5.3 ANALYSIS OF SHORT NOTICE OUTDOOR LIGHTNING RISK REDUCTION AND COMMENTS ON WHY IT SHOULD NOT BE TAUGHT

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1. INTRODUCTION:

Lightning is the second leading cause of storm deaths in the United States, killing more people on average each year than tornadoes or hurricanes (NOAA, 2006). Lightning also causes life-long debilitating injuries on many more than it kills (Cooper, 1995). Lightning is also a significant weather hazard outside of the U.S. (Holle and Lopez, 2003). Fortunately, public education is a cost effective solution to much of the problem and there is strong consensus on lightning safety recommendations.

However, short notice outdoor lightning risk reduction was discussed extensively in the lightning safety community during 2006, especially within the working group for the U.S. National Weather Service annual lightning safety awareness week and among the board of directors of StruckByLightning.Org, a non-profit lightning safety education organization. The debate focused on what constitutes good short notice outdoor lightning risk reduction, its effectiveness, and whether it should be taught. The 'short notice' part refers to what individuals can do to protect themselves when outside, away from a safe place, and thunderstorms threaten with little lead-time. This is as opposed to when thunderstorms are in the area, but not immediately threatening, and people can not go to a safe place. In that case, people can reduce their risk by avoiding risky locations and activities. This is also as opposed to institutional outdoor lightning risk reduction, e.g. adding lightning protection to frequently-used at-risk areas, lightning detection/notification systems, etc. The longer range individual actions and the institutional aspects will not be discussed.

Short notice outdoor procedures reduce the risk of lightning casualty to 41% ± 9% of that of standing. While many of assumptions in this estimate are uncertain, the overall result is insensitive to them, since even very optimistic/pessimistic assumptions give the overall estimates error bars of only ± 9%.

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It is important to note the use of the term 'risk reduction' when discussing short notice outdoor lightning risk reduction. The fundamental principle of lightning safety is 'no place outside is safe when thunderstorms are in the area' (Roeder et al., 2001). This is not mere legalistic word selection, but promotes a proper attitude towards lightning safety and reduces improper outdoor applications.

Meteorologists, especially broadcast meteorologists, or anyone else involved with lightning, are encouraged to proactively teach lightning safety to the public. Those interested in teaching lightning safety will find a recommended approach at Roeder (2007) and useful resources at the National Weather Service website on this topic (www.lightningsafety.noaa.gov). They may also contact the author for assistance (william.roeder@patrick.af.mil).

2. Short Notice Outdoor Lightning Risk Reduction:

Short notice outdoor lightning risk reduction consists of a series of steps. It is meant to be used only as a desperate last resort. If you have made one or more bad decisions and find yourself outdoors, far from a safe place, and thunderstorms are threatening, you should proceed quickly away from risky locations to the safest place you can find. Places of greatest risk from lightning include elevated places, open areas, tall isolated objects, and large bodies of water. The safest places from lightning are a large fully enclosed building with wiring and plumbing, and a vehicle with solid metal roof and solid metal sides. While on the way to the safest place you can find, if in a group, spread out with about 5 m between people so that if lightning strikes, at most only one person will likely be hurt and the rest can apply first aid. While on the way to the safest place available, watch for the signs that lightning may be about to strike: hair standing up, light metal objects vibrating, or a crackling static-like sound from the air. If any of those signs are detected, everyone should immediately use the lightning crouch. The lightning crouch consists of putting your feet together, squatting, tucking your head, and covering your ears. After about 10 seconds, slowly stand while looking for the signs that lightning may still be about to strike. If you can stand up, continue on to the safest place available.

The lightning crouch is also commonly known as the 'lightning squat', the 'lightning desperation position', and other names. It should be emphasized again that these outdoor lightning risk reduction procedures should only be used as a desperate last resort. You are much safer to plan ahead and not get into such situations.

3. Effectiveness Of Short Notice Outdoor Lightning Risk Reduction:

Lightning can cause casualties through five main mechanisms: 1) direct strike, 2) contact voltage, 3) side flash, 4) step voltage or ground streamers, and 5) upward streamer. The relative frequency of lightning casualties from each mechanism have been estimated over a wide range of values (Cooper et al., 2006a, 2006b) with the most recent and best estimates from Holle (2007) and are used in this paper. These frequencies and the relative risk reduction of the short notice outdoor procedures are shown in Table 1. The total risk of short notice outdoor lightning risk reduction is 41% ± 9% compared to average behavior. While this reduction may sound significant, it is still too risky, given the devastating impacts lightning. The relative risk for each lightning casualty mechanism is calculated below.

