NOLS Backcountry Lightning Safety Guidelines

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This paper discusses the phenomenon of lightning as it typically happens; how to seek relative safety when caught in a backcountry lightning storm; typical lightning injuries; some tips on teaching lightning risk management in the backcountry; an overview of first aid, and incident reporting guidelines. It can not be emphasized enough, that **being outdoors exposes us to random lightning hazard, no matter what actions we take.**

How Does Lightning Strike?

Lightning strikes fast: the whole process usually takes a few milliseconds. Stepped leaders leave a cumulonimbus cloud and some leaders move toward the ground. They appear as many branches, but only 1-2 branches will reach the ground. Approximately every 50 meters[1] a new step leaves each leader and heads in a fairly random direction. If a leader gets close to the ground, positively charged streamers start rising from the highest grounded objects towards the negatively charged leader. As soon as the leader is close enough to a streamer[2], it shoots directly to that streamer and "blazes a trail" for a significant charge (a return stroke) to shoot from the ground to the cloud[3]. This leader search distance concept is important to understand to avoid direct strikes.

Illustrations by Rob MacLean

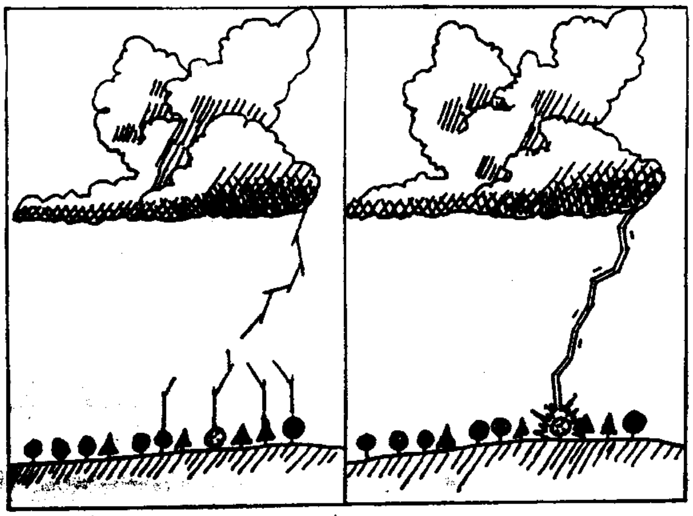

Figure 1 Left: a stepped leader moves down in 50 m steps and multiple streamers rise from tall objects near the leader.
Right: a single return stroke from a tree is the most obvious part we see.
Note the leader connected with the streamer that happened to be closest to it during the final step.

Most ground strikes occur immediately below a cumulonimbus cloud. Rarely, a bolt of lightning can move horizontally and strike somewhere "out of the blue" (out of the blue sky) as far as 10 miles (16km) away. These horizontal strikes are rare and unpredictable, so they shouldn't affect our decisions.

Using the 50 m search distance of stepped leaders (see above) lightning tends to hit the closest object within range at the end of the last step. Lightning tends to hit elevated sharp terrain features like mountain tops. Lightning tends to hit tall trees in open areas, with objects twice as high receiving roughly 4X the strikes[4]. Lightning tends to hit bushes in the desert if the bush is sticking up higher than the flat ground around it. Lightning tends to hit a boat on the water, especially if it has a tall mast. Lightning can still hit flat ground or water, but more randomly than it hits elevated objects.

Even a few less feet of height can make a difference in improving your odds of NOT being the struck object. This is why the first part of getting into the lightning position is lowering yourself down to decrease your height.

Lightning tends to hit long electrical conductors. Metal fences, power lines, phone lines, handrails, measuring tapes, bridges and other long metallic objects can concentrate currents. Wet ropes also conduct current and should be treated with the same respect as wires. Longer objects tend to concentrate more current and reach more strike points.

How Can Lightning Hurt Us?

Lightning throws an ensemble of deadly and injurious threats our way. All of these effects happen in the same few milliseconds, but none of the threats linger after each strike.

Direct strike: this means the stepped leader connected with a streamer coming out of your body, then the return stroke passed through you or over your body's surface. The return stroke is the most significant electrical event of a lightning strike and has a typical current of 30,000 amps[5] (household current is 15 amps). You greatly reduce the chances of receiving a direct strike by being inside a substantial building or a metal-topped vehicle. In the backcountry you should avoid high places and open ground and assume the lightning position[6] to decrease risk.

