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Hypoxia-Induced Loss of Consciousness in Multiple Synchronized Swimmers During a Workout

Linda Quan, Bruce H. Culver, and Roy R. Fielding

Hyperventilation by swimmers can lead to hypoxia and loss of consciousness. In this retrospective case series we describe the simultaneous onset of hypoxia in multiple 13–15-year-old female synchronized swimmers of an elite synchronized swim team based on review of Health Department and emergency medical service reports. All six swimmers performing hypoxic drills developed hypoxic symptoms (e.g., fatigue, inability to move legs, disorientation, tunnel vision, and/or loss of consciousness) and four required rescue. All swimmers regained consciousness at the scene and recovered. Two swimmers not performing hypoxic drills were unaffected. Of the environmental evaluations, only pool water temperature was higher than the recommended levels. Hyperventilation with hypoxic training can be life threatening and should be prohibited. Duration of hypoxic drills should be limited. Emergency response plans should be practiced.

Breath holding has been used by swimmers and divers to increase their underwater time. Blackouts due to hyperventilation have been described in the medical literature; however, these have involved individual cases. We describe an event where hypoxic training and hyperventilation during a pool workout caused the simultaneous onset of neurologic symptoms and respiratory failure in four adolescent female synchronized swimmers. We describe the resuscitation, the evaluation and role of environmental factors, and recommendations for preventing the occurrence of this potentially lethal condition.

Method

The pool was an indoor pool, maintained and operated as a hydrotherapy pool by a private organization. Owners and operators are required to notify their public health officer of any fatal or nonfatal drowning, death, serious injury, or serious illness associated with the water recreation facility within 48 hours after becoming aware of the occurrence. Seattle/King County Public Health routinely conducts investigations of serious injuries and illnesses at water recreation facilities.

We reviewed the investigation and final report of the Public Health Department and medical incident records of the King County Emergency Medical Service (EMS; Moran, Leung, Wyman, & Williams, 2008).

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The Incident

Eight members of a synchronized 13–15-year-old team (comprised primarily of 13–15-year-old swimmers) began at about 5:00 p.m. with stretching on the pool deck followed by a workout in the center lanes, 3 and 4, of the pool. The swimming pool was 25 yards (75 feet) in length and ranged in depth from 3.5 to 10.5 feet. The workout began with a 500 yard swim, combining kicking and pulling elements, crawl and butterfly, followed by a 200 yard swim with flutter kicking. The team then began a hypoxic drill without sprints. A hypoxic drill is a workout conducted on a restricted breathing schedule. The team's usual hypoxic drill consisted of four rounds (each round consisted of a surface swim and a final underwater portion, totaling 100 yards, or four lengths per round) with a rest of about one to two minutes between rounds. The hypoxic drill was a progressive workout, meaning that the length of the underwater portion of the swim was increased with each round as indicated in Table 1. The crawl stroke (or freestyle) lengths were conducted at the surface of the pool with breaths. The underwater swim was conducted without coming up for air during the duration of the underwater portion of the round. A fifth round was added to prepare the team for upcoming competitions. The coach was situated at the end of the pool.

Table 1 The Progressive, Hypoxic Workout for Synchro's 13–15-Year-Old Team on the Day of the Incident

Round (Each round is 4 lengths, or 100 yards)	Crawl Stroke or Freestyle (Number of lengths or yards)	Underwater Swim (Number of lengths or yards)
1	3.5 lengths (87.5 yards)	0.5 length (12.5 yards)
2	3.0 lengths (75 yards)	1.0 length (25 yards)
3	2.5 lengths (62.5 yards)	1.5 lengths (37.5 yards)
4	2.0 lengths (50 yards)	2.0 lengths (50 yards)
5 (added)	2.0 lengths (50 yards)	2.0 lengths (50 yards)

Case Reports

Swimmer A. Swimmer A made it to the finish of Round 5 but felt very tired.

Swimmer B. Swimmer B described that she had a dry mouth, felt very tired, and her legs began tingling during the underwater swim of Round 5. She described that her legs gave out but that she kept moving via use of her arms. She also reported being disoriented and not knowing what she was doing or how she arrived at the end of Round 5. The coach observed Swimmer B approaching the deep end wall of Lane 4 with a heavy head that was moving slowly from side to side. The coach observed that Swimmer B could not hold onto the wall and then observed Swimmer B begin to sink under water. The coach jumped into the pool and pulled Swimmer B out of the water.