3.a. Direct Strike:

Consider the idealized case of a single person in a flat infinite area with no vertical obstructions. The person is an average height of 1.8 m and is 0.8 m tall in the lightning crouch. Using the standard 'rolling sphere method' with a 50 m radius used in many lightning protection standards (NFPA, 2004), the relative threat of a direct strike is proportional to the area over which the step leader connects to the person. Under these conditions, the lightning crouch reduces a chance of a direct lightning strike to 45% of that of standing. Figure 1 shows the model graphically and calculation with the results summarized in Table 2. This flat open field model provides an upper limit to the risk reduction provided by the lightning crouch in the real world.

A more refined approach is provided by the proprietary lightning protection software used by ASRC Aerospace, Inc. at NASA Kennedy Space Center to help design lightning protection systems for facilities with complex structures (Mata, 2006). This software uses a Monte Carlo simulation of lightning strikes randomly distributed horizontally with the local flash density. It uses the rolling sphere method but varies the strike distances depending on the intensity of each simulated lightning flash, rather than a constant median strike distance of 50 m. The intensity of each flash is varied randomly according to U.S.-wide climatological frequency of occurrence of negative and positive polarity flashes and the U.S.-wide climatological frequency distribution of lightning peak currents for each polarity. With a local cloud-to-ground flash density of 17 Flashes/Km^{2}Yr, a 1.8 m standing person was struck by 1.9% of the flashes over a simulated 1,000-year period. A crouching person at 0.8 m was struck by only 1.0% of the flashes during the same simulated period. This implies the lightning crouch gives a risk reduction of a direct strike to 52.6% chance of that of a standing person. The 45% from the simplified lightning crouch model above is within the error bars of the Monte Carlo simulation. The risk reduction from the simplified model was calculated as a consistency check on the Monte Carlo model. Since this Monte Carlo model considers the distribution of lightning strike distances for both positive and negative polarity lightning, its solution of crouching providing 52.6% the risk of standing is the preferred solution.

However, the above analysis implicitly assumes that the signs of imminent lightning will always be perceived with enough lead-time to take full action. This is unlikely to be the case. The frequency of adequate signs of imminent lightning is not known. However, the author's limited experience with nearby lightning is that rising hair and vibrating metal are not often observed. While the static-like sound is often noted, it provides only 1-2 seconds of lead-time. If adequate lightning precursors are never perceived, then the lightning crouch is completely ineffective since it won't be used and provides 100% of the risk of standing. In lieu of good information, assume that 50% of the time there will be a sign of imminent lightning with enough lead-time to use the lightning crouch. This assumption minimizes the error that would result from choosing one of the extremes of always having notice and never having notice and is common practice in risk management. In the assumed 50% of the time that sufficient notice is perceived, the risk drops to 52.6% of standing. The other 50% of the time there will not be an adequate sign of imminent lightning and the risk will be 100% of standing (no action can be taken). The frequency weighted average of these two risks gives an overall risk of 76.3% of a direct strike as compared to standing. Therefore, the effectiveness of the lightning crouch ranges from 52.6% to 100% of the risk of standing, depending if lightning precursors are always or never perceived, respectively, with a best estimate of 76.3% of standing.

Table 1. Estimated Risk of lightning casualty using short notice outdoor lightning risk reduction procedures. The total risk is 41% ± 9% as compared to average behavior.

Lightning Casualty Mechanism	**Percent Of Lightning Casualties Of Average Behavior** (Ref. 4)	**Estimated Relative Risk If Using Short Notice Outdoor Lightning Risk Reduction** (lower = less risk)	**Estimated Casualty Rate Vs. Average Behavior** (%-casualties x relative risk)
Direct Strike	5%	76% (100% to 52.6%)*	4% (5% to 2.6%)*
Contact Voltage	30%	0%	0%
Side Flash	20%	0%	0%
Step Voltage/ Ground Streamer	40%	83% (100% to 66.7%)*	33% (40% to 26.7%)*
Upward Streamer	5%	76% (100% to 52.6)*	4% (5% to 2.6)*
			SUM = 41% (50% to 32%)* = 41% ± 9%

* The risk depends on how frequently the signs that imminent lighting are perceived with sufficient lead-time. The number before the parentheses is the best estimate, assuming that half of the events will have adequate lightning precursors. The first number in the parenthesis is a worst-case estimate that assumes lightning precursors are never perceived. The second number in the parenthesis is a best-case estimate that assumes lightning precursors are always perceived.