Streamer Currents: fast high current pulses are launched from the tops of many elevated objects near each leader as it approaches the ground (see Fig.1.) These are launched in response to the tremendously high electric field that exists, momentarily under each tip of the stepped leader. Since the tips of several or many leaders may approach the ground at about the same time, you do not have to be very near the actual ground strike point to be involved in a streamer current. Streamer currents, while much smaller than the return stroke current, are still large enough to cause injury or death to humans. You suppress the tendency to launch streamer currents from your person by crouching into a tight ball as close to the ground as possible. You avoid this possibility by avoiding high locations.

Ground Currents: ground currents occur with each strike and cause roughly half of all lightning injuries. Ground currents are driven by the enormous potential differences[7] that appear in the Earth near the ground strike point. Typical lightning-to-ground strikes inject roughly 30,000 amps into the Earth: since the Earth resists electrical flow, large potential differences will appear in the ground all around the strike point. How far the current flows varies wildly since strike current and ground conductance easily vary by orders of magnitude. But the closer you are to the direct strike, the stronger the ground current. If you are standing with your legs separated, if you are on all fours, if you are in a prone position on the ground, or if you are touching a long metallic object, you maximize your exposure to potential differences that arise from ground currents. The potential difference that appears between your legs or across your prone body can drive significant currents through and over your body. You can minimize your exposure to ground potential differences and ground currents by: keeping your feet close together, by NOT getting in a prone position, by assuming the lightning position on additional insulation such as a foam pad, and by not removing your shoes with thick rubber soles. These actions can help minimize the amount of ground current going through your body, but some experts think these efforts are moot compared to getting to a safer location. We need to be

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[1] Yards and meters can be used interchangeably. One meter = 1.1 yards.
[2] This "strike distance" can vary by 10X according to Uman in The Lightning Discharge, 1987.
[3] Return strokes of the opposite polarity tend to occur at the end of storms and under collapsed anvils. In some areas, multiple ground strike points in the same flash are common.
[4] "Towers, Lightning & Human Affairs." LG Byerley 3rd, WA Brooks, RC Noggle & KL Cummins. 11th Intl Conf on Atmospheric Electricity. 1999.

[5] Figures vary from 1-200kA, with most strikes in the 10-50kA range.
[6] This has formerly been called the lightning "safety" position and is explained later in this paper.
[7] Potential difference: if your feet are touching the ground in two different spots, each has a certain electrical **potential** based on the current flowing there. But it is the **difference** between these potentials that will drive current in one foot and out the other.

careful that we don't give students a false sense of security by getting in this defensive position.

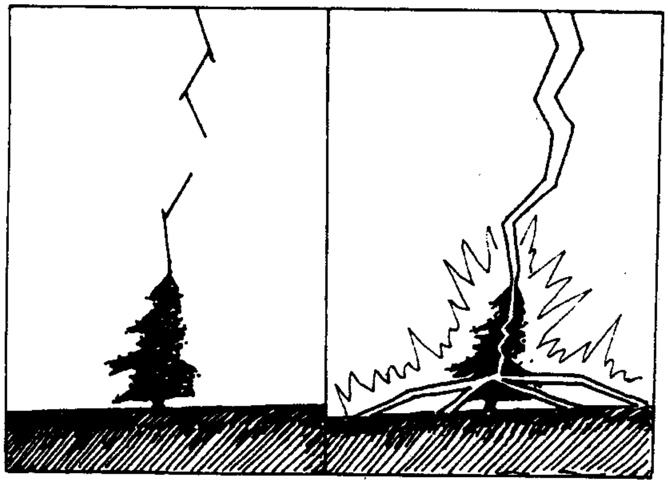

Figure 2: Left: tree with a streamer and a stepped leader.
Right: tree with return stroke, surface arcs, and electrostatic field.

Surface Arcs: high current surface arcs appear to be associated with some fraction of all cloud-to-ground discharges, during the return stroke. They appear in photographs as bright arcs of light radiating from a strike point like spokes of a wheel, in the air just above the ground's surface. (See figure 2.) These long hot horizontal currents have been measured up to 20 meters in length and may get longer. If you are in the path of a surface arc you are likely to conduct some of the surface arc current through or over your body. Since surface arcs emanate from the base of trees struck by lightning, **never seek shelter near a tree.**

Radiation: the visible, infrared and ultraviolet radiation near the strike point can damage your vision.