Swimmer C. Swimmer C described that her mouth felt dry during the workout, losing most of the feeling in her body and passing out about half way back to the deep-end wall during the final length of the underwater swim of Round 5. After

assisting Swimmer B out of the water, the coach turned and noticed that Swimmer C was approaching the deep-end wall of Lane 4 but could not make it. The coach observed Swimmer C come up to take a breath and then sink back under water. The coach jumped back in the water and pulled Swimmer C to the surface while calling for the lifeguards to assist. Swimmers A and D helped the coach pull Swimmer C from the water. One of the pool's lifeguards ran over, assisted in pulling Swimmer C from the water, and then began assisted breathing for Swimmer C.

Swimmer D. Swimmer D made it to the end of Round 5 but was very tired and had numbness in her arms and legs. Swimmer D also reported sensations of tunnel vision.

Swimmers E and F. Swimmer E described that she felt fine until the final underwater swim and then her mouth felt dry, she felt tingly, and then passed out. After removing Swimmer C from the pool, the coach turned and observed Swimmers E and F on the bottom of the pool. The coach jumped back in the water, grabbed both swimmers and swam up to the surface. A junior team coach helped pull Swimmer F from the pool. Another pool lifeguard began CPR on Swimmer E and the junior team coach provided rescue breathing for Swimmer F. The swimmers regained consciousness shortly thereafter.

Swimmers G and H. Swimmers G and H were regular guests to the synchronized 13–15-year-old team but not regular members of the team. As guests, the swimmers were not expected to perform the full hypoxic workout and were allowed to pop their heads above water to take breaths as needed during the underwater swims. Swimmers G and H did not report any adverse effects from the workout.

Case Responses

EMS was called and the first of several units arrived within 8 min. Upon their arrival, all four swimmers who had lost consciousness were conscious, oriented, talking, and had normal vital signs and oxygen saturations. One complained of feeling dizzy and nauseated and was shaking. One mother “nearly” fainted and was complaining of shortness of breath, dizziness, and exhaustion. The 4 swimmers and mother were given oxygen, monitored oxygen saturation, and transported to area hospital emergency departments. All were discharged home from the emergency departments. All other swimmers, including the two guest synchronized swimmers in the 13–15-year-old team, had no symptoms and were not evaluated.

During the synchronized 13–15-year-old team workout, other swim groups were using the indoor pool. The junior synchronized swim team (comprised of elite swimmers over 15 years of age) started their normal warm up around 5 p.m., followed by a normal warm-up swim. Subsequently, they conducted their synchronized swimming routines in the deep end of Lanes 5 and 6. In the shallow-end of lanes 1 and 2, pool staff conducted group swim lessons. No one in these other swim groups had symptoms.

Evaluation of the setting started immediately following the incident. A member of the synchronized swim team asked the onsite EMS personnel to perform indoor air quality monitoring because the area seemed stuffy. The monitoring was conducted after doors to the outside had been opened. No combustible gases were detected and oxygen levels were normal at 20.9%.

The next day, a Public Health Department team began an initial investigation of the incident. They interviewed pool staff, inspected the pool and structure, and reviewed copies of incident reports, pool water quality logs, and personnel training certificates for pool staff and coaches for the synchronized swim team.

The synchronized swim teams' families expressed concerns that water or air quality caused the events. In response to these concerns, the Public Health Department conducted additional pool water quality testing and indoor air quality testing. On 6 separate days, pool water temperature was 86–87 °F. The pool was maintained and operated at 86 °F as a warm water hydrotherapy pool for some pool users. Evaluation for thermal differences in the pool showed water temperatures varied from 85.9 to 86.6 °F. To avoid excess moisture accumulation within the facility, the air temperature was generally maintained about 81–83 °F. Air temperatures within the pool area typically varied throughout the day, especially on sunny days, being cooler in the mornings and warmer in late afternoons and evenings. On five separate days, indoor air temperature and carbon dioxide were normal, and carbon monoxide levels were undetectable in the “breathing zone” above the pool surface.