TABLE 2. Strike area for a standing person versus a crouching person using a 50 m 'rolling sphere' in a flat infinite area with no vertical obstructions. In this model, crouching reduces the chance of a direct lightning strike to 45% of standing. A more sophisticated model, discussed in the text, shows the lightning crouch has 52.6% of a direct strike compared to standing and is the preferred estimate.

Attachment Point	**Step Leader Horizontal Distance From Person (m)**	**Area Of Strike Distance (m^2)**	**Ratio Of Crouching To Standing Strike Area**
Standing Person (1.8 m)	0.0 to 13.3	555.7	0.448
Crouching Person (0.8 m)	0.0 to 8.9	248.8	
Ground	> 13.3 m	N/A	

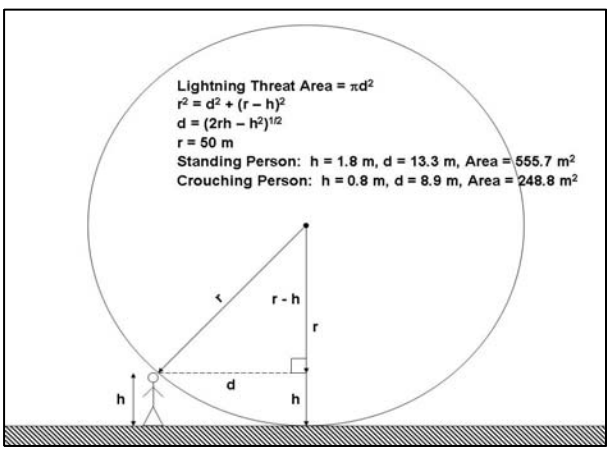

FIGURE 1. Model used to check the order of magnitude of the Monte Carlo simulation of the risk reduction of the lightning crouch for a direct lightning strike—50 m rolling sphere in an infinite flat area with no obstructions.

3.b Contact Voltage:

Lightning can inflict casualties through contact voltage. If a person is standing on the ground and touching an object that receives a direct lighting strike, there will be a voltage change across their body that will cause an electric current to flow through them. Since people are mostly salt water and are an adequate electrical conductor, they are usually the path of less resistance (technically impedance) than a tree, and a majority of the lightning current will be diverted through them to the ground. Short notice outdoor lightning risk reduction starts with rushing away from risky locations and to the safest spot available, which includes not touching objects likely to be struck directly by lightning, such as tall isolated objects like trees. Therefore, short notice outdoor lightning risk reduction virtually eliminates the risk of contact voltage, if followed properly.

3.c Side Flash:

A side flash occurs when a path of less resistance (technically impedance) to electrical ground exists close enough to an object that has been struck directly by lightning. The lightning arcs across the air gap to the lower resistance/impedance object. For a tree and a person, the distance a lightning side flash can travel is limited to about 3 m. Short notice outdoor lightning risk reduction starts with rushing away from risky locations and to the safest spot available, which includes keeping away from as tall isolated objects that are likely to be struck but lightning. Therefore, short notice outdoor lightning risk reduction virtually eliminates the risk of side flash, if followed properly.

3.d Step Voltage/Ground Streamer:

As lightning reaches the ground, it can still cause casualties as it dissipates by step voltage or ground streamer. The step voltage is a roughly radial voltage gradient along the surface of the ground. If a person is standing with their feet apart with the proper orientation, then a strong voltage change occurs across the person inducing a potentially deadly current. A ground streamer is a large spark along the ground arcing between the grains of soil. If one of these ground streamers coincidentally touches a person's foot, the current will race through the person since they are a path of less resistance (technically impedance) as compared to the soil. The lightning crouch is meant to reduce the risk of step voltage by placing the feet together—the less the distance between your feet, the less the voltage drop across the body. However, when squatting with feet together, it is difficult to keep your balance. When squatting, many people place their feet apart with about the same distance when standing. There is also the risk that they will forget this detail under the stress of a lightning threat. Thus, the lightning crouch provides essentially no risk reduction against step voltage in the real world. However, the lightning crouch may provide some risk reduction against ground streamers since most people balance on the balls of their feet. This reduces the area touching the ground to about 1/3 if standing normally. Thus the lightning crouch reduces the risk from ground streamers to about 1/3 that of standing. The relative frequency of step voltage and ground streamer in lightning casualties is not well known. In lieu of any good information, assume that they cause lightning casualties with equal frequency. Thus the total risk reduction is the weighted average of 100% (no risk reduction) for step voltages and 33.3% for ground streamers, or a combined overall 66.7% of the risk of standing.

