpm down to about 50 bpm. In addition, in suspension trauma, one experiences initially an increased heart rate that then drops significantly just prior to fainting. For one subject in a study by Pasquier et al.[53], heart rate dropped as low as 30 bpm just before fainting. In the earlier-cited case study of the youth engulfed for 4-5 hours before being rescued, his rate immediately after rescue was 173 bpm (about 90% of the maximum heart rate). However, it is important to note that, while still engulfed in the grain mass, he was going in and out of consciousness and only awoke when he heard a fireman's radio.[35] This might mean that his heart rate during the early stages of engulfment was considerably lower than what was measured, perhaps indicating the heart may be responding in a complex manner to the above and/or other psychological factors, such a fight-or-flight response and adrenaline.

Psychological factor

Human beings have a long history of fear of being buried alive, with one medical historian considering it the most primal fear.[58] There are numerous stories of persons being buried alive and societies practicing traditions such as ‘waiting mortuaries’,[43] and keeping unpreserved corpses for viewing for three days.[58]—the purpose being to prevent burying humans alive. It might be expected that getting engulfed in grain can elicit similar fears.

In addition, emotional stresses triggered by grief or fear have been known to cause chest pain and/or shortness of breath—a set of symptoms that has been called takotsubo cardiomyopathy, broken heart syndrome, and stress cardiomyopathy.[59] Such conditions have been triggered by a family member’s death, a car crash, surprise party, court appearance, tragic news, and even fear of choking.[60,61] Alone, stress cardiomyopathy has a favorable prognosis, with hospital mortality rates of 1.7-3.1% and a very low recurrence rate of 11.4% over a four-year period.[59] However, the psychological reactions of chest pain and shortness of breath, combined with a victim entrapped or engulfed in grain might lead to secondary or tertiary causes of death.

Conclusions and Recommendations

The low survival rate for grain engulfments and entrapments, coupled with the fact that these incidents continue to occur despite an overall industry-wide decrease in the number of fatalities, highlights the importance of understanding the environmental and physiological/psychological factors that impact the survival rates. The authors believe that the major cause of death in grain engulfments/entrapments is most likely aspiration. The specific roles that lateral pressure and oxygen availability play are unknown. Blood flow, heart rate, and psychological shock might be a secondary cause of death but, most likely, not the primary. It is also highly unlikely that cause of death will be from hyperthermia or exposure to low temperatures though both could have occurred. Friction only plays a role in injury during extrication from a grain mass. Although there are limited case studies, the data clearly indicate that serious physical injury (and even death) can occur by forcefully trying to extricate the victim from the grain. This includes injury to the joints and spinal column.

Needed Research Efforts

Future research and case studies are needed in this area to more fully understand—and confirm—the factors that a body experiences during entrapment, engulfment, and extrication. It is suggested that such research should focus on: (1) the ability of the chest to expand under various depths of grain, (2) oxygen availability and diffusion rates in the grain mass, (3) blood flow and heart rate for victims entrapped in grain, (4) the maximum tensile force that a spine can withstand during extrication, and 5) case studies that document the primary and secondary causes of death and injury. Better understanding each of these topics would help provide credible evidence to what is occurring to a body engulfed in grain and provide insight into how to increase survival rates for victims, especially in engulfments.

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