Water pH, free chlorine and combined chlorine levels, and total alkalinity were within prescribed ranges when tested on multiple days. In addition, pool water quality records for the previous month showed levels had been consistently appropriate. A mechanical inspection of the chlorine and acid feed system showed these systems were in proper operational condition. An inspection of the heating, ventilation, and air conditioning (HVAC) system found these acceptable and met Washington State Water Recreation Facilities Code requirements.

Representatives of the synchronized swim team were interviewed and reported that they train swimmers not to hyperventilate before underwater breath-holding activities. The coaches pointed out that performers cannot hyperventilate during competitive events so training performers with hyperventilation during practices would not be helpful. Team coaches and organizers reported that shallow water blackouts do occur, but only rarely, during synchronized swimming training sessions and competitions. The pool operator and the synchronized team were unable to provide any documentation of emergency response drills.

Discussion

This was the first report of underwater blackout occurring simultaneously in a group. This series was also unique for the detailed description of the events and rescues, onsite prehospital evaluations, and the extensive evaluation of environmental factors that might have contributed to the events.

The timing, pattern of intense workout, and symptoms of the four swimmers were consistent with hypoxia and subsequent “shallow water blackout.” Symptoms reported by the swimmers engaged in the hypoxic workout were consistent with mild hypoxia (e.g., excessive fatigue, disorientation, memory loss, decreases in motor coordination, loss of motor control) progressing to severe hypoxia (i.e., loss of consciousness, cyanosis; Davies, Donaldson, & Joels, 1995; Lindholm, 2007; National Institute of Neurological Disorders and Stroke, 2010). Other symptoms (e.g., tingling, burning or numbness in arms and legs) were consistent with lactic acid accumulation in muscles due to anaerobic exercise (Bante, Bogdanis, Chairpoulou, & Maridaki, 2007; Yamamura, Tsukashima, Matsui, & Kitagawa, 2000).

The rapid revival of swimmers and the normal oxygen saturations of swimmers when evaluated at the scene by EMS were consistent with shallow water blackout. Signs of hypoxia “usually last approximately 5-15 seconds and quickly resolve by themselves as fresh air is inhaled and arterial oxygen pressure and saturation are normalized” (Lindholm, 2007).

Other swimmers in the pool at the same time did not experience any of the adverse symptoms. The two guest swimmers practicing with the 13–15-year-old team were the “control” group as they did the same drills but were allowed to surface and take breaths as needed during the hypoxic workout and had no symptoms. The junior synchronized team and the routine swim class who also remained asymptomatic were also controls for all environmental concerns.

Control of Breathing

The control of ventilation is a complex process controlled primarily by the carbon dioxide (CO_2) level in the blood. An involuntary central controller in the brainstem generates a rhythmic signal to the respiratory muscles. It is modulated by carbon dioxide and, to a lesser extent, oxygen blood levels, and can be overridden by voluntary control. Chemoreceptors in the base of the brain and near the carotid arteries respond to a rise in CO_2 level by increasing the signal to breathe. The carotid receptors also respond to a fall in oxygen levels, but this response is modest until the oxygen level is markedly low. The two signals are interactive so that the response to a low oxygen level is significantly reduced if the CO_2 blood level is low.

The strength of these responses varies considerably among individuals. Some evidence suggests that individuals with low ventilatory drives may self-select toward endurance athletics and, in particular, to synchronized swimming (Bante et al., 2007; Bjurström & Schoene, 1987). A long voluntary breath holding time is a simple indicator of such individuals. In individuals with low ventilatory drives, if the carbon dioxide blood level is lowered only a few mm Hg below normal by a brief increase in ventilation, involuntary drive is abolished until ongoing carbon dioxide production raises the level above this “apnea threshold.” This feedback loop matches ventilation to metabolic CO_2 production to maintain arterial carbon dioxide levels very close to normal and, concurrently, to bring in sufficient oxygen to match metabolic demand. Oxygen consumption and CO_2 production both increase markedly with exercise and ventilation increases appropriately.