As for 'direct strikes', we need to allow for signs of imminent lightning not always being perceived with enough lead-time to take full action. As in paragraph 2.a., assume that 50% of the time there will be a sign of imminent lightning with enough lead-time to use the lightning crouch and the risk drops to 67% of standing. Then rest of the time there will not be an adequate sign of imminent lightning and the risk will be 100% of standing. The frequency weighted average of these two risks gives an overall risk of 83% that of standing. Therefore, the effectiveness of the lightning crouch ranges from 67% to 100% of the risk of standing, depending if lightning precursors are always or never perceived, respectively, with a best estimate of 83% of standing.

3.e Upward Streamer:

Upward streamers are sparks a few tens of meters that reach out of the ground from tall thin objects a split second before the lightning stroke. When an upward streamer contacts a step leader, the return stroke initiates. The return stroke super heats the step leader path causing the flash of light and thunder, which is commonly referred to as the lightning stroke. The lightning crouch reduces the chance of a direct strike by reducing the chance of an upward streamer forming. Thus, the lightning crouch reduces the chance of an upward streamer by the same amount that it reduces the chance of a direct strike. A person has about a 53% chance of experiencing an upward streamer in the lightning crouch as compared to standing. However, we must again allow for the signs of imminent lightning only being perceived with enough lead-time half the time. This produces a best estimate of risk of 76% compared to standing upright, with a range of 53% to 100% depending if lightning precursors are always or never perceived, respectively.

4. Reasons Not To Teach Short Notice Outdoor Lightning Risk Reduction:

Even though the short notice outdoor lightning risk reduction is effective, it should not be taught because of the devastating consequences of being struck by lightning and several education/communication difficulties. The reasons for not teaching short notice outdoor lightning risk reduction are discussed below and summarized in Table 3. However, teaching short notice outdoor lightning risk reduction may be appropriate for sophisticated users that spend large amounts of time far away from safe places from lightning.

This recommendation applies only to the 'short notice' part of short notice outdoor lightning risk reduction, when threatened by thunderstorms outdoors with no safe place available with little or no lead-time. Other parts of outdoor lightning risk reduction should still be taught, e.g. scheduling outdoor activities to avoid lightning and risky places to avoid if you must be outside when thunderstorms are in the area.

One of the main reasons not to teach short notice outdoor lightning safety is the devastating impacts of a lightning strike. Lightning can cause death or life-long debilitating injuries (Cooper, 1995). Even if the chances of a casualty are reduced by about half, the consequences are not worth even the reduced risk.

Lightning safety educators have enough trouble getting people to curtail outdoor activities when lightning threatens. Since people tend to overly focus on the lighting crouch, this could decrease proper safety action in the misguided belief that the lightning crouch is a good idea. One of the reasons that people may have overly focused on the lightning crouch is that it was the only picture of people taking action in many NOAA brochures. NOAA plans to reprint those brochures, when supplies are exhausted, with a picture of a person running to safety instead of the lightning crouch.

This focus on the lightning crouch can also lead to overconfidence in the effectiveness of the lightning crouch and other short notice outdoor lightning risk reduction. It is important to avoid this overconfidence since it may detract from the more important aspects of lightning safety, such as scheduling outdoor activities to avoid lightning, and avoiding risky locations when you must be outdoors when thunderstorms are in the area.

Teaching the lightning crouch can also give the appearance of contradicting the fundamental principle of lightning safety -- 'no place outside is safe when thunderstorms are in the area' (Roeder et al., 2001). This can undermine the credibility of lightning safety education, since most people will not catch the subtle but important distinction between safety and risk reduction.