Sound: the thunder pulse can damage hearing temporarily and possibly permanently.

Electrostatic Field Changes: there is a large change in the electrostatic field out to 30m from the ground strike point. If you are standing, then you maximize the voltage across your body, which in turn maximizes currents that pass through and over your body. It takes very little current to interrupt heart function. Minimizing your height by assuming the lightning position is one way to minimize the field change across the length of your body.

Corona: During any stage of a thunderstorm, the electrostatic field can be enhanced enough around grounded objects to cause brush or point discharge (corona). At night, you may be able to see corona as a faint glow from sharp rock outcrops or the tops of bushes or trees — sometimes even from the fingers of your outstretched hand. You may hear corona as a sizzling or buzzing sound. Even if you can't see or hear corona, you might smell ozone, one of the chemical products of point discharge in air. Ozone has an irritating, acrid "swimming pool" smell.

On land it is unusual to have optimum conditions for sensing corona. If you feel hairs on your head, leg or arms tingling and standing on end, you are in an extremely high electric field. If you or any member of your group experiences any of these signs, it should be taken as an indication of immediate and severe danger. The response to any of these signs should be to instantly (seconds matter) drop and move away from all packs, remove metal shoe fittings, spread out, and adopt the lightning position. Do not ignore these signs and do not try to run to safety, unless safety is literally seconds away. If any of these signs are detected, the probability of a close discharge is high and every effort should be made to minimize injuries and the number of injured.

How Can We Reduce Lightning Risk In The Backcountry?

Backcountry lightning safety data is sparse, so these suggestions are "best hunches" by experts who study lightning safety. Random circumstance is a significant factor in where lightning might strike, meaning that these behaviors help reduce your "Las Vegas" odds of lightning injury, but can never make you safe. If you need to stay safe, you need to remain indoors in well protected buildings.

There are things you can do to reduce risk during a thunderstorm, but you can never get as safe as you could be in town. Ron Holle of the National Severe Storm Lab uses a 10-scale for lightning safety. (Going into a modern building and avoiding metal is as safe as it gets at 10, being in a hard-topped car is a 5, sitting on a steel tower on a mountaintop is a 0.) Ron thinks backcountry precautions only move you up .1 on this scale. Other scientists say they think these precautions move you up 4 points on Ron's 10-scale. Some risk reduction factors, like taking off a metallic belt buckle, might reduce burns but have little to do with avoiding becoming a fatality from a direct strike or ground currents. But there are five actions that can reduce your risk, in order:

- **time visits to high risk areas with weather patterns**
- **find safer terrain if you hear thunder**
- **avoid trees**
- **avoid long conductors**
- **get in the lightning position.**

Timing activities with safe weather requires knowledge of typical and recent local weather patterns. There is no such thing as a surprise storm. You need to set turnaround times that will get you off of exposed terrain before storms hit. You need to observe the changing weather and discuss its status with your group. Logistical problems en route should alter whether you complete the paddle or the climb, not whether you get exposed during a storm.

Begin your turnaround if you hear thunder (which means lightning is one to ten miles away.) In calm air you can hear thunder for about ten miles. In turbulent air you can hear the thunder for about five miles[8]. In a driving storm you may only hear it out to one mile. Some parties in rain storms have been struck before they heard any thunder at all.

Safer terrain in the backcountry can decrease your chances of being struck. High pointed terrain attracts lightning to the high points, and even to the terrain around it. Avoid peaks, ridges, and significantly higher ground during an electrical storm. If you have a choice, descend a mountain on the side that has no clouds over it, since strikes will be rare on that side until the clouds move over it. Once you get down to low rolling terrain, strikes are so random you shouldn't worry about terrain as much. If you are exposed to lightning, you need to get in the lightning position as soon as possible, which obviously means you stop moving to safer terrain at that point. Many people have died while upright and walking to safer terrain, but no one has died while stopped in the lightning position. Move to safer terrain as soon as you hear thunder, not when the storm is upon you.