Hyperventilation

Hyperventilation is defined as ventilation in excess of metabolic demand. Hyperventilation can be achieved by taking very deep breaths or rapid breaths or both. Hyperventilation, particularly involving more than a few breaths, lowers CO_2 levels. This process extends the time during which there is no signal to breathe until CO_2 rises to the level where the urge to breathe becomes overwhelming. While hyperventilation also brings in more oxygen than can be immediately consumed, this increase is minimal. During a breath holding episode, body metabolism rapidly depletes available oxygen. During an extended time without breathing, the ongoing depletion of oxygen may reach a level insufficient for muscle function, resulting in an inability to swim and inadequacy for brain function, resulting in loss of consciousness.

The development of hypoxemia, low blood oxygen level, is accelerated by the increased rate of oxygen consumption with active underwater swimming. Highly trained swimmers can develop and tolerate significantly lower levels of oxygen after swimming at maximum effort and therefore are potentially at greater risk of the effects of hyperventilation than are untrained swimmers (Spanoudaki, Maridaki, Myrianthefs, & Baltopoulos, 2004).

Hyperventilation also rapidly raises the blood pH, which contributes to reducing oxygen delivery to the brain sufficiently to cause dizziness or fainting, despite a very adequate level of oxygen in the blood. The abrupt shifts in tissue chemistry and pH also cause sensations of numbness or tingling around the mouth or in the extremities. These symptoms, more commonly seen with anxiety attacks, are often described by swimmers deliberately sustaining hyperventilation before underwater swimming (Craig, 1961) but would be expected to abate with time during breath holding as the CO₂ level and acids reaccumulate.

Shallow Water Blackout and Hypoxic Training

The term “shallow water blackout” is commonly used to describe the loss of consciousness, syncope, caused by inadequate oxygen to the brain toward the end of a breath-holding dive in shallow water. Several factors contribute to the development of underwater blackout. Hyperventilation is the usual cause by allowing the swimmer to hold the breath for an extended time so that hypoxia develops (Figures 1 & 2).

Normal dive

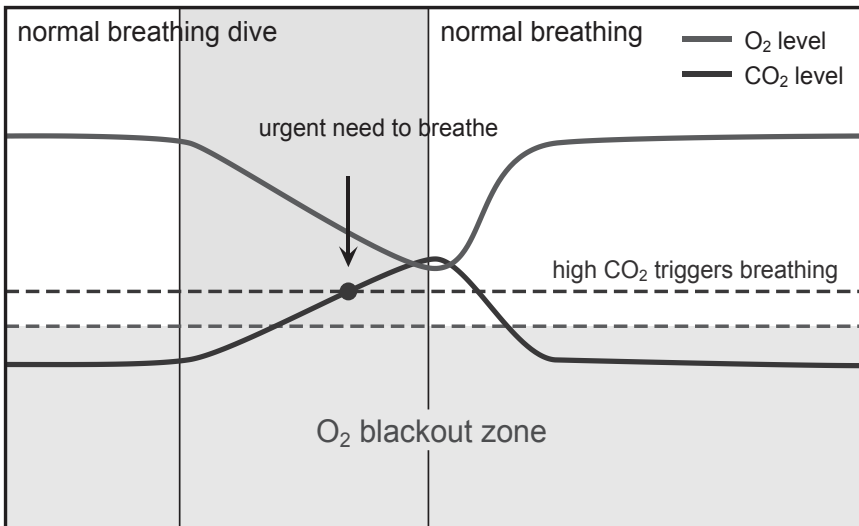


Figure 1 — Blood oxygen and carbon dioxide levels and breathing response in underwater swimming. Source: Shallow water blackout. Retrieved 06/16/2010 from Wikipedia: http://en.wikipedia.org/wiki/Shallow_water_blackout.