The complexity of outdoor lightning risk reduction also causes people to misremember and misapply the lightning crouch frequently, especially under a high stress situation like an imminent lightning strike. A truism in training is that complex procedures can have problems under stressful situations. One of the common misapplications of the lightning crouch is that you should spend the whole storm in that position. This leads people to waste time that would be better spent seeking the safest place possible. The author has even seen a weather broadcaster advising children to use the lighting crouch in a playground rather then running into the school building only tens of meters away. The lightning safety community has seen other examples of people misremembering recommendations. The old 'Flash To Bang' method required people to estimate the time between lightning and its thunder, divide the number of seconds by 5 seconds per mile, and take action when lightning was within six miles. However, people frequently misremembered the conversion factor as 1 second per mile. This was one of the factors that led to the '30-30 Rule' (Holle et al., 1999); the conversion factor and distance are subsumed into the first '30' (30 seconds corresponds to 6 miles). The other factor was the need to stay inside for 30 minutes after the last thunder was heard (the second '30' in the '30-30 Rule'). More recently, the first part of the '30-30 Rule' has been evolving into keying on hearing thunder to seek a safe place (Roeder, 2007).

In most lightning casualties, the victims were relatively close to a safe location (large proper building or proper vehicle). These people should not use the lightning crouch, rather they should get inside immediately (and practice indoor lightning safety when they get there). The number of lightning casualties in remote places, where the lightning crouch would be used, is relatively small (Holle, 2005a, 2005b). This is also consistent with the author's anecdotal review of several hundred internet media reports of lightning casualties from around the world since 1998. Also, because the details of when and where and how to use the lightning crouch are so detailed, you can spend far more time teaching it than is justified. Thus, it is not cost-effective to teach outdoor lightning risk reduction, especially when so much of the public still needs training on the basics of lightning safety. Training time is better spent on the first three levels of lighting safety, not this fourth level of desperate last resort, in the hopes of avoiding the need for the final fifth level of first-aid (Lushine at al., 2005).

Table 3. Reasons not to teach short notice outdoor lightning safety to the general public.

Weakness	Repercussion
Devastating consequences of lightning striking a person	Death or life-long debilitating injuries in many of the cases. Even a risk reduction of about half is not enough.
Fixation on lightning crouch	May lead people to ignore more effective lightning safety procedures.
Over confidence in effectiveness	May lead people to spend too much time under unsafe conditions.
Subtle distinction between outdoor lightning risk reduction and safety	Lightning crouch may undermine credibility of lightning safety training by appearing to contradict fundamental principle that 'no place outside is safe near a thunderstorm.'
Too complicated	People may misremember, especially under stress, such as when a lightning strike is imminent.
Too complicated	People may misapply, especially under stress, such as when a lightning strike is imminent.
Too complicated	Not cost effective to teach. Takes time away from more effective lightning safety training.
Relatively few lightning casualties in remote locations away from safe place	Not cost-effective to teach. Training time better spent on lightning safety procedures with more impact.

5. Reasons To Teach Short Notice Outdoor Lightning Risk Reduction:

Besides being effective, there is only one reason to teach short notice outdoor lightning risk reduction – customer requirement. Some people spend extended periods away from lightning shelter in at risk locations. However, this author does not believe the need of this relatively small group justifies adding the lightning crouch to education for the general public. However, short notice outdoor lightning risk reduction may be justified as specialty training for sophisticated users.

6. Summary:

Short notice outdoor lightning risk reduction is effective, reducing the probability of a lightning casualty to 41% of average behavior, ranging from 50% to 32% depending if the signs of imminent lightning are never or always perceived with sufficient lead-time, or ± 9%, respectively Despite that this represents a significant risk reduction, the author recommends that last minute outdoor lightning risk reduction not be taught as part of lightning safety education for the general public. This is due to the devastating consequences of lightning striking a person and several practical problems in education and real world application (Table 3). However, teaching short notice outdoor lightning risk reduction may be appropriate for sophisticated users that spend large amounts of time far away from safe places from lightning.

This recommendation applies only to the 'short notice' part of short notice outdoor lightning risk reduction, when threatened by thunderstorms outdoors with no safe place available with little or no lead-time. Other parts of outdoor lightning risk reduction should still be taught, e.g. scheduling outdoor activities to avoid lightning and risky places to avoid if you must be outside when thunderstorms are in the area.

Disclaimer:

This paper is presented for informational purposes only and no guarantee of lightning safety is stated or implied by the recommended procedures.

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