Tents may actually increase the likelihood of lightning hitting that spot if they are higher than nearby objects. Metal tent poles conduct ground current and may generate streamers. Use your understanding of terrain and lightning to select tent sites that may reduce your chances of being struck or affected by ground current. If you are in a tent in "safer terrain" and you hear thunder, you at least need to be in the lightning position. But if your tent is in an exposed location, such as on a ridge, in a broad open area, or near a tall tree, you need to get out of the tent and get into the lightning position before the storm starts, and stay out until it has passed. It would be wise to anticipate additional hazards of getting out of tents in the dark of night during a storm. Determine a meeting spot, have rain gear and flashlights accessible, and have a plan for managing the group during this time.

In **gently rolling hills** the lower flat areas are probably not safer than the higher flat areas because none of the gentle terrain attracts leaders.

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[8] Use the 5 sec/ mile (3sec/km) flash-bang rule to measure the distance in ideal conditions, but this can distract people from the big picture.

Strikes are random in this terrain. Look for a dry ravine or other significant depression to reduce risk.

Wide open ground offers high exposure during an electrical storm. Avoid trees and bushes that raise above the others, since the highest objects around tend to generate streamers. Your best bet is to look for an obvious ravine or depression before the storm hits, but when the cloud is over you, spread out your group at 50' intervals to reduce multiple injuries and assume the lightning position.

Naturally wet ground, like damp ground next to a stream, isn't any more dangerous than dry ground, so don't worry about this. It used to be said that wet ground was more dangerous, because it conducted more ground current, but wet ground actually dissipates ground current faster. Neither wet nor dry is considered more dangerous than the other. Standing *in* water should be avoided.

Dry **snow** is an insulator, but wet snow is a conductor. This should make travel on dry snow safer than on bare ground, because it will be harder for a person to generate streamers or conduct ground current.

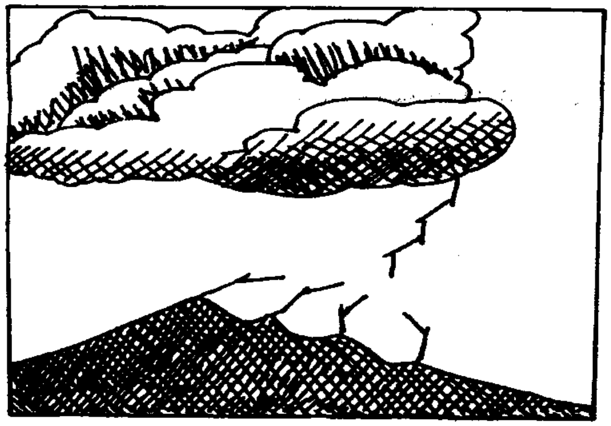

Figure 3: terrain with streamers and a stepped leader. Where do you think the strike will occur?

Avoid **cave entrances.** Small overhangs can allow arcs to cross the gap. Natural caves that go well into the ground can be struck, either via the entrance or through the ground: cavers should avoid being inside a cave, near an entrance, during a thunderstorm[9]. You should never be anywhere near any metal handrail, wire or cable during a storm. People who have been shocked standing in water deep inside caves cite weak charges, indicating that deep within a cave is safer than being on the surface. If you are near an entrance during electrical activity, don't stand in water, avoid metal conductors, and avoid bridging the gap between ceiling and floor. Move quickly through the entrance (in or out) to minimize the time of your exposure. If you are stopped waiting for others near an entrance area, assume the lightning position.

Boaters should start to get off of the water as soon as they hear thunder. There are no reported incidents of lightning accidents on rivers in canyons, probably because the higher terrain above the canyon attracts the leaders. But there is ample lightning injury data for boaters on rivers in flat terrain, on lakes, and on the ocean. When you get to shore, look for protective terrain to wait out the storm. Be especially cautious of trees at the edge of the water because they might be the tallest objects around the body of water. Boats that can't get off the water in lightning-prone areas should have lightning protection: see this website for information: http://www.cdc.gov/niosh/nasd/docs/as04800.html

Avoid trees because they are taller than their surroundings. Tall trees are especially adept at generating streamers that attract strikes. If you need to move through a forest while seeking safer terrain, stay away from the tree trunks as you move. You should also avoid open areas that are 100 m wide or wider. Lone trees are especially dangerous: the laws of probability say you are hundreds of times safer in a forest with hundreds of trees than you are near a lone tree in an open space.