Dive with hypocapnia

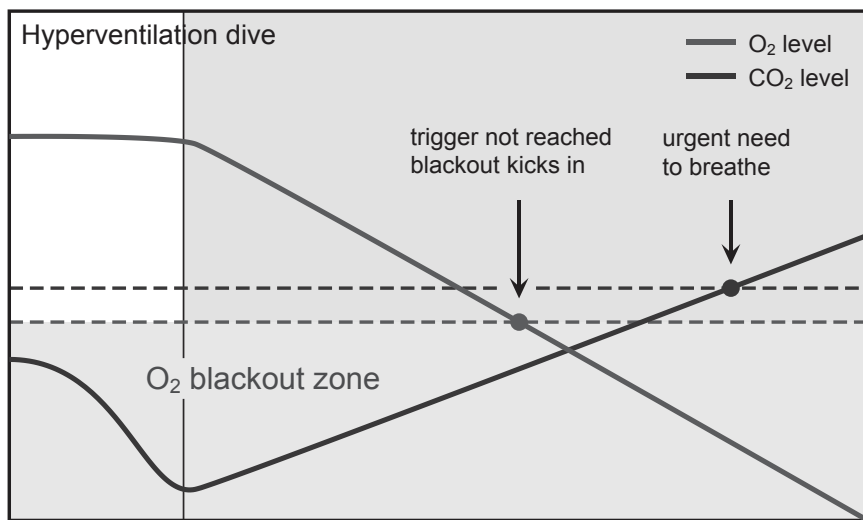


Figure 2 — Blood oxygen and carbon dioxide levels and breathing response following hyperventilation and underwater swimming. Source: Shallow water blackout. Retrieved 06/16/2010 from Wikipedia: http://en.wikipedia.org/wiki/Shallow_water_blackout.

Underwater blackout may develop without hyperventilation. Prolonged exercise can affect the set point at which oxygen and CO₂ levels terminate breath holding. Lindholm found that in breath holding divers, who had fasted from carbohydrates with subsequent elevated lipid metabolism, breath holding was terminated with a lower oxygen and CO₂ level than when they had not fasted. Lindholm (2007) surmised that exercise induced changes in lipid metabolism increased the risk for syncope due to hypoxia in these divers. Thus, prolonged exercise and fasting can increase the risk of hypoxia and syncope.

Shallow water blackout has been well described in breath holding diving competitions and other aquatic activities. Fitz-Clarke (2006) reported that symptomatic hypoxia is common in breath holding diving competitions; loss of motor control and underwater syncope were the most common symptoms. Outcomes were good because organized rescue procedures were in place. Others have reported the occurrence of short seizures following loss of consciousness that did not affect rapid recovery (Kumar & Ng, 2010). Death has occurred in excellent swimmers who hyperventilated before swimming underwater lengths (Lindholm, 2007).

“Hypoxic training” is sometimes confused with hyperventilation. On the contrary, “hypoxic training” is enforced hypoventilation. Developed by legendary swimming coach, Dr. James Counsilman of Indiana University, hypoxic training, so called “low oxygen” training, involves the reduction or elimination of breathing while training. In swimming, this typically involves breathing every five, seven, or nine strokes, or limited underwater swimming. It was originally thought that reducing levels of oxygen would result in physiological adaptations

similar to high-altitude training. In addition, reducing the number of breaths might increase the swimmer's speed by decreasing the drag associated with breathing. Subsequent research has proven that sea-level hypoxic training does not produce any physiological adaptations in swimmers (Truijens, Toussaint, Dow, & Levine, 2003). According to Sperling (2008), "hypoxic training, however, remains popular because it familiarizes swimmers with the discomfort and stress of low oxygen and can discipline swimmers to keep strong techniques during the stress of a race."

Synchronized Swimming

In a classic study, Bjurström and Schoene (1987) demonstrated that elite synchronized swimmers compared with controls have increased lung volumes, blunted hypoxic ventilatory responses, prolonged normoxic breath-holding times, and marked bradycardia during apnea. Despite the increased lung volumes that provide them a somewhat larger reservoir of oxygen with low ventilatory drives, they can hold their breath longer and become significantly hypoxic. Hypoxia has been a recognized risk in synchronized swimming (Bante et al., 2007; Davies et al., 1995; Yamamura et al., 2000).