"Cone of protection" from trees and cliffs is an arguable concept and has no place in lightning safety education anymore. Lightning has been photographed striking 100 m from 200 m towers, and surface arcs have been photographed exactly where "cones of protection" inferred we were all safe. Instead we need to teach the 50 m leader search distance concept (see the first paragraph of this paper.) If someone is within 50 m of a significantly higher object, they have a greatly reduced chance of being struck directly. You can still be struck, especially indirectly, but the chances are reduced. The 50 m concept works best with cliffs and other steep terrain that provide protection without directing the strike toward you. The 50 m concept does not work well for trees because the base of the tree may send out surface arcs. (see figure 2)

Avoid long conductors. Lightning currents tend to pass in long electrical. conductors — particularly ones that are on or near the surface of the Earth. Metal fences, power lines, phone lines, railway tracks, handrails, measuring tapes, bridges, and other metal objects can carry significant lightning current even if these objects are at some distance from the lightning ground strike point. Near the ground strike point of a lightning discharge, wet ropes can conduct lethal currents. During a thunderstorm, wet, extended ropes should be regarded as equivalent in risk and danger to metal wires.

Assume the lightning position[10] when at risk. This will reduce the chances of getting a direct strike and it may reduce the other effects of lightning, but it offers no guarantees. Some scientists argue that it only moves you up to 0.1 on the 10-scale; others argue that it is much more valuable because the data says that no one in this position has ever been hurt. This position includes squatting (or sitting) and balling up so you are as low as possible without getting prone. Wrap your arms around your legs, both to offer a safer path than your torso for electrons to flow from the ground, and to add enough comfort that you will choose to hold the position longer. Close your eyes.

Figure 4: the lightning position: squat or sit, ball up, put feet together, wrap arms around legs.

While the prone position is lower, being spread out increases potential for ground current to flow through or across you. Keep your feet together so you don't create potential for current to flow in one foot and out the other. If you have any insulated objects handy, like a foam pad or a soft pack full of clothes, sit on them. Avoid backpacks with frames since the frame may concentrate current. Don't touch metallic objects like ice axes, crampons, tent poles or even jewelry. You won't get a warning that a strike is imminent because the lightning event from cloud to ground and back occurs faster than you can blink an eye, so stay in the lightning position until the storm passes. The lightning position reduces the chances of lightning injuring you as badly as if you were standing, but is no substitute for getting to safer terrain or structure if it is immediately available. A dangerously close strike actually offers a moment of opportunity to move, while the electrical field rebuilds itself. But in wide open country or gentle rolling terrain there are no simple terrain advantages, so use this position to reduce exposure. If you are concerned enough to assume the lightning position, you should have your group dispersed at least 50' apart to reduce the chances of multiple injuries.

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[9] This is anecdotal data from Cavers' Digest.

[10] We used to call this the lightning SAFETY position, but this name easily allows the illusion of safety.

Ground current may spontaneously trigger your leg muscles to jump while in the lightning position, so take care to avoid being near hazards when you drop into this position.

Anecdotal injury data shows that persons with metal cleats on their shoes are more prone to injury. So take crampons off while in the lightning position. But if taking crampons off will slow your descent from a hazardous spot, leave them on to reach safer terrain faster, since terrain is a much better protector than the lightning position is.

The Effects Of Lightning Strikes On Humans

There are three ways lightning hurts us:

- Electrical shock
- Secondary heat production
- Explosive force[11].

Neuro-electrical Damage: Current through the torso or brain can stop the heart or stop breathing. Hearts often restart themselves quickly, but it can take the breathing control center longer to recover. Cardiac or respiratory arrest that isn't restarted quickly will eventually cause anaerobic conditions that make recovery problematic. Current through the tissues can also lead to numbness, paralysis or other nervous system dysfunction.

Burns: Lightning victims can get burned from the high current electricity that turns into heat in conductors that resist its flow. Strike victims can get linear burns from head to feet along the skin, punctate (spotted) burns, or feathering skin marks (not really burns) from the charge flowing over their skin. They can get secondary burns from metallic objects like belt buckles and jewelry that heat up from the current. Burns can also occur from lightning-ignited clothing.

Large entry and exit burn wounds from lightning strikes are rare. Most victims have a flashover effect (current travels over their skin) that saves them from the more severe wounds: these people can get linear or punctate burns or feathering patterns. But flashover can also travel into orifices, which may explain the many ear and eye problems that result from lightning strikes.

Wet people may carry more current over their skin, instead of through their bodies, reducing their injuries. It is not suggested that you intentionally get wet in case you are struck, but it does mean you shouldn't be scared that being wet will increase the risk for you.

Trauma: The explosive force of lightning can result in direct or indirect trauma resulting in fractures or soft tissue injuries. Watch for explosive injuries at the feet. The high current can also trigger significant muscle spasms that can fracture bones.

Psychological Effects: Electrical injury can injure the brain. Immediate problems may include altered consciousness, confusion, disorientation or amnesia. Long term problems may include anything from headaches and distractibility to persistent psychiatric disorders and dementia[12].

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First Aid For Lightning Victims

Medical aspects of lightning injury are covered in "NOLS Field Medical And Drug Protocols 2000" and in Ch 4 of the NOLS Wilderness First Aid[13] text 3rd ed. The following overview does not supercede those documents.

All patients require a complete body survey and careful evaluation for head, spinal, long bone, or cardiac injuries; peripheral pulses and sensory and motor status should be assessed. Check the skin for small hidden burns. The patient in cardiopulmonary arrest may require prolonged CPR, especially **respiratory support** if spontaneous pulse and blood pressure return. *Unlike normal triage protocols,* first attention and resources should be directed to those who appear dead and those requiring immediate support of airway and breathing. Any patient who has shown any signs and symptoms of lightning injury should be evacuated for further evaluation and treatment.

Teaching Lightning Risk Management

Teaching backcountry lightning safety has the risk that our students will defer to these techniques when civilization offers significantly better options. There are two things we can do to mitigate this possibility.

1) When we are in town, if lightning hazards present themselves, it is important that we model the reaction to seek safety in buildings or vehicles[14]. Once inside, we need to avoid pipes, wires and other metallic objects that could conduct a strike. If you aren't sure whether to "do the drill," err on the side of caution for the sake of having your students practice the routine. Just like CPR, emergency actions are best learned in the kinesthetic mode rather than an intellectual one, so they will be more memorable in times of stress.

2) We can easily teach non-wilderness lightning safety techniques during a wilderness program, since the intown choices are so simple and so effective. Getting in a modern building or inside a car during an electrical storm are the only reasonable options when they are available. Indeed, we can use the relative ease of good choices while in town, and the comparatively high risk of backcountry options, to help our backcountry students default on the side of conservatism when it comes to getting up peaks by noon, getting off the water, choosing safe campsites and generally avoiding exposed terrain when storms threaten us.

Record Keeping For Lightning Incidents

Normal near-miss forms need to be completed quickly to accurately document any near miss. Near misses are used to inform others what hazards to be careful of, and to help predict accident types. Any lightning incident also needs a record of actions taken to avoid the hazard before the incident, weather observations, and thunder and lightning observations before the incident. You should sketch who was where relative to surrounding terrain and vegetation, with estimated distances, heights and elevations, a North arrow, and at least one definitive landmark. If you have time for a detailed sketch, measure using paces that you can convert to meters later. Be sure to record people who were and were not injured by the strike. A precise record of the time[15] and location of the ground strike may help lightning scientists give you some data about that actual strike[16].

Thank you to Mary Ann Cooper MD, Ron Holle, Martin Uman and others for their tremendous contributions to the field and to this collection of information. Lightning scientists do not all agree on these adaptations of their careful scientific studies. Any misrepresentation or maladaptation of their material is my fault, not theirs. JTG

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[11] Cooper, Mary Ann, MD. Ch 7: Lightning Injuries. In Paul Auerbach MD's Wilderness Medicine: Management Of Wilderness And Environmental Emergencies, 3rd ed. 1995.

[12] "Behavioral Consequences of Lightning and Electrical Injury". Margaret Primeau, Ph.D., Gerolf H. Engelstatter, Ph.D. and Kimberly K Bares, M.S. Seminars in Neurology, V15, N3, Sept 1995.

[13] Schimelpfenig & Lindsey, NOLS Wilderness First Aid, 3rd ed, Stackpole, 2000.

[14] See http://www.uic.edu/~macooper/faq1.htm for recommendations of the Lightning Safety Group.

[15] Check watches to the nearest second, then calibrate them with an atomic clock, available at any Radio Shack.

[16] The National Lightning Data System records most strikes in the continental US. Buy data at www.lightningstorm.com