In this incident, hypoxia was possibly exacerbated by the temperature of the pool water during the workout. Pool water temperatures at the time were higher than recommended for synchronized swimming. The Federation Internationale de Natation (FINA; 2005–2009), the international governing body for championship swimming events, establishes water temperatures for synchronized swimming of not less than 26 degrees Centigrade plus or minus 1 degree Centigrade (81–82 °F). USA Synchro (2010) states the ideal minimum pool water temperature is 80–83 °F. Water and air temperature can significantly impact a swimmer's oxygen consumption. In a study of metabolic responses to swimming in water at varying temperatures, a swimmer working at maximal effort in 93 °F pool had a 13% lower content of expired oxygen compared with the same swimmer at maximal effort in 79 °F pool. In other words, oxygen consumption is greater in warmer waters. The authors also noted that the swimmer in warm water complained of general fatigue and dizziness (Holmér & Bergh, 1974). High ambient temperature also increases blood flow to the skin, reducing the flow available to muscles and brain.

Safety Recommendations

Strong warnings to prevent underwater blackout either severely limit or absolutely prohibit voluntary hyperventilation for all aquatic sports. In addition, recommendations limit the duration and number of breath holding activities.

A recently issued informational DVD titled *Shallow Water Blackout* (Griffiths, 2008) advises that all aquatic facilities ban prolonged, competitive, and repetitive breath-holding activities. For underwater hypoxic training, Griffiths advises "one breath, one time; or one length, one time." The American Red Cross recently revised the same guidance in its *Safety Training for Swim Coaches* (2008). USA Swimming, a national governing body for the sport of swimming, recently provided the following guidance about hyperventilation and hypoxic training in the *USA Swimming Safety/Loss Control Manual* (USA Swimming, 2007).

To prevent hyperventilation, have swimmers take only one, or, at the most, two deep breaths before beginning hypoxic training. Hypoxic training (breathing on a restricted schedule) may be used safely in a training program of experienced swimmers in good physical condition with proper supervision and instruction. The number of repeats of hypoxic swimming should be limited. Adequate time for recovery will vary from swimmer to swimmer. (p. 11)

The Advisory Council on First Aid, Aquatics, Safety and Preparedness (ACFASP) of the American Red Cross recently conducted a scientific review of voluntary hyperventilation before underwater swimming and breath holding published in this journal (Fielding, Pia, Wernicki, & Markenson, 2009). In its Advisory Statement (Advisory Council, 2009), it recommended the following as a standard:

Voluntary hyperventilation prior to underwater swimming and underwater breath holding is a dangerous activity. Swimmers should not engage in hyperventilation prior to either practice. Aquatic managers, lifeguards, and swim instructors should prohibit all persons from hyperventilating prior to underwater swimming and breath holding activities. All aquatic facilities should have a policy of actively prohibiting hyperventilation. (pp. 448-449)

Specific recommendations on breath holding have long existed for synchronized swimming. Davies, Donaldson, and Joels (1995) concluded that “potentially dangerous levels of hypoxia may develop during competitive synchronized swimming and that prolonged underwater sequences should not be encouraged” and suggests that “underwater sequences should be limited at most to 40 to 45 seconds” (p. 19).

Those who are supervising swimmers should be aware that hyperventilation can be accomplished in two ways: rapid shallow breaths or slow (6 per minute) deep breaths.

While the team’s synchronized swim coaches in the current study did not teach hyperventilation, their swimmers must have hyperventilated in order for them to develop such a degree of hypoxia. This may have occurred during the short rest period between rounds or during the surface-swim. Repeated hypoxic drills and possibly warm water temperatures contributed to the development of hypoxia.

Possible ways to prevent such an incident from occurring include (a) providing longer intervals between hypoxic swims, (b) putting in nonhypoxic swims between sets of hypoxic swims, (c) closely observing swimmers by coaches to ensure that the swimmers are not trying to hyperventilate before the event, (d) specific training for coaches to understand how voluntary and involuntary hyperventilation can take place and its consequences, and (e) practicing emergency response drills.

Summary

In summary, this event underscores the life threatening risk associated with hyperventilation followed by hypoxic training. Prevention of such incidences requires attention to several aspects of swimming. First, hyperventilation should be prohibited in all swimming venues. Coaches remain responsible for prohibiting hyperventilation before underwater activities and need to ensure adequate recovery time between exercises. Second, underwater sequences in hypoxic training should

be limited in number and duration. Further, any pool setting where hypoxic training occurs should have in place and practiced an emergency response plan capable of managing multiple victims. Finally, the subsequent evaluation was an example of the oversight role and contribution of environmental and public health in the aquatic environment.

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